Measuring and Supporting Adherence to Dietary Reporting and Dietary Intervention Using a Smartphone Application in the PREDITION Trial (PRotEin DIet SatisfacTION)

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Abstract

Objectives:

Adherence within nutritional research studies have remained a challenge, despite technological advances. The current thesis aims to measure and support adherence to dietary intervention and adherence to dietary reporting in the Predition Trial, using a smartphone application. An exploration of the barriers to achieving optimal adherence to dietary reporting will be investigated, as will the association between baseline characteristics and adherence to dietary intervention and dietary reporting.

Methods:

40 young adults (aged 20 to 35) were recruited to participate in the ten-week Predition Trial and were randomised into two dietary intervention groups: a flexitarian diet (n=20) or a vegetarian diet (n=20). Participants were required to consume all three serves of protein provided each week and record all dietary intake into the smartphone diet recording application "Easy Diet Diary (EDD)." Non-adherence to dietary intervention or dietary reporting resulted in text message reminders by the research team. Adherence to dietary intervention and adherence to dietary reporting were monitored through biweekly compliance checkups and developed into the adherence compliance score and reporting compliance score, to measure how well participants were adhering to either dietary intervention or dietary reporting. Compliance to the study was defined as adherence to dietary reporting and dietary intervention simultaneously, and was measured using a composite compliance score, which combined both adherence compliance scores and reporting compliance scores. Trends in adherence to dietary reporting, dietary intervention, and compliance, were measured as percentage of participants that did not adhere at each weekly interval. Barriers to recording into the EDD application was measured using the Barriers to Recording Questionnaire in the pilot groups (n=20) at week 5 using quantitative and qualitative analysis, and three months post intervention. Predictors of adherence to dietary reporting, adherence to dietary intervention and compliance to the study were analysed using multiple linear regression analysis.

Results:

All 40 participants completed the study and there were no dropouts. Adherence to dietary intervention and compliance to the study were both higher in the red meat intervention group and statistically significant between intervention groups. Adherence to dietary intervention and adherence to dietary reporting decreased as the study progressed, in both intervention groups, where the vegetarian group showed more non-adherence to both dietary intervention and dietary reporting. The Barriers to Recording questionnaire found: 89% of participants reported it was helpful to undergo the trial with a pair/partner, 94% of participants reported it was helpful to receive text message reminders and 100% of participants reported feeling well supported throughout the trial. Four themes were categorised from participant responses to the questionnaire: 1) Lack of functionality with the EDD application; 2) More regularity with text message reminders; 3) Lifestyle barriers; 4) Recording Inaccuracies. The Positive Eating scale was positively associated with composite compliance scores in adjusted models, demonstrating that positive eating was associated with better compliance to the study. No other baseline characteristics were associated with adherence to dietary intervention, adherence to dietary reporting or compliance to the study.

Conclusions:

Overall, the study was successful in measuring and supporting adherence to dietary intervention and dietary reporting in the Predition Trial, using a smartphone application. The text message reminders were a supportive strategy to improving compliance to the study and the EDD application was well accepted by participants. Interestingly, the red meat intervention group showed better adherence to dietary intervention and better compliance to the study, when compared with the vegetarian intervention group. This was related to higher baseline positive eating scores in the red meat intervention group, suggesting that relationship, enjoyment, and emotions with eating may affect an individual's level of compliance to dietary intervention studies.

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Preface

This thesis project encapsulates all work from March 2021 to April 2022 as a partial requirement for the Master of Heath Sciences in Nutrition and Dietetics. The aspects of involvement that the candidate, Larissa Li had been in are outlined below:

1. Review of the literature (100%)
2. Development of EDD instructional email handout (100%)
3. Development of Huawei Band 4 Pro instructional brochure (100%)
4. Development of the Barriers to Recording Questionnaire (100%)
5. Development of recipes for the Predition Trial Cookbook (25%)
6. Development of thematic analysis for qualitative outcomes (65%)
7. Data collection for adherence to dietary reporting using the smartphone application (100%)
8. Data collection for adherence to dietary intervention using the smartphone application (100%)
9. Data analysis for investigating trends in adherence to dietary reporting and dietary intervention (100%)
10. Data analysis for the Barriers to Recording Questionnaire (75%)
11. Statistical analysis using R 4.0.3 statistical software-completed by registered dietitian and nutrition researcher, Nicola Gillies (0%)
12. Writing of thesis, with assistance from the candidate's primary supervisor (100%)

1 Introduction

1.1 Members of the Research team

This Master's thesis project has been completed by Larissa Li, a second-year dietetic student from The University of Auckland. Larissa has always been interested in the health effects of meat consumption as part of a healthy dietary lifestyle, as she had grown up with a diet consisting of eating meat every day. Therefore, this research project sparked an interest as Larissa wanted to further understand the health benefits and consequences of meat, and in particularly red meat, in this thesis project. The primary supervisor of this project was Dr. Andrea Braakhuis, the Academic Director for the Master of Health Sciences in Nutrition & Dietetics at the University of Auckland. Other heavily involved individuals in this project were Nicola Gillies, registered dietitian and nutrition researcher at the University of Auckland, and Anna Worthington, registered dietitian, and PhD candidate at the University of Auckland.

1.2 Rationale

The current thesis is part of a larger investigation; Predition Trial Objective 4, examining the effects of red meat consumption as part of a healthy diet. The intervention will compare a flexitarian to vegetarian eating pattern for a medium period of time of ten weeks. To obtain accurate results for the Predition Trial, it is crucial that participants report their dietary intakes for the duration of the trial. This ensures that participants are adhering to their allocated dietary intervention arm. Dietary reporting can be difficult; hence this thesis project aims to measure and support adherence to dietary reporting and adherence to dietary intervention, using a smartphone application. In addition, association between baseline characteristics with adherence to dietary reporting and dietary adherence are also explored. The literature review will start with a summary of red meat consumption in New Zealand young adults, the evidence on the health benefits and consequences of red meat consumption, including data on flexitarian and vegetarian eating patterns, then move into current methods of measuring and supporting adherence to dietary reporting and dietary intervention, and lastly discuss baseline characteristics in association with adherence to dietary reporting and dietary intervention.

1.2.1 Red Meat Consumption in New Zealand Young Adults

There is limited research investigating dietary patterns of the New Zealand (NZ) young adult population. Young adults are in the timeline of their life where they are exploring a variety of lifestyles, including different academic pathways, environmental exposures, and dietary habits (Kemper & White, 2021). An increasing trend in a more flexitarian and plant-based diet has been emerging in the young adult's dietary lifestyle (Brunton, 2019). A 2019 survey in NZ found that 15- to 34-year-old NZ young adults were the largest age group that followed a flexitarian diet (Bayer, 2019). The transition to a flexitarian diet was driven by multiple factors, such as improving health, cost-effectiveness, environmental awareness, and ethical awareness. The most current research showing statistical meat consumption of NZ young adults was gathered from the 2008/2009 New Zealand Adult Nutrition Survey (NZANS) (University of Otago & Ministry of Health, 2011). The survey found that over 65% of 19- to 30-year-old adults consumed red meat one to four times per week. This suggests that red meat is a regularly consumed food product in the dietary lifestyle of many NZ young adults. However, as the survey contained data from over 10 years ago, the data is not likely to have captured the increasing trend of flexitarianism that has emerged over the past few years.

There is a need to conduct a more recent survey to gage more accurate representations of red meat consumption in NZ young adults. In addition, it would be beneficial to understand an individual's experiences and perceptions of a healthy dietary lifestyle, and whether this includes red meat. As dietary patterns of a young adult are likely to transition into adulthood, it is important to understand the current dietary habits in young adults and promote healthier dietary behaviours, to prevent diet-related health consequences in the future.

1.2.2 Health Benefits and Consequences of Red Meat Consumption

A diet including or excluding red meat can both be beneficial to health and susceptible to health consequences. Red meat is a very nutritious food product with a complex nutritional matrix, which makes obtaining adequate nutrition simple and unchallenging (Appleby & Key, 2016; Bohrer, 2017; Wyness, 2016). Red meat contains polyunsaturated fatty acids, a complete protein profile, vitamin B12, and iron (Howe et al., 2007; B. J. Meyer et al., 2003; Phillips, 2005; Saunders et al., 2013). Plant foods are generally less nutritionally complete when compared with animal products, therefore vegetarian and vegan diets require increased variety to achieve adequate nutrition. Vegetarian and vegan consumers are more at risk of

nutrient deficiencies, and this can lead to lower mood and psychological wellbeing (Baş et al., 2005; Iguacel et al., 2021; Lim et al., 2016; Rondanelli et al., 2012). However, plant foods are nutrient-rich, high in fibre and lower in saturated fat, therefore, are recommended in higher quantities as part of a healthy diet. There is strong evidence that high red meat intakes are associated with an increased risk of cardiovascular disease, heart disease and stroke, due to red meat containing higher saturated fat content per serving, when compared with other protein source foods (Valsta et al., 2005). Excessive meat consumption is also associated with excessive energy and fat intake, causing other health-related issues such as Type 2 Diabetes and obesity (Afshin et al., 2019; Pan et al., 2012; Sinha et al., 2009; Willett et al., 2019). Therefore, a diet including red meat should adhere to current healthy dietary guidelines and recommended serving sizes to prevent consequences related to the overconsumption of red meat.

It is clearly evident that a diet predominantly consisting of plant foods, such as the Mediterranean diet, is part of a healthy dietary lifestyle (Bradbury et al., 2017; Papier et al., 2019; Tosti et al., 2018). However, some organisations such as the EAT-Lancet commission group are suggesting optimal intake of red meat to be reduced to 0 grams per day in individuals who have consumed red meat for many years (Willett et al., 2019). This statement disregards the benefits of red meat as well as the many challenges that can arise with abstaining from meat, such as the need for supplementation of certain micronutrients and increasing the variety of the diet (Lim et al., 2016). The nutrient deficiencies that occur as a result of abstaining from meat are often caused by a lack of knowledge from the individual undertaking this diet (Craig, 2010). Therefore, the current NZ Eating Guidelines recommend including moderate intakes of red meat within a healthy dietary lifestyle, and to consult with a health professional before switching to a vegetarian or vegan diet (Ministry of Health et al., 2020).

1.2.3 Adherence to Dietary Reporting and Dietary Intervention

Adherence remains a challenge in health-related studies and is heavily explored in clinical trials investigating medication adherence to treat disease, prevent disease and promote healthier lifestyles. In nutritional studies, adherence to healthy dietary patterns are commonly explored to prevent or improve diet-related health conditions such as obesity and Type 2 Diabetes. Ultimately, these studies aim to identify reasons as to why participants have

difficulty with adhering to intervention and how to support or further improve adherence for future studies. Common reported difficulties that participants face with adhering to health interventions are financial difficulties, limited knowledge, low self-efficacy, and difficulty breaking lifestyle habits (Azami et al., 2020; Demirtaş & Akbayrak, 2017; Kemper & White, 2021; Taha et al., 2011). To overcome the reported difficulties, researchers are constantly looking for ways to decrease participant burden.

Mobile health (mHealth) and electronic health (eHealth) have emerged as more incentivising approaches to measuring adherence to dietary reporting and dietary intervention in nutrition studies (Cade, 2017; Pendergast et al., 2017; Wang et al., 2006). Adherence to dietary reporting is an important aspect of nutritional research. eHealth and mHealth aim to improve participant adherence to dietary reporting by reducing participant burden of labour and time, and therefore producing a more accurate representation of habitual dietary intakes for research purposes. The new approaches have evidently become more effective for participants and researchers, with participants reporting eHealth was easier of use, more time effective, and researchers reporting more efficient data processing, less bias, and less human error (Chen et al., 2017). Although eHealth and mHealth approaches have helped improve adherence of nutrition studies, challenges with adherence still remain problematic, with most studies seeing adherence rates drop as the study progresses (Morris & Schulz, 1992; Simpson et al., 2017; Wilhelmsen & Eriksson, 2019). Therefore, there is a need to further understand difficulties with adherence to dietary intervention and dietary reporting, and how to provide support for participants and researchers to overcome this.

1.3 Thesis Aims, Objectives and Structure

1.3.1 Aim

The primary aim of this thesis project was to measure and support adherence to dietary reporting and dietary intervention in the Predition Trial, using a smartphone application, "Easy Diet Diary." The purpose was to inform researchers on the usefulness of eHealth and mHealth approaches to measuring and supporting adherence in future dietary intervention studies. In addition, this thesis project explored barriers to dietary reporting and associations between baseline characteristics with adherence to dietary reporting and dietary intervention.

1.3.2 Objectives

1. To measure and support adherence to dietary reporting and adherence to dietary intervention in the Predition Trial using a smartphone application.
    1a. To specifically investigate trends in adherence to dietary reporting and dietary intervention throughout the Predition Trial.
2. To investigate barriers to achieving optimal dietary reporting.
3. To investigate the relationship between baseline characteristics with adherence to dietary reporting and dietary intervention.

1.3.3 Structure

Section One: Introduction to the Thesis

Section Two: Review of the Literature

Section Three: Research Methods

Section Four: Research Results

Section Five: Discussion (analysis and interpretation of the research findings)

Section Six: Conclusion (summary of the research findings)

2 Review of the Literature

2.1 Red Meat Consumption in New Zealand Young Adults

2.1.1 Establishing Healthy Dietary Patterns in Young Adults

The current dietary lifestyle adopted by NZ young adults demonstrate unhealthy dietary patterns, high intakes of processed foods and low fruit and vegetable consumption (University of Otago & Ministry of Health, 2011). "Young adults" in the context of this thesis project are referred to as 20- to 35-year-old individuals. This includes some of the "Generation Z" population (10 to 25 years old) and some of the "Millennial" population (26 to 41 years old). This age group was identified for the thesis project, based on their largely variable day-to-day lifestyle affecting behaviour choices, and subsequently demonstrating the largest variation in meat intake (Lairon et al., 2007). However, in many of the studies discussed below, the term "young adults" may not refer to the exact age range as defined in this thesis project. Attempts to specify the age range in the further discussed literature have been implemented where appropriate.

The current research shows that dietary intake plays a major role in the onset, management, and prevention of chronic and non-communicable diseases (NCD) such as obesity, cardiovascular disease, diabetes and cancer (Afshin et al., 2019; Cena & Calder, 2020; Ministry of Health et al., 2020; Wyness, 2016). The World Health Organisation (WHO) emphasises a key fact that *"noncommunicable diseases kill 41 million people each year, equivalent to 71% of all deaths globally"* (World Health Organization, 2021a). One of the major driving forces of NCDs was an unhealthy lifestyle consisting of an unhealthy diet and a lack of physical activity (World Health Organization, 2021a). Unsurprisingly, the prevalence of NCDs has increased in recent years (World Health Organization, 2021a). As young adults have demonstrated undesirable dietary habits, this highlights the importance of educating about healthy dietary lifestyles to reduce the risk of developing NCDs. Therefore, the current literature review aims to identify barriers that young adults face with adhering to a healthy diet and explore current methods that support adherence to a healthy diet.

2.1.2 Nutrition Recommendations for Young Adults in New Zealand

The current healthy eating guidelines that are deemed appropriate for young adults in NZ are the Ministry of Health (MoH) Eating and Activity Guidelines for New Zealand Adults (Ministry of Health et al., 2020). The general recommendation for a healthy diet suggests including a variety of nutritious foods every day. Some key statements from the guidelines are:

- Plenty of fruits and vegetables
- Some milk and milk products, mostly low and reduced fat
- Grain foods, mostly whole grain, and those naturally high in fibre
- Some legumes, nuts, seeds, fish and other seafood, eggs, poultry and/or **red meat with the fat removed**
- Less than 10% of total energy intake coming from saturated and trans fats.
- 2 ½ hours of moderate, or 1 ¼ hours of vigorous physical activity each week.

The recommendations of the MoH guidelines are similar to other international resources, such as the EAT-Lancet report, emphasising a diet that encourages higher overall intakes of plant-based foods (Willett et al., 2019). It is important to eat a variety of foods to meet the macronutrient and micronutrient needs of all adults as each food offers different types and amounts of nutrients. The current guidelines recommend no more than three times per week of red meat intake, with total amounts not exceeding 350-500 grams of cooked red meat, or 700-750 grams of raw red meat.

The NZ 2008/2009 NZ Adult Nutrition Survey (NZANS) is the most recent statistical data that presented nutritional intakes of young adults in NZ (University of Otago & Ministry of Health, 2011). It is important to consider that this survey aimed to explore all adult age groups, ranging from 15 years and over. The survey showed that 60% of NZ adults (aged 19 to 64) ate red meat at least three times per week. However, approximately only half of all NZ adults were meeting the recommendations for servings of fruit and vegetables per day. When looking specifically at young adults from the NZANS (aged 19 to 30), the overall eating habits were unhealthy and irregular, consisting of; higher intakes of processed foods, less than recommended intakes of fruit and vegetables, more likely to consume soft drinks, energy drinks, fruit juice, fast-food and takeaways three or more times a week, and frequent meal skipping patterns (University of Otago & Ministry of Health, 2011). In the MoH NZ Healthy Survey (2020/2021), the prevalence of obesity in young adults aged 25 to 34 years old was

33.8% (Ministry of Health, 2020). This has remained relatively stable when compared with previous years, but an alarmingly high proportion, nonetheless. Therefore, this highlights the need to promote healthier dietary lifestyles in young adults to prevent the risks of long-term dietary-related health consequences.

The most recent data on the frequency of red meat consumption in NZ young adults aged 19 to 30 years, was published in the 2008/2009 NZANS survey (University of Otago & Ministry of Health, 2011). To our knowledge, there is no newer data showing patterns of current red meat consumption in NZ young adults. The survey shows that a large proportion of young adults consumed red meat one to two times per week or three to four times per week for both genders. When looking at the total population of NZ, most NZers similarly consumed red meat one to two times per week or three to four times per week. As livestock farming is a large industry in NZ, it is of no surprise that most NZers grew up with a dietary lifestyle rich in meat consumption (Kemper & White, 2021; Stats NZ, 2021).

2.2 Health Benefits and Consequences of Red Meat Consumption

2.2.1 Is Red Meat Part of a "Healthy Diet?"

The current literature is unsettled around the acceptability of including red meat within a healthy dietary lifestyle. There is an increase in vegetarian and vegan consumers in many countries and supported emphasis to decrease red meat intake from multiple nationwide dietary recommendations to prevent the risk of diet-related diseases (Goyal et al., 2020; Neff et al., 2018). Sustainability challenges that arise with animal farming is another significant influence towards the emphasis of reducing red meat intakes globally (Allievi et al., 2015). The EAT-Lancet commission recommends (Willett et al., 2019):

"A diet that includes more plant-based foods, and fewer animal source foods would confer significant health and environmental benefits." (p.46)

The EAT-Lancet report concludes that high intakes of red meat are associated with high risks of cardiovascular disease, diabetes, and some cancers (Willett et al., 2019). This was related to the larger concentration of saturated fat and heat-induced carcinogens found in red meat, and higher sodium, nitrate and nitrite amounts in processed red meats. The recommendation

from the report was an intake of 0 grams per day to 28 grams per day, where *"in populations that have consumed it for many years, optimal intake might be 0 grams per day"* (Willett et al., 2019). However, other studies have strong evidence that red meat is a quality food product to include as part of a healthy diet (Bohrer, 2017; Wyness, 2016). Research has also emerged to show that a small to moderate intake of red meat as part of a healthy diet may provide more nutritional benefits whilst minimising disease risk (Appleby & Key, 2016). Meanwhile, some large studies suggest that red meat is not an essential food item and is linearly associated with total mortality (Pan et al., 2012; Sinha et al., 2009; Willett et al., 2019). Nonetheless, there are discrepancies in the current knowledge and perception of red meat as part of a healthy dietary lifestyle. In many circumstances, studies that have shown an association between red meat intake and negative health outcomes did not control for other confounding factors such as physical activity, sleep patterns, underlying health issues, gender, and mental health status (Appleby & Key, 2016). This makes it difficult to confidently conclude that red meat intake is the direct cause of dietary-related health consequences.

As mentioned above, a combination of healthy dietary habits as part of a healthy lifestyle seems to be the better approach to optimising health and preventing disease risk, rather than just the element of reducing red meat intake. The aim of Objective four in the Predition Trial is to consider the effects of moderate consumption of pasture-fed lean red meat as part of an otherwise vegetarian balanced diet and its impact on biomarkers of sustained health and well-being. Therefore, to determine accurate results from the Predition Trial, it is important to ascertain precise measurements of habitual dietary intakes from the participants of interest. To do so, effective measurement and support strategies are necessary to optimise adherence to dietary reporting and adherence to dietary intervention.

2.2.2 Are New Zealanders Becoming Meat Reducers? The Rise in Meat Alternatives

Red meat is defined as flesh and muscle from mammals that are red in colour when the meat is raw (beef, veal, lamb, mutton, pork) (Heart Foundation NZ, 2020). In 2021, NZ beef and veal consumption was 11.7 kilograms per capita, NZ pork consumption was 19.1 kilograms per capita, and NZ sheep consumption was 3.4 kilograms per capita (OECD, 2021). The overall reduction in beef and lamb in New Zealand in ten years' time from 2007 to 2017-2018, was 42% (Windle, 2019). 17.2 kilograms of beef was reduced per capita consumption

(38% reduction), 5 kilograms of lamb was reduced per capita consumption (45% reduction) and 0.7 kilograms of mutton was reduced per capita consumption (72%) based on statistics from the Beef and Lamb New Zealand Economic Service (Windle, 2019). Interestingly, the demand for naturally raised, grass-fed, hormone-free, and antibiotic-free red meat remains untapped and stable in New Zealand (Windle, 2019). The reduction in red meat consumption has been attributed to increased awareness around health concerns and consequences associated with high red meat intakes (Kemper & White, 2021). Additionally, other forces driving the shift to eating less red meat include ethical, ecological, environmental, and social influences on animal welfare. The New Zealand Vegetarian Society reports:

"A rise in vegetarians: 1 in 10 New Zealanders mostly, or completely, meat-free." (Brunton, 2019; NZ Vegetarian Society, 2019).

The increase in meat-free and plant-based diets has given rise to the development of multiple meat alternatives available to the consumer market. This increase in supply and demand is likely to have formed through a combination of research, media, government, and other systemic forces advocating their knowledge on healthy eating and predominantly plant-based dietary patterns. Some popular methods to reducing red meat consumption are: increasing poultry and fish consumption (subsequently decreasing red meat consumption), increased intake in plant-based protein sources (beans, legumes, pulses, tofu), and new company developments of vegan meats and meat alternative/meat imitation products (Würtz et al., 2021). Some examples of meat alternative products used in New Zealand are: Bean Supreme, Craft Meat Co and Alternative Meat Co. Meat alternatives appear to be acceptable and promising to consumers as a method of incorporating plant-based proteins and have therefore continued to grow and expand in New Zealand and globally (Windle, 2019).

Although the current literature shows strong evidence that overconsumption of red meat is associated with negative health outcomes, confounding lifestyle factors that affect health status are often disregarded, therefore limiting the plausibility of this research (Appleby & Key, 2016). This emphasises that there is a knowledge gap on the association of direct red meat consumption with direct positive or negative health outcomes. Red meat contains a nutrient-dense food matrix that provides an abundant range of nutrients required for function in the human body (Leroy & Cofnas, 2020). As NZers are consuming less red meat (Windle, 2019), it is important to ensure that the progression of this trend promotes optimal dietary and

lifestyle behaviours. Therefore, the need for research on direct health and wellbeing effects of red meat intakes whilst minimising confounding factors is necessary.

2.2.3 Nutritional Matrix of Red Meat

It is important to understand the nutrient matrix of red meat because whilst red meat has a nutrient dense profile making it a nutritious food, there are also nutritional consequences associated with red meat consumption. The nutrients explored in this literature review are protein, fatty acid, iron, and vitamin B12, which are discussed below.

Red meat contains essential nutrients that cannot be synthesised in the body and therefore must be obtained from dietary intake. Red meat is often described as a high-quality protein source for the body as it contains all 20 amino acids required for optimal growth and function in the human body (Wyness, 2016). Nine of these 20 amino acids are essential amino acids, making red meat a desirable choice for maintaining adequate protein intake (Wyness, 2016). In addition, red meat contains two essential polyunsaturated fatty acids (PUFA) which cannot be synthesised by the body. These are alpha-linolenic acid (ALA), which is an omega-3 fatty acid (ω-3) and linoleic acid (LA), which is an omega-6 fatty acid (ω-6). Omega-3 fatty acids have been associated with benefits to brain function and mental health, improving the symptoms in people with Alzheimer's, depression, and schizophrenia (Howe et al., 2007). Omega-6 fatty acids are positively associated with controlling serum cholesterol levels and have a multifactorial approach to counteract cardiovascular disease risk (Djuricic & Calder, 2021). PUFAs are found abundantly within fatty fish sources such as salmon, sardines, and mackerel (B. J. Meyer et al., 2003). Sources of omega-3 and omega-6 PUFAs can also be found in plant foods, nuts, and meats, but in smaller amounts.

Iron is an important mineral for the human body as it is a component of haemoglobin; responsible for providing oxygen from the lungs into the muscles (Saunders et al., 2013). Iron cannot be synthesised by the human body and must be absorbed from dietary sources. There are two types of dietary iron: heme iron and non-heme iron. The different types of dietary iron have different bioavailability and absorption rates in the body. Heme iron can only be found in animal flesh products and is more bioavailable with an absorption rate of 15-35% in the human body (Saunders et al., 2013). Meat, fish, and poultry contain roughly 40% of heme iron and can be good dietary sources to increase iron absorption (Saunders et al., 2013). Non-

heme iron can be found in both animal and plant food sources and is less bioavailable with an absorption rate of 2-20% in the human body (Pretorius et al., 2016). For individuals that do not consume animal products, 100% of iron sources will have to be obtained from the less bioavailable non-heme iron (Saunders et al., 2013).

Common nutrient deficiencies in vegetarian and vegan consumers are iron, vitamin B12, zinc and low essential fatty acid consumption (Iguacel et al., 2021; Phillips, 2005). Vitamin B12 is only found in animal sources and is an important nutrient for producing and maintaining healthy blood cells and nerve cells (Phillips, 2005). Inadequate B12 can lead to pernicious anemia and damage to nerve cells overtime (Phillips, 2005). Therefore, vegetarians and vegans must retain vitamin B12 through supplementation and consistently monitor vitamin B12 status. In previously conducted studies, mild cognitive impairment, dementia, and depression were observed in subjects with low levels of B vitamins (Lim et al., 2016; Rondanelli et al., 2012). Similarly, inadequate iron levels can cause iron stores to deplete and lead to iron deficiency anemia. Symptoms of iron deficiency include feeling tired, fatigue, pale skin, shortness of breath and damaged hair or skin (Saunders et al., 2013). Plant products contain much less bioavailable iron for absorption and no vitamin B12, as well as lower levels of other key nutrients such as zinc, when compared with red meat. Furthermore, naturally occurring plant-based proteins such as legumes, nuts and seeds do not provide a complete amino acid profile (Wyness, 2016). Each plant contains different amounts and different sources of amino acids, hence why consuming a variety of plant foods is recommended for individuals who choose not to consume meat (Heart Foundation NZ, 2022).Therefore, consumers are often recommended to seek professional guidance and education when adhering to a plant-based diet (Heart Foundation NZ, 2022).

2.2.4 Issues related to Overconsumption of Red Meat

The evidence is clear that overconsumption of red meat can be associated with adverse nutritional consequences. Red meat is made up of fatty acids in the form of two lipids: triglycerides and phospholipids. The fatty acids found in red meat include saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) (Higgs, 2000). High SFA intake is associated with hypercholesterolemia and in particular raising low-density lipoprotein cholesterol (LDL) (Siri-Tarino et al., 2010). High LDL cholesterol is associated with increased risk of stroke, heart disease, type 2 diabetes, and

other cardiovascular diseases (Siri-Tarino et al., 2010). When comparing the composition of lean red meat versus lean white meat (poultry and fish), the average proportion of SFA found in red meats such as beef and lamb are higher than white meats such as chicken and turkey (Valsta et al., 2005). Therefore, high red meat intake has shown to be associated with the health-related consequences of high SFA intake.

2.2.5 Flexitarian and Vegetarian Eating Patterns

A flexitarian diet is defined as: *"One that is primarily vegetarian with the occasional inclusion of meat or fish"* (Derbyshire, 2017).

A vegetarian diet is primarily the consumption of plant foods and are categorised based on the level of exclusion of meat products (Sevmiş, 2020). These are:

- Lacto-vegetarian
- Ovo-vegetarian
- Lacto-ovo-vegetarian
- Pescatarian
- Pollotarian
- Vegan

In New Zealand, there is an increasing trend of vegetarian and vegan consumers within the past ten years (Brunton, 2019). In NZ, young adults also contribute largely to the rise of flexitarian eating patterns due to awareness of health, sustainability, ethical and environmental concerns (Kemper & White, 2021). A 2020 study in NZ conducted interviews on 18- to 35-year-old NZers to explore their understandings and perceptions of a flexitarian diet. The study found that many young individuals were interested in flexitarianism due to increased environmental and social exposures that have influenced dietary patterns, such as documentaries, social discussions, living away from home, becoming responsible for grocery shopping and learning cooking skills. Young adults were motivated by their concerns for ethical, environmental and health consequences related to overconsumption of red meat, however, were also faced with the challenges of cravings for meat dishes and compromising taste preferences in social settings (Kemper & White, 2021). Hence, young adults had an overall positive attitude towards flexitarianism, seeing it as an "in-between" and pragmatic approach to reducing red meat intake and improving dietary habits.

Many studies suggest that low meat, vegetarian, or vegan diets are associated with lower risks of a high body mass index (BMI), cardiovascular disease, diabetes and other non-communicable diseases (Appleby & Key, 2016; Papier et al., 2019). However, there are many other lifestyle factors that vary between meat eaters and non-meat eaters that may contribute to these findings. In the EPIC-Oxford cohort study, one third of total energy came from high protein foods in meat eaters, whereas a variety of food items from different food groups were consumed to meet energy requirements in non-meat eaters (Papier et al., 2019). Additionally, non-meat eaters consumed more soy, legumes, nuts, seeds, wholegrains, vegetables, and fruit when compared with meat-eaters who generally consumed more refined grains, processed foods, alcohol and sugar-sweetened beverages (Bradbury et al., 2017; Orlich et al., 2014; Papier et al., 2019). This shows that non-meat eaters' typical dietary patterns were more consistent with healthy eating guidelines, which were related to lower risks of health consequences. These results do not conclude that red meat consumption is the direct cause of negative health consequences. Non-meat eaters also generally had more positive attitudes and increased awareness for healthy eating habits and maintaining health, and more strongly perceived that meat was "unhealthy" (Lea et al., 2006). Subsequently, the higher levels of awareness in health found in non-meat eaters resulted in this population group being more physically active and incorporating higher frequency of exercise, demonstrating a lifestyle more consistent with healthy activity levels (Bedford & Barr, 2005). This indicates that other lifestyle factors such as exercise, awareness of health and background diet can also influence individual health outcomes.

The DASH diet as part of the Dietary Approaches to Stop Hypertension trial followed a flexitarian diet, rich in fruit, vegetables, complex carbohydrates, low-dairy products and a small amount of meat or fish daily (T. J. Moore et al., 2001). Results from the DASH trial showed that reduced sodium with the combination of a flexitarian diet decreased blood pressure and overall saturated fat and total fat intake (T. J. Moore et al., 2001). This suggests that a controlled intake of red meat as part of a healthy diet can have beneficial health effects and may not be harmful. Another dietary pattern that has shown credible benefits to health is the Mediterranean diet. The Mediterranean diet was first discovered as a traditional diet adopted by olive-growing regions such as Italy, Greece, and Spain (Martínez-González & Sánchez-Villegas, 2003). This consists largely of fruits, vegetables, legumes, grains, moderate intake of red wine and low to moderate intakes of meat and dairy. The Mediterranean diet has also been associated with preventative measures against the risks of

cardiovascular disease and metabolic diseases (Panagiotakos et al., 2015; Tosti et al., 2018). Both the flexitarian DASH diet and Mediterranean diet involve a combination of healthy eating behaviours, including moderate red meat consumption, that are positively associated with a healthy lifestyle. This indicates that perhaps red meat consumption is not the direct contributing factor to risks in dietary-related health consequences.

2.3 Dietary Intervention in Nutritional Research

2.3.1 The Challenge with Adherence and Compliance

Dietary intervention studies seek the relationship between food exposure and the outcome of health and disease (Middleton et al., 2013). This may require adherence to a short-term or long-term dietary intervention arm to gather accurate results on specific outcomes. One of the most challenging aspects for a participant is adherence and compliance to dietary intervention throughout the duration of the trial (Middleton et al., 2013).

Compliance was a term first applied and defined in the late 1970s by Haynes (Haynes & B., 1979). The definition of compliance can be understood as:
"The extent to which the patient's behaviour (in terms of taking medications, following diets, or executing other lifestyle changes) coincides with medical or health advice." (Haynes & B., 1979).

Adherence was a term adopted from Haynes' definition of compliance (Haynes & B., 1979), and is defined by the WHO Adherence Project "Adherence to Long-Term Therapies-Evidence for Action (World Health Organization, 2003) as:
"The extent to which a person's behaviour-taking medication, following a diet, and/or executing lifestyle changes, corresponds with agreed recommendations from a health care provider."

The WHO emphasises a key difference between adherence and compliance, in which adherence additionally requires the participant's active agreement to clinical recommendations being put into place to enhance care (World Health Organization, 2003). For this literature review, the terms compliance and adherence may be used interchangeably based on the terminology used in the reviewed literature, and both terms will be understood

as the extent to which a participant's behaviour corresponds with the intervention of the study. For the thesis project, the terms "adherence" and "compliance" will not be used interchangeably and will be specifically defined in the methods section.

Many studies have explored strategies to improve adherence, yet this still remains a challenge in dietary intervention trials. The consequences of non-adherence and non-compliance in health research include increased drop-out rates, increased costs, decreased cost-effectiveness, negative health outcomes and poor patient care (Onoruoiza et al., 2015). Therefore, when conducting dietary intervention trials, it is important to explore the positive and negative influences of adherence and compliance to improve study outcomes of nutritional research.

2.3.2 Current Validated Dietary Assessment Methods

There are currently several validated tools for assessing dietary intake in nutritional research (Hooson Jzh et al., 2020). This includes the food-frequency questionnaire (FFQ), twenty-four-hour food recall, diet history and diet record (Hooson Jzh et al., 2020). Traditionally, these methods of assessing dietary intake have been carried out using pen and paper. For the current thesis project, the research design has incorporated two dietary assessment tools: FFQ and diet records, as methods of measuring habitual dietary intake and monitoring adherence to dietary reporting and dietary intervention. Therefore, FFQ and diet records will be explored further below.

2.3.2.1 Food-Frequency Questionnaire

The Food-Frequency Questionnaire (FFQ) is a retrospective assessment tool that is mostly used in large long-term nutritional epidemiological studies (Henríquez-Sánchez et al., 2009). FFQs are designed to understand a participant's habitual dietary pattern by gathering information on the frequency and portion sizes of a list of food items within a period of time (weeks, months, years). The data produced from an FFQ of a large study enables an understanding of habitual dietary intakes and patterns at a population level (Steinemann et al., 2017). The advantage of this dietary assessment method is that it is relatively lower in costs and time, reducing burden on both participants and researchers. Limitations to the use of FFQs includes indefinite values of specific nutrient intakes, lack of detail regarding specific food items and potential inaccuracy as participants primarily rely on memory to respond to

the questionnaire (Steinemann et al., 2017). The reliance of memory to complete an FFQ creates other barriers to the assessment tool as it excludes participants with cognitive, memory or literacy impairment. In this thesis project, an FFQ was used to measure participant's habitual dietary behaviours.

2.3.2.2 Diet Records

The diet record is a prospective, open ended dietary assessment tool that collects data on the type and amount of food intake over one or more days (Thompson & Subar, 2017). Dietary intake is recorded by the individual, preferably at the time of consumption to produce "real time" assessment data. This is a major strength as recording at a closer proximity to the time of consumption improves the level of detail with responses, minimises reliance on memory and therefore increases the accuracy of collected data. Diet recording periods can be short (days) or long (weeks, months) and the accuracy in the gage of habitual dietary intake increases with longer recording periods. However, current research shows that frequent recording over long periods of time increases participant burden, non-compliance, non-adherence, and decreased reactivity (Thompson & Subar, 2017). A strategy that has been used to minimise this challenge was to reduce the number of consecutive days of recording required in long-term studies. Furthermore, diet records require a high level of cooperation, time commitment, motivation, food knowledge and literacy to complete accurate diet recording (Thompson & Subar, 2017). This can become a demanding duty overtime and participants may lose motivation to record accurate and detailed data. For example, a participant that feels the burden of time with diet records may purposely modify their dietary behaviours for recording convenience, which produces an inaccurate representation of their habitual dietary behaviours (Hooson Jzh et al., 2020). Researchers have implemented strategies that have been shown in current research to improve adherence, compliance, and motivation to diet recording. This includes behaviour change, social cognitive theories and techniques, participant training, motivational interviewing and researcher education and involvement (Turner-McGrievy et al., 2019). The use of technology has also been particularly helpful with assisting compliance to dietary reporting. Nowadays, most nutritional research associated with dietary reporting and monitoring have shifted to technology-assisted methods (Zhao et al., 2021). The advantages and disadvantages of using mobile phone applications to monitor dietary reporting and dietary intervention are discussed further in this literature review.

2.3.3 Limitations of Traditional Dietary Assessment Methods

The use of traditional pen and paper dietary assessment methods have reduced over the years. Limitations associated with traditional dietary assessment methods include misreporting, participant burden, decreased adherence, shortcomings in nutrient databases, issues with standardising procedures and difficulty with accurate data analysis (Thompson & Subar, 2017). Studies that have used mobile-assisted dietary assessment systems have reported that participants found this method more socially acceptable and reduced inconveniences associated with traditional methods of dietary recording (Burke et al., 2011; Chen et al., 2017).

The limitations of traditional dietary assessment methods significantly affect adherence to dietary reporting. Participant adherence was commonly high in the first half of the week, then gradually reduced towards the weekend, in studies requiring seven or more days of consecutive diet recording (Lev-On & Lowenstein-Barkai, 2019; Thompson & Subar, 2017). A study evaluating the feasibility of paper documentation saw that availability to record was a major barrier for participants when they were in an environment where documentation could not be carried out appropriately (Jimoh et al., 2018). Stone et al. evaluated patient compliance with both paper and electronic diaries and saw that actual compliance with electronic diaries was 94% and actual compliance in paper diaries was 11% (Stone et al., 2003). However, patients in the paper diary group self-reported high compliance (90.5%), but this was due to participants backfilling diaries based on retrospective recall and forward filling for upcoming visits (Stone et al., 2003). The success with compliance observed in the electronic diary group was due to features of technology that enhanced reminder messages and participant engagement, therefore minimising retrospective recalling and improving real-time data collection (Stone et al., 2003). These findings highlight the challenges observed with traditional dietary assessment methods and the promising features of technology to further assist and improve adherence and compliance in future studies. Energy, micronutrient, and macronutrient intakes are often primary outcomes of interest in dietary assessment. With traditional pen and paper dietary assessment methods, dietary data is often analysed based on participant's self-reported estimations, which can lead to underestimation or overestimation of nutrient and energy intakes.

2.4 Technological Growth in Dietary Intervention Studies

2.4.1 The Increasing Use of Technology in Young People and in Society

The advances in technology and growing use of electronic devices in the modern world have become an advantageous tool in the global market. Worldwide, the number of smartphone users is growing at an annual rate of 7 percent and reaching 5.31 billion unique mobile phone users by the start of 2022 (DataReportal, 2022). Smartphones are handheld devices that combine the function of a mobile phone and connection to a cellular network, with access to web browsers, the internet, and commercial applications (Dennison et al., 2013). The internet and digital technology have become one of the most practical and convenient ways to receive and distribute information every day in developed countries (Pendergast et al., 2017).

Young people have described the use of smartphones with the following beneficial features: portability, social interactivity, context sensitivity, connectivity, and individuality (Farman, 2007). These features have allowed dietary assessment and dietary monitoring in nutritional research to shift significantly towards a technology-assisted approach in the past twenty years (Carter et al., 2015).

The 2016 National Survey published by New Zealand Council for Education Research (NZCER) reported overall "generally positive views" on the inclusion of digital technologies in the curriculum by teachers and principals. Eighty one percent of parents reported the use of digital technology as part of their child's learning was of "high" or "medium" importance. In 2018, the International Data Cooperation (IDC) reported 75% of intermediate and secondary schools, 38% primary schools and 33% composite schools in New Zealand have established a policy around Bring Your Own Device (BYOD). This data shows the integration of technology into the New Zealand Curriculum and an expected further growth in technology use within young people's lifestyles in the near future.

2.4.2 Mobile Phone Applications for Dietary Assessment

Nowadays, there are numerous mobile phone dietary recording applications available on the commercial market for consumers and researchers to download and use as a tool for tracking dietary intake. This has allowed a platform for everyday consumers to monitor dietary habits and allowed nutritional research to become more technologically advanced. This new method

of assessing dietary intake has provided valuable benefits in dietary intervention studies, as this was more time-effective, cost-effective, easier to use, increased accuracy, increased response rate, improved data quality, increased adherence, reduced participant and researcher burden and improved communication between participants and researchers (Cade, 2017; Pendergast et al., 2017; Wang et al., 2006). With increasing use of technology in society, smartphone applications can be a more efficient way to collect "real-time" data and therefore increase accuracy, validity, and quality of research outcomes.

Participants often found mobile dietary assessment methods more preferable over traditional methods of dietary assessment (Sharp & Allman-Farinelli, 2014). Studies comparing interview-led 24-hour food recalls and online 24-hour food recall assessment tools showed that adolescents and young adults found online assessment tools much easier to use, engaging and appealing compared with paper-based methods (Albar et al., 2016; Bradley et al., 2016). A study of 18–30-year-olds revealed that users selected mobile phone food recording as the preferred technology, the most practical to use and the one that promoted more self-consciousness of food habits because of real-time calculation of energy and nutrient intake (Chen et al., 2017). This suggests that using technology is an appropriate and favoured method of recording dietary intakes for young adults.

Commercial smartphone dietary applications such as Easy Diet Diary, My Fitness-Pal, Im2cal and Australian Calorie counter are linked to food composition software that pre-calculate and analyse the macronutrients and micronutrients of food items within the application (Pendergast et al., 2017). This reduces burden of time for participants because diet recording is more convenient, accurate and user-friendly, as they can select specific food items and brands within the downloaded database of the application. This is also more time effective for researchers as they are able to easily export data from diet recording applications through the application database, ultimately improving efficiency in diet recording studies.

The Easy Diet Diary (EDD) smartphone application will be used in the current thesis project to collect information on participant dietary intakes. The mobile application has an "Easy Diet Diary Connect" function, which allows researchers and health professionals to "connect" with participants. This function gives full access to the participant's type of dietary intake, frequency of recording, meal occasion, food composition breakdown and any additional notes that participants want to communicate through to researchers. Therefore, the

applicability of smartphone dietary recording applications show promise in improving adherence to dietary reporting by increasing convenience, detail, and accuracy whilst minimising participant and researcher burden.

Advantages of technology-assisted dietary assessment includes easier, faster, and more effective communication between researchers and participants, which subsequently allow for better monitoring of participant adherence (Cade, 2017; Pendergast et al., 2017; Wang et al., 2006). The current use of mobile phone food diary applications is a well-accepted and popular method of measuring dietary compliance in clinical trials (Yuksel & Bektas, 2021). This is because mobile phones are largely integrated in a modern lifestyle, therefore making smartphone applications very practical and attainable for consumer use.

Smartphone diet recording applications now have the capacity to produce image-based data, allowing a visual capture of dietary information. This opens up a broader understanding of the reported data, such as cooking method, portion size, unreported food items, condiments and eating environment. As a result, there is a more accurate representation of the type and quantity of food being consumed as it is visually available for interpretation by researchers (Resende e Silva et al., 2018). Some studies require participants to capture images "before" and "after" consumption of food items to provide further detail on the quantity of food consumed at each meal (McCloskey et al., 2019). Another development in smartphone diet recording applications is a barcode scanning function embedded within the database. Consumers can use the camera function on their mobile phone to scan barcodes and QR codes of food packages, which automatically displays the nutrient composition and standard serving size for the scanned food item (Franco et al., 2016). When the food item is selected, consumers can choose to select the standard serving size or alter portion sizes using other measurement options provided in the application. Individuals are able to select the unit of measurement with an easy tap of the screen (gram, millilitres, teaspoon, tablespoon, cup), reducing the time and difficulty that is required with estimating food quantity associated with traditional pen and paper methods. Developments in technology assistance has shown sizeable and significant benefits on the accuracy, effectiveness, convenience, and quality of data produced (Carter et al., 2013).

2.4.3 Dietary Assessment Using a Technological Approach

Using technology assisted methods is advantageous for research in the dietary intake of young adults. This is because the young adult cohort (aged 18 to 35) demonstrate the highest use of technology and the internet as their primary access to information and entertainment when compared with other cohorts (Selig, 2020). Young adults being the most dominant user group suggests a higher chance of familiarity with smartphone technology and therefore more ease of use with electronic dietary assessment methods.

There is increasing use of technology to assist with diet recording due to the role of simplifying traditional tasks of self-monitoring. As a result, digital diet recording applications have shown improvements with compliance, reliability, and validity of nutritional research outcomes (Ngo et al., 2009). A study conducted in Malaysia assessing acceptability and adherence to diet recording in young adults showed a preference towards technology aided tools and high levels of perceived usefulness, ease of use, attitude, enjoyment, and smartphone experience based on a five-point Likert scale ranging from "strongly agree to strongly disagree" (Chen et al., 2017). The study was assisted with technology based on the perception that young adults had high dexterity with smartphone use and high day-to-day variability within their diet and lifestyle. Similarly, results in a study comparing an electronic food diary with a traditional nonquantitative food frequency questionnaire saw that the electronic diary produced less biased data, better control over participant adherence, reduced transcription errors and reduced reporting errors (Kos & Bättig, 1996). These findings suggest that technology may be a more effective and pragmatic approach to improving adherence to dietary reporting.

Some dietary assessment trials have included a fiducial marker in image-based diet recording. Image-based recording requires participants to use the camera function of their smartphone to capture the food item they are consuming. Having a fiducial marker such as a USB-sized item to put alongside the food item when taking photographs can help researchers more accurately estimate portion sizes and energy intakes (Daugherty et al., 2012). However, challenges arise with this approach as it becomes burdensome for participants. Examples of participant burden include having to travel with the fiducial marker at all times, size preferences of the fiducial marker and increased burden with the requirement of taking photographs (Daugherty et al., 2012). The study by Chen et al. (2017) reported: "*participants regarded the fiducial marker, although thin and easy to carry, as a burden for them to carry*

along and some tended to forget to place it together with their food when taking food photographs"(Chen et al., 2017). Other approaches include wearable electronic devices such as cameras worn around the neck with a lanyard (Sun et al., 2010). This method provided researchers with real-time visual data on participants' dietary intake and eating behaviours (Sun et al., 2010). Participant's lifestyle behaviours such as eating environment, habitual eating patterns, cooking method and physical activity levels were also accessible to researchers in this assessment method (Sun et al., 2010). However, a major limitation to this assessment method is limited lifestyle privacy and therefore possible dietary and lifestyle behaviour changes that participants may alter to further align with study requirements (Motti & Caine, 2015; Thomaz et al., 2013).

2.4.4 Electronic Health

Electronic health (eHealth) was first developed in the early 1970's and has become increasingly advanced overtime. eHealth is incorporated in the current healthcare system in New Zealand and globally as more advanced approaches to improve health and the health care system. There is no universally accepted definition of eHealth, but it can be understood generally as; an integration of technology to improve the overall efficiency and effectiveness of health and health care. The World Health Organisation recognises eHealth as one of the most rapidly growing areas in health today, stating:

"eHealth is the cost-effective and secure use of information and communication technologies in support of health and health-related fields, including health-care services, health surveillance, health literature, health education, knowledge and research"(World Health Organization, 2022b).

Current eHealth implementations include electronic health records, electronic software systems, health education, research, mobile health (mHealth), and electronic data systems (World Health Organization, 2022b). The 2015 New Zealand Independent Review of Electronic Health Records Strategy state:

"Since information technology is a key enabler for productivity, efficiency and quality in any sector, it would appear that healthcare IT could make a better contribution towards lifting sector performance" (Deloitte New Zealand, 2015).

Although this review primarily focuses on health record systems within NZ healthcare, the same principles of technology enabling "productivity, efficiency and quality" can be used to improve research for nutrition and dietary intervention trials.

2.5 Adherence to Dietary Reporting in Health-Related Research

Current research shows that the use of mobile phone applications and electronic food diaries improve the quality of dietary reporting among young adults (Chen et al., 2017; Daugherty et al., 2012). This was related to the feasibility of smartphone and camera use which have become more versatile and practical when compared with traditional pen and paper methods (Chen et al., 2017; Daugherty et al., 2012). Electronic dietary reporting increases flexibility for participants to record at any point in time of their busy day-to-day lifestyles and flexibility for researchers to analyse recorded data at any point in time (Young et al., 2019). Encouragingly, dietitians' perceptions of electronic mobile applications to monitor adherence to dietary reporting are positive and highly preferred when compared with traditional dietary reporting methods (Jospe et al., 2015).

An NZ study used image-assisted mobile applications to improve dietary habits and behaviours of seventeen male field hockey players (aged 18 to 20) (Simpson et al., 2017). Results of the study showed that compliance with logging meals started at 86% in week one and decreased to 59% by week six at the end of the study. The total overall compliance rate was 66%. One hundred percent of participants reported "no preference" or that image-assisted mobile applications would be "more preferable" when compared with traditional pen and paper methods of diet records. This shows that the use of mobile applications is more favoured and an effective tool, which may increase adherence to dietary reporting in young adults. Additionally, a study by Jimoh et al (2018) comparing diet and exercise adherence in adolescents using a smartphone application and a paper food diary showed general preference in the use of the smartphone application as it was "less boring" and "more socially acceptable" (Jimoh et al., 2018). In dietary trials intended to run for longer durations, it is important to consider what participants find more acceptable, convenient, and easy to use to optimise participant adherence in long-term interventions (Carter et al., 2013). To this day, adherence remains an issue with dietary reporting despite the improvements and successes that technology assisted methods have provided. The general trend in most dietary interventions was a drop in adherence to dietary reporting at about 40% to 50% by the end of

the dietary intervention trial (Carter et al., 2013; Chen et al., 2017; Crichton et al., 2012; Jimoh et al., 2018; Simpson et al., 2017). The most frequently cited reasons for dropping out were; lack of time to complete recording, inconvenience, negligence at completing the food records, or participant could not be reached by phone, text or in person between visits.

2.6 Adherence to Intervention in Health-Related Research

Achieving adequate adherence is complicated, especially in long-term dietary intervention studies, due to multiple factors can influence participant adherence, such as individual participant beliefs, environmental influences, social influences, support from research team, self-efficacy, and motivation (Armstrong et al., 2011; Dai & Catanzaro, 1987; Genoni et al., 2016; Horne et al., 2013; Karimy et al., 2016; Sparks et al., 2019). A 12-month weight loss and dietary intervention trial by Crichton et al. (2012) aimed to review the challenges that participants faced with adherence to either a high dairy intake or a low dairy intake in overweight adults (Crichton et al., 2012). Results of the trial demonstrated that 38% of participants reported difficulties with maintaining adherence and an overall 49.3% dropout rate (Crichton et al., 2012). The most commonly reported barrier for participant adherence in this trial was being unable to adhere to the requirements of the study for a long period of time. Other reported barriers were time commitment, frustration with not seeing weight loss results and intervention becoming repetitive and boring (Crichton et al., 2012). Some reported recommendations to improve adherence were; frequent contact with participants to maintain awareness and interest, reducing time commitment the study, financial rewards and broadening the variety of dietary intervention options (Crichton et al., 2012).

Current research shows that participant characteristics and beliefs are also positively associated with adherence to intervention (Dai & Catanzaro, 1987). Participants had higher adherence to dietary intervention trials they felt were consistent with their own perceptions of health and wellness (Dai & Catanzaro, 1987; Genoni et al., 2016). A four-week dietary intervention trial in Australia saw that participants who believed the Palaeolithic diet had health benefits were more likely to comply and adhere to the dietary pattern (Genoni et al., 2016). Studies have also explored the association between participant adherence and medication use, to treat illness, prevent the onset of illness, and promote health. Participants that perceived medication as necessary, safe, and effective for a population group at risk of illness or further onset of illness, reported a stronger association with adherence to

medication use (Horne et al., 2013; Ross et al., 2004). Systematic and meta-analytic reviews of medication adherence in patients with other long-term illnesses found that stronger beliefs on the severity of illness, higher risk of complications, barriers to taking medications, effectiveness of medication and self-efficacy demonstrated higher medication adherence (Al-Noumani et al., 2019). This suggests that more understanding of participant beliefs and perceptions of medical intervention, are necessary to improve medication adherence. Therefore, recognising participant beliefs and concerns can help improve the quality of healthcare in terms of improving treatment and supporting adherence to lifestyle changes for long-term illnesses (Horne et al., 2013; Ross et al., 2004). The presence of other comorbidities and perceived health status in individuals can also affect medication adherence, once again, demonstrating the complexity with achieving adequate adherence (Al-Noumani et al., 2019; Crichton et al., 2012). The literature demonstrates that individual health beliefs have a very significant effect on participant adherence to all types of health interventions. Therefore, identifying personal perceptions and experiences are promising approaches to strengthening adherence in health-related studies.

2.6.1 Supportive Measures to Improve Adherence

A lack of communication and minimal contact with participants were related to decreased adherence and engagement to the study (Ludden et al., 2015). An online intervention study looked at adherence to three different internet-based trials for; diabetes self-management, supporting smoking cessation and utilising online personal health records (Wangberg et al., 2008). The study found that by using tailored emails, website content and electronic post-assessment reminders, participant adherence to intervention in the smoking cessation group increased up to five months when compared to the other two intervention groups (Wangberg et al., 2008). The SMARTER pilot study tested the use of real-time text message feedback on the outcomes of weight loss and user engagement, through a smartphone diet recording application (Burke et al., 2017). A range of one to four standardised text messages were sent daily to trial the feasibility. Although no significant differences in weight loss were found between the group receiving text messages versus the group not receiving text messages, participants reported that the messages were an effective reminder system with helping adhere to dietary reporting (Burke et al., 2017). A limitation with reminder texts was that some participants reported that text message prompts can be repetitive and annoying. In a three-month text message intervention trial for improving self-management of Coeliac

disease (TEACH trial), results found that the group receiving supportive text message reminders had significantly improved patient activation and quality of life, when compared with the group not receiving supportive text messages. 78% of participants preferred to receive text messages, 65.4% of participants enjoyed text messages, 52.2% reported text messages reminded them to stay gluten-free, and 80% reported interest in future studies of longer duration with text messages. The most helpful text messages that participants reported were online resources, humorous reminds and bidirectional questions (Haas et al., 2017).

The challenge with reminder text messages is determining the appropriate frequency as some users may feel irritated and hassled with receiving multiple reminders, whilst other preferred more text message reminders (Burke et al., 2017; Chen et al., 2017). Therefore, usefulness of text messages may positively or negatively influence motivation and willingness to adhere (Chen et al., 2017; Dennison et al., 2013). Future studies should consider evaluating the acceptability of text message frequency and adapt to participant feedback to achieve optimal adherence to dietary reporting and dietary intervention.

2.7 Baseline Characteristics and Adherence to Dietary Reporting

An interesting finding from a scope of the literature was that there was very limited to no research on the association between baseline characteristics and adherence to dietary reporting. Much of the literature explored the association between baseline characteristics and adherence to dietary intervention. It is important to recognise the influence of baseline characteristics with adherence to dietary reporting because many dietary intervention studies require an understanding of habitual dietary intakes. To gain an understanding of habitual dietary intakes, this can only be done through participants reporting their dietary intakes into a diet recording system. For a thorough and accurate diet record to be produced, participants must be adherent to dietary reporting requirements, yet it is unknown as to what baseline characteristics participants portray that may improve adherence to dietary reporting. Therefore, this highlights a gap in the literature in aiming to investigate baseline characteristics with adherence to dietary reporting, to improve the quality of dietary intervention studies.

Many dietary interventions that explore participant adherence look at behavioural outcomes, for example, motivation, self-efficacy, mood, barriers to change (Al-Noumani et al., 2019;

Carter et al., 2013; Chen et al., 2017; Daugherty et al., 2012; Jimoh et al., 2018; Ross et al., 2004). Therefore, nutrition trials often recommend adopting behaviour change techniques, motivational interviewing techniques and helping overcome barriers to change, as strategies to improve participant adherence. These outcomes are equally as important; however, this disregards potential baseline characteristics that may affect participant adherence to dietary reporting and dietary intervention. Therefore, the current thesis is particularly interested in investigating the association of baseline sociodemographic characteristics (age, weight, BMI, occupation, gender), psychological characteristics (self-efficacy, positive eating, well-being), and lifestyle characteristics (physical activity, sleep, and diet) with adherence to dietary reporting and dietary intervention. A broad range of health-related studies including the medical, clinical, and nutritional field have been included in this literature review.

2.8 Association Between Sociodemographic Characteristics and Adherence to Dietary and Health-Related Intervention

Baseline characteristics may influence a participant's willingness or ability to adhere to dietary reporting and dietary intervention. Previous studies have explored baseline characteristics particularly in drug and disease treatment adherence (Nursalam et al., 2020; Razali & Yahya, 1995; Taha et al., 2011; Yuksel & Bektas, 2021). The drug trials in the literature have looked at association between gender, socioeconomic status, education levels, personal motivation, self-efficacy, general health status and lifestyle factors with adherence.

Nutrition trials have poorly investigated the association between baseline characteristics with adherence to dietary reporting and dietary intervention. In a study by Daugherty et al. (2012), sociodemographic characteristics did not demonstrate significant differences in skills, preferences, and perceptions of technology use between individuals (Daugherty et al., 2012). To our knowledge, this was the only study that investigated baseline characteristics in association with adherence to dietary reporting.

2.8.1 Gender

Gender was associated with participant adherence to intervention in some nutritional studies, but not associated in other nutritional studies. When looking at studies specifically measuring adherence to dietary intervention, females demonstrated better adherence to dietary recommendations when compared with men. 306 adolescents and young adults participated

in a coeliac study investigating adherence to a gluten-free diet (Greco et al., 1997). Adherence to a gluten-free diet was related to gender and self-esteem; females had better adherence to a gluten-free diet when compared with males, and females with higher self-esteem had the highest adherence to a gluten-free diet (Greco et al., 1997). A study carried out in Finland aimed to investigate patient compliance to the management of hypertension (Kyngäs & Lahdenperä, 1999). The study proposed two research questions, one of which was: *"What kind of factors are connective with hypertensive patients' compliance: lifestyle, follow-up visits and medication?"* Results of the study found that compliance to dietary restrictions was the lowest (30% of participants showed "good compliance"), and compliance to medication was the highest (75% of participants showed "good compliance"). Gender had a statistically significant correlation ($p<0.001$) with compliance to sodium recommendations; 83% of females followed the recommendation, whilst only 17% of males followed the recommendation. However, the study was limited to its accuracy with measuring compliance, for example, all compliance questionnaires were given at clinic visits, but not all participants attended all clinic visits, therefore resulting in an inaccurate representation of actual total compliance with the study.

Clinical trials have also explored the association between gender and participant adherence. As previously mentioned, Wangberg et al. (2008) explored adherence rates of three different internet-based trials; diabetes self-management, supporting smoking cessation and utilising personal online health records (Wangberg et al., 2008). From the study, no significant association was found between perception of illness or self-care management with adherence to intervention. However, females were associated with more logins in the trial in the group supporting smoking cessation and gender was a predictor of the number of logins in this particular trial. Another study explored treatment-based intervention of antihypertensive medication as a measure of compliance to the management of hypertension (Braverman & Dedier, 2009). The study found that females with "lower than high school education" were less adherent (61%) than females with "more formal education" (74%). Interestingly, the opposite was seen with males, where males with lower education were more adherent (91%) than males with higher education (72%). The study hypothesised that women with lower education were more likely to have other priorities of children and family, therefore less time to prioritise the study intervention. However, there was not sufficient evidence to support this hypothesis.

A drug intervention program trialled in Malaysia measured the compliance to treatment in patients with schizophrenia through retrospective assessment questionnaires (Razali & Yahya, 1995). The results of the study showed that 27% of patients met the criteria for 'good compliance,' but no statistical significance was found in compliance between sociodemographic characteristics. Good compliance tended to be more present in patients that were female and patients above 21 years of age. A more recent study in 2020 aimed to investigate the relationship of individual characteristics with compliance to haemodialysis sessions in patients with chronic kidney disease (Nursalam et al., 2020). The largest influencer of good compliance in this study was gender; females had a better level of adherence to haemodialysis sessions at 88.9% adherence, when compared with men (78.3% adherence). The research from the literature shows that in some dietary and clinical studies, gender can have an association with participant adherence. In particular, females had better adherence to interventions when compared with men. However, gender is only one of the many factors associated with adherence and therefore other individual characteristics must also be considered.

2.8.2 Socioeconomic Status

Socioeconomic factors have shown to influence adherence to dietary and clinical intervention. Socioeconomic status encompasses a sociological and economic measure of an individual or group, particularly education, occupation, and income (Oxford Reference, 2007). A 2003 review article published in the American Journal of Managed Care (AJMC) identified low education and low socioeconomic status as common barriers to medication compliance (Loghman-Adham, 2003). Low socioeconomic status is associated with lower educational achievement, poor health, and financial limitation, therefore individuals with lower socioeconomic status are more likely to consequentially have lower education levels. This is why studies that see participants with lower socioeconomic status, lower education levels and financial constraints had a significant correlation with decreased compliance to treatment and dietary recommendations (Blumenthal et al., 1982; Demirtaş & Akbayrak, 2017; Taha et al., 2011). In contrast, studies showing participants with higher education levels and high economic status had a significant correlation with better adherence to treatment and dietary recommendations (Wangberg et al., 2008; Yuksel & Bektas, 2021).

Studies that explored compliance to management of Type 2 diabetes in patients, found that financial constraints were a major barrier for participants (Taha et al., 2011; Yuksel & Bektas, 2021). Participants felt that the recommended dietary lifestyle was not always affordable, glucose strips were expensive, and the patients could not access healthy food as desired (Taha et al., 2011; Yuksel & Bektas, 2021). A 2018 study looked at barriers to dietary adherence in type 2 diabetic patients at an Ethiopian hospital (Ayele et al., 2018). Seventy eight percent of participants reported being unable to afford the costs of the dietary recommendations, therefore financial restraints was a barrier to dietary adherence. Eighty seven percent reported a lack of education around dietary knowledge, therefore low education was a barrier to dietary adherence. When explored in more detail, participants with no formal education, living in rural areas, and who had a monthly income below $150 (US dollars), were more likely to have poor adherence to dietary recommendations than those who had higher education, lived in urban areas, and had a monthly income above $150 (US dollars) (Ayele et al., 2018). Interestingly, the study found no significant association between gender and age with adherence to dietary recommendations.

Other studies looked directly at whether costs of healthy foods were a barrier to adhering to healthy eating recommendations. Tong et al. (2018) investigated the association between cost of food with adherence to a Mediterranean diet in a non-Mediterranean country, using a 130-item FFQ (Tong et al., 2018). Results of the study found that participants that spent higher dietary costs on foods traditionally known to be healthy in a Mediterranean diet (fish, vegetables, fruit, olives) reported higher adherence to the Mediterranean diet, when compared with participants that spent fewer dietary costs on foods traditionally known to be healthy in a Mediterranean diet (Tong et al., 2018). Additionally, adherence to the Mediterranean diet was significantly associated with low socioeconomic status, in particular low education, income and occupation.

The association of socioeconomic status and education levels has been shown to influence adherence in studies focused on treatment and management of disease. However, the evidence is less abundant around the association of baseline socioeconomic status and education levels with adherence to dietary intervention and dietary reporting. Financial constraints were a commonly reported barrier, therefore decreasing the cost of healthy foods and improving education systems can improve adherence to healthy lifestyle recommendations at a population level. Based on the findings from the literature,

socioeconomic status and level of education could potentially influence both dietary behaviours and dietary spending habits, suggesting that further research in health needs to consider how to improve systemic education and reduce large disparities in socioeconomic standings in society.

2.9 Association Between Lifestyle Factors and Adherence to Dietary and Health-Related Intervention

2.9.1 Sleep Quality

The current thesis is interested in trialling Smartwatch wearing to evaluate the lifestyle factors sleep and physical activity, and whether these lifestyle factors influence adherence to dietary reporting and dietary intervention. Adherence to wearing a Smartwatch becomes a common issue in long-term studies (Jeong et al., 2017; J. Meyer et al., 2017; Purta et al., 2016). In a 2017 Apple Watch study, 50 college students (aged 18 to 37) were asked to wear a Smartwatch for a total of 203 days, to investigate what factors affect wearability and wearing behaviours of the Smartwatch (Jeong et al., 2017). Participants commonly reported discomfort with wearing the watch to bed, finding an appropriate time to charge the watch battery, aesthetic concern, and overall discomfort with daily activities (Jeong et al., 2017). A large cohort study looking at sleep and physical activity of college students using Fitbit Smartwatches found a decrease in adherence to wearing the watch overtime and an overall adherence rate of 67% (Purta et al., 2016). Similar to the Apple Watch study, a major factor that influenced adherence to watch wearing was related to charging issues. Participants also experienced trouble with syncing data and reported that more reminders would motivate syncing of the watch regularly (Purta et al., 2016).

Sleep patterns and quality of sleep vary between different age groups. This is related to internal and external influences such as lifestyle habits, lifestyle choices, environmental factors, social factors, mood, and stress (Fernádez-Mendoza et al., 2010; Kang & Chen, 2009). Low quality sleep and sleep deprivation can result in impaired cognitive function, memory, and concentration. In NZ, young adults are the most likely age group to have National Certificate of Educational Achievement (NCEA) qualifications of at least NCEA level 2, or a Bachelor's degree, or higher (Ministry of Social Development, 2016). This reflects that education continues to grow for young cohorts in NZ. Therefore, young adults

require adequate sleep to perform and function throughout day-to-day activities and maintain academic performance.

A study exploring sleeping habits and patterns of college medical students (average of 21 years of age) saw an average of 5.9 ± 1.6 hours sleep time including both night time and nap episodes during the day (Bahammam et al., 2005). Students that reported "excessive daytime sleepiness" compensated for this by taking naps during the day, however, only 54% of students reported "self-satisfaction" with overall sleep quality and quantity (Bahammam et al., 2005). Students reported difficulty sleeping due to studying at the expense of sleep, poor personal organisation, drinking stimulants and thinking about the difficulty of studying (Bahammam et al., 2005). A study of 1271 university students explored the effects of circadian preference and night time sleep on daytime functioning (Fernádez-Mendoza et al., 2010). Similar to the previously discussed study, results suggested that lifestyle factors play a significant role in students' circadian preference and sleep-wake schedules (Fernádez-Mendoza et al., 2010). The most commonly reported variables that affected irregular sleep and sleep quality were; difficulties initiating sleep, oversleeping, excessive daytime sleepiness and the use of tobacco and alcohol (Fernádez-Mendoza et al., 2010).

It is important to explore the quality of sleep as sleep health has shown to be associated with improved health outcomes (Buysse, 2014). Poor sleep quality can result in general health symptoms of tiredness, stress, reduced concentration, and increased psychological distress, depression, and anxiety (Keshavarz & Ghalehbandi, 2009). There is also some emerging evidence that the quality of sleep can influence the quality of the diet, in the sense that poor sleep can lead to poor dietary choices and behaviours, therefore further promoting dietary-related health consequences (Fenton et al., 2021). A study measuring adherence to the Mediterranean diet used the Pittsburg Sleep Quality Index (PSQI) to analyse sleep quality in participants, and found that better sleep quality and consistent sleep duration improved adherence to the Mediterranean diet (Muscogiuri et al., 2020). Muscogiuri et al. (2020) hypothesised that the improved adherence to the Mediterranean diet was likely related to other healthy lifestyle behaviours, such as a lifestyle characterized by regular physical activity (Muscogiuri et al., 2020).

2.9.2 Physical Activity

The evidence to support physical activity as part of a healthy lifestyle is widely abundant and highly recommended in global health models and guidelines. The NZ MoH guidelines recommend at least 2.5 hours of moderate or 1.25 hours of vigorous physical activity throughout the week (Ministry of Health et al., 2020). Therefore, habitual physical activity is of particular interest to the current thesis as it is hypothesised that this healthy behaviour may positively influence adherence to dietary behaviours.

The literature shows that physical activity intensity and duration vary amongst different age groups (Brunet & Sabiston, 2011; Freund, 2006; Freund & Baltes, 2000; Heckhausen, 1997; Renner et al., 2007). The type and level of motivation for physical activity also varies within different age groups. Overall, middle-aged adults were less physically active than younger adults (Brunet & Sabiston, 2011; Renner et al., 2007). Young adults (aged 18 to 24) were highly motivated by intrinsic motivation, introjected regulation and autonomy, and self-efficacy largely influenced their intention to participate in physical activity (Brunet & Sabiston, 2011). The main reports of engagement to physical activity in young adults were for; appearance, physical attractiveness, social recognition, and overall enjoyment (Brunet & Sabiston, 2011). Adults and middle-aged adults were motivated by increased health awareness and benefits to; being more physically competent, improving management of health, maintaining physical function, and increased health concerns (Renner et al., 2007). In middle-aged and older adults, factors that facilitate the intention to engage in physical activity were; perception of risk to low physical activity levels, outcome expectancies, wanting alone time, and self-efficacy to act (Renner et al., 2007). The literature shows that different age groups have different values, goals, and perceptions to physical activity. The trend shows that younger adults create goals for gaining or achieving benefits to health, whereas older adults create goals that prevent losses or negative consequences to health (Freund, 2006; Freund & Baltes, 2000; Heckhausen, 1997).

The literature shows that there is a positive association between physical activity levels and a diet more consistent with a healthy lifestyle. However, the evidence of the association between baseline physical activity levels with adherence to dietary intervention is limited. Much of the available literature as of current have explored physical activity as an influencing factor of adherence to the Mediterranean diet (Morelli et al., 2021; Zurita-Ortega et al., 2018). A 2018 study aimed to explore factors that influence adherence to the

Mediterranean diet in university students (Zurita-Ortega et al., 2018). Eighty two percent of students who regularly engaged in high levels of habitual physical activity had higher adherence to the Mediterranean diet and consequently showed better nutritional status (Zurita-Ortega et al., 2018). Students who did not engage in any physical activity were more likely to have lower adherence to the Mediterranean diet (Zurita-Ortega et al., 2018). A recent study (Morelli et al., 2021) implemented a nutrition education program to improve adherence to the Mediterranean diet in healthy adolescents (aged 14 to 17) (Morelli et al., 2021). Physical activity was categorised into three levels: inactivity, moderate intensity, and vigorous intensity. The study found that having a nutrition education program had an overall positive effect on adherence to Mediterranean diet. The group of adolescents who performed vigorous physical activity had greater adherence to the Mediterranean diet when compared to the group of adolescents who were physically inactive, and no significant differences in adherence were seen between the moderate physical activity group and physically inactive group (Morelli et al., 2021). The statistical power of the study was limited due to a small sample size that was not able to produce significant results in some variables (Morelli et al., 2021). Nonetheless, the literature shows that physical activity was positively associated with adherence to the Mediterranean diet, but evidence remains unclear as to whether physical activity would be associated with adherence to other healthy dietary patterns. As the Mediterranean diet is credible of following healthy eating patterns, it is possible that participants who perform regular and adequate physical activity are more likely to partake in healthier dietary choices and therefore consequentially adhere closely to a Mediterranean diet.

2.10 Association Between Psychological Factors and Adherence to Dietary and Health-Related Intervention

2.10.1 Eating Behaviours

Eating behaviours can be influenced by psychological and psychosocial factors, such as individual perceptions, beliefs, and relationships with food (Story et al., 2002). Several tools have been developed as a means to understanding individual relationships with food, eating behaviours, disordered eating patterns, and emotional eating. Examples include the Emotional Eater Questionnaire (EEQ), Three-Factor Eating Questionnaire (TFEQ), Intuitive

Eating Scale (IES) and Positive Eating Scale (PES) (Brytek-Matera, 2020; Dalen et al., 2010; López-Moreno et al., 2021) A study in 2020 aimed to determine behaviours of disordered eating and cognitive restraints between individuals adhering to a vegan, vegetarian, and omnivorous diet, using the TFEQ (Brytek-Matera, 2020). The study found that vegan and vegetarian consumers presented with the least cognitive restraints, lower emotional eating, and less uncontrolled eating, when compared with omnivorous consumers (Brytek-Matera, 2020). However, vegan and vegetarian consumers also presented with sharing characteristics similar to orthorexia nervosa, which were associated with cognitive restraints in the study (Brytek-Matera, 2020). Examples of similar characteristics include only focusing on organic and high-quality foods, setting rigid rules that limit the flexibility of one's diet, and labelling "allowed" and "forbidden" terminology on certain foods (Brytek-Matera, 2020). As found in the literature, vegan and vegetarian consumers had more nutrition knowledge and were generally more health-focused when compared with omnivorous consumers, however, can demonstrate obsessive behaviours if they become overly health conscious (Brytek-Matera et al., 2019; Heiss et al., 2017; Parker & Vadiveloo, 2019). These findings indicate that individual psychological factors can heavily influence eating behaviours and create negative relationships with food in some cases.

There is little research on baseline eating behaviours and relationship with food in association with adherence to dietary intervention. Some studies implemented strategies such as intuitive eating and mindful eating as the study intervention, to investigate whether this could improve adherence to a particular diet (Dalen et al., 2010). A six-week pilot study used weekly two-hour classes to promote mindful eating in ten obese individuals (Dalen et al., 2010). Eating behaviours were measured using the TFEQ and Binge Eating Scale (BES), and mindful eating was measured using the Kentucky Inventory of Mindful Skills (KIMS) (Dalen et al., 2010). All ten participants lost weight at the end of the intervention, and increases in subscales related to mindful eating were observed, when compared with baseline scores, such as the "observe," "accept" and "awareness" subscales. Additionally, decreases were observed in uncontrolled eating, binge eating and feelings of hunger, when compared with baseline scores. Findings from the study by Dalen et al. (2010) suggest that implementing mindful eating or other psychologically targeted behaviour change techniques may be promising for future studies that aim to promote healthy dietary behaviours (Dalen et al., 2010).

A study investigated adherence to a Mediterranean diet, alcohol consumption and emotional eating in Spanish university students with an average age of 21 years, using the EEQ to measure emotional eating (López-Moreno et al., 2021). Results of the study found that students with a higher BMI were more likely to present with emotional eating patterns, however, the correlation was not strong. Despite this, multiple studies have found that emotions and stress can negatively influence eating behaviours, such as overeating or undereating to cope as a response to negative emotions (Geliebter & Aversa, 2003; Ozier et al., 2008). Therefore, an association between emotional eating and a higher BMI seen in the study by López-Moreno et a. 2021 emerges as an appropriate and reasonable finding (López-Moreno et al., 2021). De Leon et al. (2020) investigated barriers to adhering to a Mediterranean diet in a weight-loss intervention and revealed individual-level barriers to adherence that all demonstrated psychological distress (de Leon et al., 2020). The most significant individual-level barriers to adherence were knowing when to stop eating, knowing how much to eat, controlling cravings and emotional eating (de Leon et al., 2020). These individual-level barriers all demonstrate some level of psychological stress to the individual, which can influence emotions and actions and therefore influence eating behaviours. Other individual-level barriers found in this study were poor habitual eating patterns and impatience with weight-loss progress. Based on the literature, a positive relationship with food can be associated with healthier dietary patterns. Therefore, future studies exploring adherence to healthy dietary intervention may wish to focus on eating behaviours and improving participant relationships with food.

2.10.2 Mental Health

Mental health has long been known as an influencing factor to consuming healthy dietary behaviours. The Depression Anxiety and Stress Scale 21 (DASS-21), General Health Questionnaire (GHQ) and World Health Organization-Five Well-Being Index (WHO-5) are examples of commonly used tools to measure mental health and psychological wellbeing (Crawford & Henry, 2003; Meegan et al., 2017; Topp et al., 2015). Some studies have found that depressive symptoms, anxiety and stress were associated with less desirable dietary behaviours (Muñoz et al., 2008; Tehrani et al., 2018), and some studies found that less desirable dietary behaviours were associated with depressive symptoms, anxiety and stress (Jacka et al., 2017; Opie et al., 2015; Parletta et al., 2019). This indicates that how an

individual feels in their mental state can influence how an individual chooses to eat, and how an individual chooses to eat can also influence how an individual feels in their mental state.

A total of 263 adolescents (average age of 16 years old) were involved in a study investigating the association between adhering to a Mediterranean diet and symptoms of depression, anxiety and stress, using the DASS-21 questionnaire (Tehrani et al., 2018). The study found that the quintile demonstrating highest adherence to the Mediterranean diet had a significantly lower prevalence of depression (59%), when compared with the quintile demonstrating the lowest adherence to the Mediterranean diet. Tehrani et al. (2018) were unable to explore the direct roles of the Mediterranean diet in relation to preventing depression but suggested potential hypothesis for the results observed. Tehrani et al. (2018) hypothesised that a Mediterranean diet was usually guaranteed to be adequate in B vitamins, which were associated with mechanisms in the body that produce the mood-stabilising hormone; serotonin, and omega-3 fatty acids, which have shown to be protective against depressive symptoms in previous studies, therefore, better adherence to a Mediterranean diet would result in less depressive symptoms (Tehrani et al., 2018). Another hypothesis by Tehrani et al. (2018) and other similar studies recognised that the Mediterranean diet emphasized sociocultural aspects of eating together, social support and hospitality, which may promote enjoyment and positive behaviours that influence mental health and psychological wellbeing (Muñoz et al., 2008; Tehrani et al., 2018). This was an interesting finding as it explores the psychosocial aspect of eating, encapsulating the complexity of influencing factors that may contribute to mental health and dietary behaviours.

Studies have also investigated implementing a healthy dietary pattern to individuals with depressive symptoms, mental health disorders and self-reported concerns with psychological wellbeing. 152 adults (aged 18 to 65) with self-reported depression were recruited in a six-month randomised controlled trial that investigated the effects of the Mediterranean diet and fish oil supplements with improving mental health (MedDiet group), compared with attending social group sessions with improving mental health (social group) (Parletta et al., 2019). The DASS-21, the Assessment of Quality of Life (AQoL-8D) and the Positive and Negative Affect Scale (PANAS) were used to measure mood, mental and psychological wellbeing. Both groups showed improvements in mental health scores, however the MedDiet group showed increased adherence to the Mediterranean diet after three months, greater improvements in the AqoL-8D score, and significantly greater improvements in the DASS-

Depression score (45% improvement), when compared with the social group (26.8% improvement). These changes were sustained after six months. The improved mental health scores in both groups suggests that a Mediterranean diet was not only associated with dietary behaviours, but also lifestyle behaviours of social support and collective culinary activities. This was similar to the hypothesis discussed by Tehrani et al. (2018) and other studies that have explored the social benefits of the Mediterranean diet (Muñoz et al., 2008; Tehrani et al., 2018). In a 12-week randomised-controlled trial by Jacka et al. (2017), participants with moderate to severe depression (aged 18 and over) were randomised into receiving dietary support or social support in association with improving depressive symptoms, using the Montgomery-Åsberg Depression Rating Scale (MADRS) (Jacka et al., 2017). Significantly improved MADRS scores and increased consumption of fruits, wholegrain cereals, pulses, dairy, olive oil and fish were seen after 12 weeks in the dietary support group, when compared with the social group (Jacka et al., 2017). The dietary support group received nutrition counselling, motivational interviewing, goal setting, mindful eating and tailored advice from a clinical dietitian. Based on the successful implementation of dietary support in the study, Jacka et al. (2017) suggests implementing targeted dietary supportive strategies to future studies addressing mental health. The literature suggests that there is a significant association between dietary behaviour and mental health, in which depression and depressive symptoms were the most heavily explored aspect of mental health in dietary intervention studies (Opie et al., 2015). Unsurprisingly, no studies had investigated baseline mental health status in association with adherence to dietary reporting, which future studies may benefit from exploring as dietary reporting plays a significant role in understanding habitual dietary patterns in many nutrition studies.

2.10.3 Social Support

Group therapy and social support have shown positive effects with enhancing motivation and adherence to behavioural changes in dietary intervention trials (Armstrong et al., 2011; Paul-Ebhohimhen & Avenell, 2009). A systematic review of the effectiveness of group versus individual treatment for obesity in adults saw significant increased effectiveness in weight change in groups-based treatments compared with individual treatments (Paul-Ebhohimhen & Avenell, 2009). A study by Sparks et al. (2019) aimed to investigate individual and social influences on college students' adherence to a gluten-free diet (18 to 22 years) (Sparks et al., 2019). A significant barrier was difficulty adhering during social events and outside of home

as most students reported eating out at least once a week. A potential solution to overcoming this barrier in future studies is to have peers or partners to complete dietary interventions as a social support system for young adults. Simpson et al. saw positive dietary behaviours were strengthened with group support, peer modelling and the provision of resources in their dietary intervention trial (Simpson et al., 2017). Peer support has become a significant component of delivering quality care, therefore can be a useful way to increase motivation and adherence in dietary intervention trials.

A study aiming to promote healthy eating habits in college students by comparing a diet diary and a smartphone application saw that the students benefited from learning through observation, imitation and modelling off each other (Watanabe-Ito et al., 2020). Dietary intervention trials have successfully incorporated group meetings, focus groups, and educative sessions to receive feedback on progress, provide further support, and engage participants with intervention strategies (Armstrong et al., 2011; Jacka et al., 2011; Sparks et al., 2019). As group sessions are reliant on assistance, the facilitator plays an important role in carrying out a successful group discussion. Therefore, facilitators should be professional and trained for their target group and intervention strategy. In dietary intervention trials, the current research shows that the facilitation of group sessions can be effective with trained nutritionists or dietitians (Cant & Aroni, 2008). Young adults are often heavily reliant on peer support and connections with friends and family as part of their support system (Turner, 1999). As social acceptability and influence of social environment can influence decision making for young people, creating group discussions with like-minded peers may promote positive influences and lead to better adherence and engagement with intervention strategies.

2.11 Association Between Behavioural Techniques and Adherence to Dietary and Health-Related Intervention

Current research shows evidence that adhering to medical treatment or intervention is more likely to result in better health outcomes (Potpara et al., 2015; World Health Organization, 2013). Therefore, adhering to dietary intervention trials that are in line with a healthy dietary lifestyle is hypothesised to more likely result in positive health outcomes. Dietary intervention trials that explore habitual dietary intake require high levels of adherence, to gage an as accurate as possible representation of an individual's habitual dietary pattern. Multiple theories, models and questionnaires have been developed and experimented to

understand and support current and future participants with adherence to dietary and health-related intervention.

2.11.1 The Theory of Planned Behaviour to Predict Adherence

The Theory of Planned Behaviour (TPB) has been used in nutritional research to explore human characteristics that may influence their dietary actions and behaviours (Ajzen, 1991). The model uses an individual's attitude, perceived behavioural control and subjective norms to identify factors that influence their beliefs, which subsequently contributes to their behaviour (Ajzen, 1991). A recent study by Malek et al. (2017) aimed to understand the relationship between intention of healthy eating and actual eating behaviour of pregnant women in Australia using the TPB model (Malek et al., 2017). The TPB predicted 66% of the variance in the participant's intention of healthy eating in the study. The study found perceived behavioural control and subjective norms were significantly strong predictors and attitude was a significant predictor of healthy eating intention. Participants that had a stronger intention of consuming healthy foods were more likely to adhere to the food group recommendations. A systematic review and meta-analysis conducted by McDermott et al. (2015) reviewed 22 studies on the relationship between the TPB with predicting dietary patterns and behaviours. *"TPB variables were found to have medium to large association with both intention and behaviour. Attitudes had the strongest association with intention, followed by planned behavioural control and subjective norms"* (McDermott et al., 2015). Interestingly, there was a stronger association between intention and behaviour with adherence to restricted dietary patterns, rather than intention and behaviour with adherence to healthy dietary patterns. A 2019 study by Mahmoodabad et al. looked at compliance rates to the DASH diet of prehypertensive individuals using the TPB. The study saw 72% of predicted variance in behavioural intention, and also found that attitude was the strongest predictor of behaviour out of all the TPB constructs (Mahmoodabad et al., 2019). Ultimately, all constructs of the TPB (attitude, perceived behavioural control and subjective norms) were significantly associated with behavioural intentions (Mahmoodabad et al., 2019). The literature therefore demonstrates that the TPB model produces high variance rates in participant response to intentions of planned behaviour and further highlights the role of multivariable personal factors that can influence adherence. However, it is important to note that intention to act on a behaviour does not always result in behavioural action, therefore, strategies to further enhance action of behaviour change need to be applied in combination.

Identifying individual perceptions using the TPB shows promise with predicting motivation, influences and barriers to behavioural intention, which can help researchers further understand how to develop more effective intervention strategies to improve adherence.

2.11.2 The Health Belief Model to Predict Adherence

The Health Belief Model (HBM) is another widely used conceptual tool for predicting individual behaviours and adherence to intervention (Champion & Skinner, 2008). The model utilises five domains; perceived susceptibility, perceived severity, perceived benefits, perceived barriers and self-efficacy, to analyse an individual's behavioural intentions and actions. Self-efficacy is defined as the belief that an individual has in their own capability to act on a behaviour change based on performance accomplishment, vicarious learning, verbal encouragement and emotional states (Champion & Skinner, 2008). Self-efficacy is a domain of the HBM but is also an individual concept that has been popularly measured through tools such as self-efficacy questionnaires and self-efficacy scales (Betz, 2013). The literature demonstrated success in the use of the HBM to predict adherence to health behaviours in dietary and health-related intervention (Janz & Becker, 1984; Karimy et al., 2016; Mahmoud et al., 2018; Yang et al., 2016).

A cross-sectional study used the HBM to investigate adherence to self-care behaviours in women (aged 30 to 60) with type 2 diabetes (Karimy et al., 2016). Self-care behaviours were measured using the Summary of Diabetes Self-Care Activities Measure (SDSCA) and consisted of questions that measure adherence to diabetes self-care activities such as diet, medications and exercise. The strongest predictor of self-care behaviours that was found in this study was self-efficacy (Karimy et al., 2016). Participants that had both stronger perceived benefits of self-care and stronger perceived severity of Type 2 Diabetes were more adherent to self-care behaviours. However, participants that only had stronger perceived barriers were negatively associated with self-care behaviours. This was also seen in other studies and was likely related to perceived barriers hindering an individual's motivation and self-efficacy to undertake intended behaviour changes (Jalilian et al., 2014; Janz & Becker, 1984). In a 2018 study looking at compliance to therapeutic regimens in women with gestational diabetes using the HBM, results saw a positive association between total compliance and perceived susceptibility, perceived severity and perceived benefits (Mahmoud et al., 2018). Participants with high levels of perceived barriers were more likely

to result in unsatisfactory compliance to the regimen. (Mahmoud et al., 2018). Similarly, a study by Yang et al. (2016) determining adherence to antihypertensives based on the HBM found that lower perceived barriers were associated with higher levels of adherence to antihypertensive medications (Yang et al., 2016). Some common perceived barriers found in this study were side effects of medication, cost of medication, and not remembering to take medication (Yang et al., 2016). From these findings, future researchers should aim to reduce perceived barriers to improve adherence to dietary intervention. Furthermore, promoting perceived benefits and reinforcing self-efficacy may help to positively influence behaviour change and adherence to dietary intervention.

Participants that followed habitual restricted dietary patterns of a weight loss, vegetarian, vegan, paleo and gluten-free diet were recruited to explore the predictors of behaviour that influenced adherence to the dietary pattern (Cruwys et al., 2020). Predictors of behaviour were measured using personality characteristics, mental health and motivational factors. The study was unique in investigating direct effects of dietary adherence in participants, rather than comparing adherence between diet groups. The most common perceived barriers to dietary adherence that was seen in all diet groups were: lack of willpower and inconvenience with lifestyle. Disordered eating patterns resulted in significantly lower and reduced dietary adherence, whereas self-efficacy was a significant predictor of high dietary adherence. Participants who had stronger beliefs and social identification with their dietary group also had better adherence (Cruwys et al., 2020). This further suggests that participants' beliefs with the intervention arm plays an important role in behaviour intention.

From the literature, this suggests that when individuals have a better understanding and raised awareness around the proposed behaviour, they are more likely to adhere. For example, if an individual is more informed about the risks and consequences of uncontrolled diabetes, they will have a higher perceived susceptibility of the condition and therefore are more likely to improve adherence to healthy behaviour changes. Using the same concept for assessing dietary reporting in dietary intervention trials, the HBM shows potential in predicting perceptions, beliefs and influences that affect individual's behaviours and therefore can be an effective tool to eliminate barriers and improve adherence to dietary intervention.

2.11.3 Other Behaviour Change Techniques Used to Predict Adherence

Behaviour change techniques such as the Cognitive Behavioural Theory, Motivational Interviewing, Self-Efficacy and the Transtheoretical Model have demonstrated success in supporting changes to dietary behaviour (Armstrong et al., 2011; Cassidy & Barnes, 2018; Lara et al., 2014; Michie et al., 2011; Nour et al., 2016). Behaviour change is influenced and onset by multiple factors such as environmental influences, personal determinants, overall health and quality of life. Therefore, being able to understand what factors affect an individual's willingness and motivation to make behavioural changes is incredibly beneficial for designing intervention strategies that individuals can adhere to. The 1991 Dahlgren-Whitehead "Rainbow Model" illustrates that health determinants are influenced at multiple levels; individual level, community level and population level (Dahlgren & Whitehead, 2021). This denotes the wide range of factors that can determine barriers and motivation to an individual's behavioural intentions and therefore using behaviour change techniques that target multiple levels concurrently would be the optimal approach.

A 2014 meta-analysis looking at the association of behaviour change techniques (BCT) with effectiveness of dietary intervention in elderly populations used the Coventry, Aberdeen and London Refined taxonomy (CALO-RE) to standardise BCT definitions (Lara et al., 2014). Results of the review showed that the BCTs most commonly used in these studies were behaviour goal setting, outcome goal setting, providing information on the consequences of the behaviour, being given instructions on how to perform the behaviour and feedback on progress. Additionally, studies in the review that showed sustained participant behaviour changes to dietary intervention integrated problem solving, social support, identifying barriers, follow-up reminders and goal setting (Lara et al., 2014). This shows similarity with the previously mentioned models (TPB and HBM) that identify the importance of factors such as perceived barriers, perceived behavioural control, subjective norms and attitude.

A 2016 systematic review and meta-analysis of 12 studies exploring the validity of eHealth and mHealth based interventions to promote vegetable consumption in young adults saw studies that produced the most success incorporated constructs of behaviour change (Nour et al., 2016). Examples of behaviour change techniques that were used were goal setting, individual tailored advice and the integration of the Transtheoretical model to give feedback based on an individuals' stage of change (Nour et al., 2016). The literature has shown that text messages based on the Transtheoretical model being used in eHealth and mHealth

dietary interventions have large effects on influencing behaviour change in young adults (Partridge et al., 2015; Rompotis et al., 2014; Shahril et al., 2013). As mobile phones are significantly embedded in a young adult's lifestyle, the use of text messaging to relay BCTs and communication may be more acceptable, subsequently improve adherence to dietary intervention. Commonly reported barriers with adherence to dietary intervention using eHealth and mHealth were: more reminders to prompt users, and provision of real-time feedback to increase their rate of adherence (Carter et al., 2013; Chen et al., 2017; Kikunaga et al., 2007; Wang et al., 2006).

A 2020 randomised controlled trial by Azami et al. (2020) evaluated the effects of motivational interviewing (MI) on dietary intake and weight changes in overweight and obese preconception women (aged 18 to 35 years) to achieving normal BMI (Azami et al., 2020). The study found that the MI group had reduced energy intakes and more weight loss when compared with the control group. In the MI intervention group, there were six structured MI sessions: the first two sessions providing education and training using informed booklets and the remaining four sessions using group MI. Although significant benefits were seen with adherence in the MI group, the study had a short follow-up time period of eight weeks, therefore weakening the evidence of long-term sustainability of adherence to the intervention (Azami et al., 2020). The Diabetes Prevention Program recommends an "extensive network of centralised training, feedback and support," including the use of reflective listening, motivational interviewing and empowerment strategies (Diabetes Prevention Program (DPP), 2002). A systematic review and meta-analysis of 11 RCTs using MI to improve weight loss in overweight or obese patients saw that the studies with the largest weight reduction used MI in group-based weight loss programmes (Armstrong et al., 2011). This suggests group therapy and social support in combination with MI contributed strongly towards behaviour change and adherence. In 2018, Cassidy and Barnes (2018) conducted a 12-week RCT evaluating the association of diet, exercise and motivation with weight reduction and health behaviours in young adults aged 18- to 35- years old (Cassidy & Barnes, 2018). There were three intervention groups within the study: diet information only (group one), diet information and moderate aerobic activity (group two), and diet information, moderate aerobic activity and MI (group three). MI showed the greatest effect in promoting weight loss with eight times more weight loss achieved in the group receiving diet information, moderate aerobic activity and MI, when compared with the group that received

diet information only. Overall, the evidence suggests that incorporating MI as a BCT alongside dietary intervention promotes behaviour change and adherence to intervention.

2.12 The Need to Improve Adherence to Dietary Reporting and Dietary Intervention in Nutrition

There is currently abundant research that focus on improving adherence to dietary reporting and dietary intervention in the literature. eHealth and mHealth approaches have shown to increase communication and engagement for participants and as a result, this has significantly improved dietary reporting when compared with traditional dietary reporting methods. However, limitations and challenges are still seen with adequate dietary reporting in nutritional studies, consequently impairing the accuracy of collected data. The current thesis project aims to measure and support adherence to dietary reporting using a smartphone application in the Predition Trial, as well as investigate barriers that participants may face with achieving optimal dietary reporting. Strategies to improve adherence to dietary intervention also remains a challenge in nutritional research. The current literature shows that social support, eating behaviours, self-efficacy, socioeconomic status and mental health status can all influence participant engagement and willingness with intervention trials. Therefore, this thesis project aims to measure and support adherence to dietary intervention, using methods that have shown to be effective in the literature, such as sending text message reminders and reducing participant burden of time and financial restraint. Furthermore, this thesis project was interested in exploring potential baseline characteristics that may influence participant adherence to dietary reporting and dietary intervention to further improve the quality of this area of nutritional research.

3 Research Methods

3.1 Study Design

This was a randomised controlled trial (RCT), measuring and supporting adherence to dietary reporting and dietary intervention using a smartphone application, exploring barriers to achieving optimal dietary reporting, and the relationship between baseline characteristic with adherence to dietary reporting and dietary intervention. Eighty participants were recruited from Auckland, New Zealand, into the ten-week dietary intervention trial: Predition Trial. A two-week assessment period (T-2 phase) was commenced, where participants were screened

and randomised to adhere to a red meat intervention ('Flexitarian') or a vegetarian intervention ('Vegetarian'). The full protocol for the trial titled "A Modern Flexitarian Dietary Intervention Incorporating Web-Based Nutrition Education in Healthy Young Adults: Protocol for a Randomised Controlled Trial" has been published elsewhere (Braakhuis et al., 2021). Participants received three serves of red meat each week in the red meat intervention group, and three serves of meat alternatives each week in the vegetarian intervention group. In addition, all participants received three complimentary vegetarian meal-kits each week, to minimise participant burden with cooking. Participants reported dietary intake into the smartphone application "Easy Diet Diary" (Xyris Ltd, Australia). Two components of adherence were measured:

1. Adherence to dietary reporting through the Easy Diet Diary, enabling recording through manual, image-based and barcode scanned entry of food items.
2. Adherence to the dietary intervention of either a flexitarian or vegetarian diet.

Adherence to both components was defined as being compliant to the study.

Participant Inclusion Criteria

Our eligibility criteria were as follows:

- All participants were required to be omnivores prior to recruitment, who in the last 2 months consumed at least 2 to 3 meals per week containing meat of any description (red or white fleshed meat, including fish).
- Participants were recruited as pairs of individuals (partner, spouse, companion), who will cohabitate for the duration of the trial.
- All participants must be willing to consume both red meat and meat-analogues for the purposes of the trial.
- 20 to 34 years of age, male and female.
- BMI $\leq 30 kg/m^2$.
- Are free of chronic health conditions, such as obesity, cancer, heart disease, diabetes, hyperlipidemia
- Do not use medications (except for occasional nonsteroidal anti-inflammatory drugs and antihistamines) and recreational drugs.
- Non-smokers.
- Have no history of anosmia and ageusia (issues with smell and taste)

- Do not show signs of disordered eating patterns, based on Three-Factor Eating Questionnaire (TFEQ) score greater than 75% as an exclusion criterion.

3.2 Data Collection Method

3.2.1 Using the Smartphone Application 'My Easy Diet Diary'

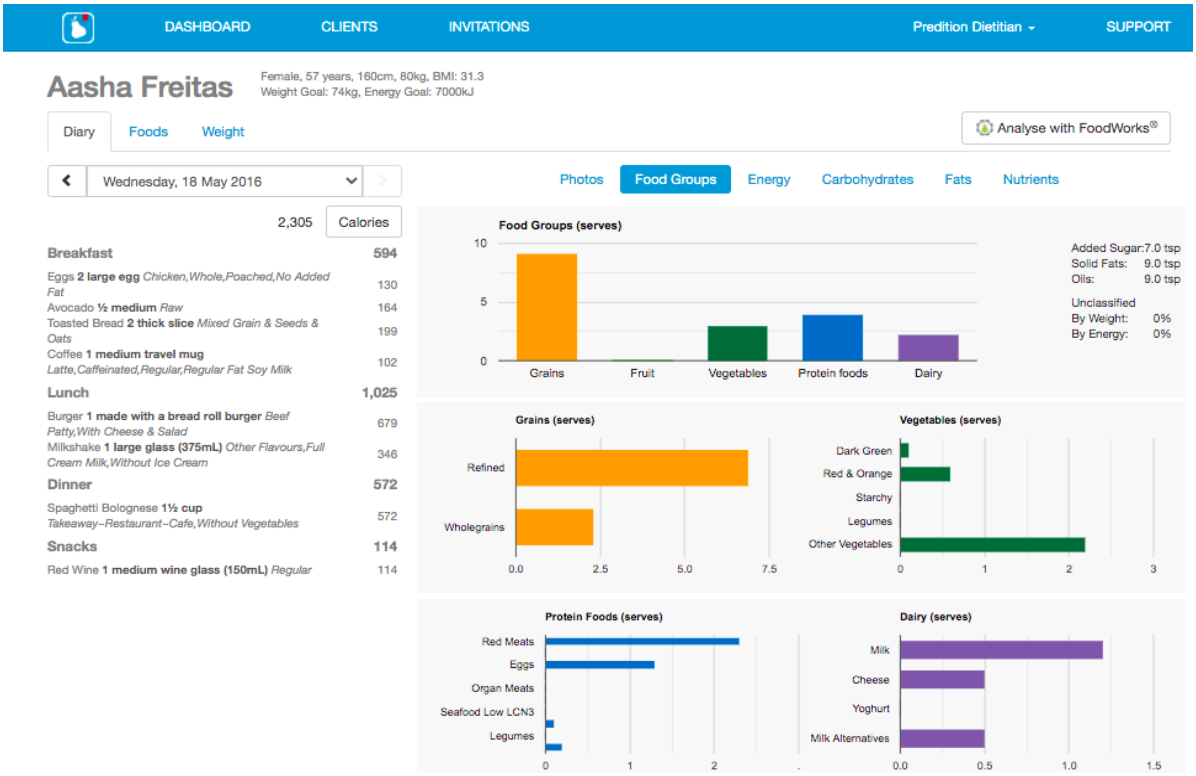
Eighty paired participants (partners, flatmates, siblings) were required to record daily dietary intake into the Easy Diet Diary (EDD) smartphone application to investigate adherence to dietary reporting and dietary intervention. The researchers provided participants with an email link with an invitation to register with Easy Diet Diary; this allowed the participant to directly share data with the researchers. Participants were required to record their dietary intake manually through text insertion into the direct database on two days of the week (Sunday and Monday). For the remaining five days of the week (Tuesday to Saturday), participants were required to record their dietary intake through a choice of image-based food records or manual text insertion. Participants were divided into groups of 10, totalling 8 groups for the entire study. Each group was randomised to a different intervention arm and started one week apart from each other.

The "Easy Diet Diary" is a freely available mobile phone application used to record food and fluid intake by the mobile user through an electronic smartphone device that was compatible with the application. Dietary intake could be recorded through five categories in the EDD application; "breakfast," "lunch," "dinner," "snacks" and "notes." The "notes" section was formatted as free text, to support any clarification of the food items that users may feel were necessary to support their entries. Additional features of the application included weight and exercise monitoring but were not relevant to this study, as these items were measured using alternative methods.

Participants were given instructional support on how to use the Easy Diet Diary application using written and verbal strategies. Prior to screening (T-2 phase), participants were emailed a handout of instructions developed by a dietetic student (LL) on how to navigate the EDD application (Appendix 1). At the first clinic visit (T-0 phase), two research dietitians (AW, NG) provided face-to-face verbal instructions to the participants and provided emphasis on key strategies to optimise dietary reporting into the application.

The Easy Diet Diary application was developed by an Australian nutrition software company Xyris Pty Limited (Australia) and food within the EDD database were derived from FoodWorks 10, which sources nutritional data from the Australian Food Composition Database and the 2013 Australian Food and Nutrient Database (Xyris Pty Limited, 2020, 2022). For manual text insertion, participants were able select from the range of commercial products or create using the "recipes" section for foods not available within the database. Food items that had barcodes could also be scanned using the barcode function of the application if the food item was available within the application database. For image-based entries, participants were able to use the camera function embedded in the application to take a snapshot of their food. Images could not be uploaded onto Easy Diet Diary at another point in time through the mobile phone gallery or photo album, therefore all image-based entries were taken at the time of eating. All data from the mobile phone application were shared directly with the researchers via "Easy Diet Diary Connect" or http://connect.easydietdiary.com/. This was a website that allowed researchers to view participant data online. See Figure 1 for an example of access to the Easy Diet Diary Connect website of a fictitious entry.

Figure 1. Researcher Accessibility to a Sample Client's Dietary Reporting Through "Easy Diet Diary Connect" (Fictitious Entry)



Fictitious entry from Easy Diet Diary Connect (Xyris Pty Limited, 2022)

3.2.2 Measuring and Supporting Adherence to Dietary Reporting and Dietary Intervention

The researcher (Larissa Li, student dietitian) (LL) assessed participant adherence to dietary reporting and dietary intervention using the EDD cloud every three to four days (two times per week), totalling twenty assessment periods over the ten-week trial for each participant. This was the method used for measuring adherence to dietary reporting and dietary intervention in the Predition trial. As burden of long-term dietary reporting had been observed in the literature, the researchers have taken a pragmatic approach to dietary reporting, allowing participants to primarily report image-based recording to support adherence (Armstrong et al., 2011; Carter et al., 2013; Thompson & Subar, 2017).

In each assessment period, participants were required to record at least one full day of dietary intake, which was defined as three entries of at least two meal occasions, and one meal or snack occasion (either manual or image-based recording). Any skipped meal occasion that was reported into the EDD application was considered as a meal occasion, because participants acknowledged and initiated the action of reporting a meal occasion. For example, if a participant reported "breakfast," "skipped lunch," and "banana as a snack," within one day, this would be considered as two meal occasions and a snack occasion, demonstrating a full day of dietary reporting. If participants reported less than one full day of recording within an assessment period, they were sent a standardised text message with specific nudges, to support adherence to dietary reporting. At each one-week interval, participants were required to adhere to dietary intervention, which was defined as all three servings of meat or meat-analogues consumed and reported into the EDD application and abstaining from all other meat products. If participants did not report all three servings of meat or meat alternative products, or consumed meat outside of the dietary intervention, they were sent a standardised text message. Non-adherence to either dietary reporting or dietary intervention were considered as non-adherent to the study at the time of check-up. Following two consecutive assessment periods of non-adherence requiring text message reminders, a phone call was made from the research team. At the phone call stage, the household study partner was contacted by text message to indicate the risk of continuation in the study if the study partner failed to adhere to dietary reporting or fails to adhere to dietary intervention. After consecutive two weeks of non-adherence to dietary reporting or dietary intervention, the participant was excluded from participating further and provision of the dietary intervention was stopped. The participant pair was also excluded.

All data collection from the twenty assessment periods were collated into an Excel spreadsheet. The spreadsheet was created to monitor adherence to dietary reporting and dietary intervention with specific coding for the table requirements. One researcher (LL) was responsible for monitoring adherence to dietary reporting and dietary intervention at all assessment periods and input all adherence data into the spreadsheet, and two registered dietitians (Nicola Gillies, Anna Worthington) (NG, AW) were responsible for checking through the spreadsheet and sending text messages to participants, as deemed necessary. To standardise the measurement of adherence, a Dietary Adherence Standard Operating Procedure (SOP) document was developed (see Appendix 2). Standardised text message reminders that were sent to participants were assembled into three categories; 1. Recording, 2. Clarification, 3. Adherence. Any additional notes that were to be communicated between researchers were recorded in the "notes" section of the Excel spreadsheet.

The researchers (LL, NG, AW) further supported participant adherence to dietary intervention by developing the "Predition Trial Cookbook." The cookbook contained recipe ideas for vegetarian and meat-analogue dishes, basic cooking tips and label reading advice. All meat and meat-alternative products were provided complimentary to participants and delivered to each household, to minimise the burden of cost and time for participants. Additionally, vegetarian meal-kits were provided three times each week for all participants of the study, to support dietary intervention.

The literature shows that social support was positively associated with improved adherence to dietary intervention (Armstrong et al., 2011; Paul-Ebhohimhen & Avenell, 2009). Participants within the same intervention arm and intervention period were invited to join an online Facebook group with two research dietitians (NG, AW). The research dietitians were then able to support participants with adhering to the dietary reporting and dietary intervention individually and collectively throughout the trial. Examples of support through the online Facebook group included peer support, nutrition education from research dietitians, and responding to questions that participants may have.

The literature shows that limited knowledge, limited cooking skills, lack of education and financial constraints were barriers to adhering to a healthy dietary lifestyle (Azami et al., 2020; Blumenthal et al., 1982; Demirtaş & Akbayrak, 2017; Kemper & White, 2021; Taha et al., 2011). Therefore, providing supplementary resources to support participants was deemed

appropriate to reduce barriers and improve adherence to dietary reporting and dietary intervention in the Predition Trial.

3.2.3 Investigating Barriers to Achieving Optimal Dietary Reporting with the EDD Application

The Barriers to Recording Questionnaire was developed by one researcher (LL) to investigate barriers to achieving optimal dietary reporting in the EDD application (Appendix 3). The questionnaire was conducted in the pilot groups (n=20) at the half-way point of the trial (T5 phase). There were nine questions in total. Questions one to seven were measured using a 4-point Likert scale ranging from "strongly disagree" to "strongly agree," where a score of 1 indicated "strongly disagree" and a score of 4 indicated "strongly agree." The mean and standard deviation of scores for questions one to seven were calculated. Questions eight and nine from the Barriers to Recording Questionnaire were analysed using qualitative analysis, to explore common themes reported by the participants.

3.2.3.1 Qualitative Analysis

Questions eight and nine were formatted to collect open ended, non-numerical, and free-text responses from participants. Two researchers (Larissa Li, Andrea Braakhuis) (LL, AB) completed thematic analysis separately to measure responses to questions eight and nine and came to similar conclusions. The thesis candidate (LL) conducted thematic analysis using a table to collect key words and phrases, and then put together similar themes and messages that were portrayed (Appendix 4).

3.2.4 Measuring Lifestyle Characteristics

In the current thesis, the lifestyle characteristics: physical activity, sleep and diet quality were measured. The Huawei Band 4 Pro Smartwatch is a fitness tracking device worn on the wrist and was used to measure sleep and physical activity in the Predition Trial. The watch has a 3-axis accelerometer and wrist heart rate sensor which determine physical activity and sleep patterns. Earlier versions of the smartwatch have been successfully used in behaviour change interventions (Chia et al., 2019). The Smartwatch works by connecting through Bluetooth of a mobile phone that is compatible with the downloadable integrated Smartwatch application (Huawei Health) to sync data from the Smartwatch into the mobile phone. Additional

features of the Smartwatch include oxygen saturation detection, which we did not record as it was not relevant to this study.

Participants registered under their contact number with a standardised password, so that physical activity and sleep data could be accessible to researchers from the Huawei Health "cloud." At the clinic visit (T-0 phase), an A4 format instructional handout developed by the dietetic student (LL), containing detailed steps on how to use the Smartwatch was provided to participants (Appendix 5). To further support adherence with regularly wearing the Smartwatch and syncing data, participants were given verbal face-to-face tips at the clinic visit (T-0 phase) to maximise adherence to watch wearing and sent text reminders regularly throughout the intervention to sync Smartwatch data with the Huawei Health application.

Physical activity was measured by the number of steps using the automatic step count function of the Smartwatch. Sleep data was measured using the automatic built-in sleep tracker system "Huawei TruSleep." "Huawei TruSleep" recognises body movement, heart rate and breathing data to determine sleep and sleep stages of an individual (wake, rapid eye movement, light sleep and deep sleep). The average steps taken per week were recorded into an Excel spreadsheet and the average hours and minutes of sleep duration per week were recorded into an Excel spreadsheet.

An adapted Healthy Diet Score (HDS) was developed by two Registered Dietitians (NG, AW) in the research team to assess participants' dietary behaviours. Data from the Short Food Frequency Questionnaire (FFQ) for New Zealand adults was used to calculate participant's scores. In brief, participants selected their usual intakes of 57 food items in the past three months with eight frequency categories ranging from 'never or less than once per month' to '4-6 per day'. Participants also reported an average daily intake of fruits and vegetables as open-ended text, with examples of a standard serve size provided in line with the New Zealand Food and Nutrition Guidelines (Ministry of Health et al., 2020).

The Healthy Diet Habits Index for New Zealand adults (Wong et al., 2017) was used to guide the scoring criteria, and adapted according to data that was available from the FFQ (summary questions and food frequencies) and behaviours that were targeted by the nutrition education programme in the Predition Trial (Worthington, 2021). The score included five items,

including daily intake of fruits and vegetables, weekly intake of sugar-sweetened beverages (SSBs) and fast-food, and types of breads or cereals consumed.

Items were scored on a scale from 0 to 4. A higher score indicates the behaviour aligning with Ministry of Health Eating Guidelines (2020), such as meeting the recommended serves of fruit and vegetables, lower intake of SSB and takeaways, and regularly choosing wholegrain breads or cereals (Table 1). The sum of the five item scores was then converted to a final score on a scale from 0 to 100.

Table 1. Components and Scoring of the Healthy Diet Score for Participants in the Predition Trial

Item	**Scoring**				
	0	**1**	**2**	**3**	**4**
Fruit	None	-	1 per day	-	>2 per day
Vegetables	None	1 per day	2 per day	3-4 per day	>5 per day
Wholegrain Breads or Cereals[1]	None	-	Occasionally (1-7 per week)	-	Regularly (>7 per week)
Sugar-sweetened Beverages[2]	>7 per week	5-6 per week	2-4 per week	<1 per week	None
Fast-food	>7 per week	5-6 per week	2-4 per week	<1 per week	None

[1] Wholegrain options in the FFQ include high fibre breakfast cereals (e.g., porridge, muesli, bran flakes, all bran), wholemeal or multigrain breads (including tortillas, pita, rolls, wraps), roti/chapatti (traditionally prepared with whole-wheat flours), or brown rice and wholemeal pasta.
[2] Sugar-sweetened beverage options in the FFQ include soft drinks, juices, cordials.

3.2.5 Measuring Sociodemographic Characteristics

The sociodemographic characteristics of interest were age, gender, level of education and occupation. The Predition Trial Objective 4 Study Screening Questionnaire was used to collect data on these sociodemographic characteristics during participant recruitment.

3.2.6 Measuring Anthropometric Variables

At baseline (T-0 phase), participants were required to attend a clinic visit with two trained dietitians (NG, AW) to assess anthropometric measurements: height, body weight, body mass index (BMI), and percentage body fat. The visit was conducted at the Nutrition and Dietetics Clinic on Grafton Campus, University of Auckland.

The DEXA scan was performed using the GE Healthcare Lunar iDXA-LU43768, manufactured January 2021. Participants completed a total body scan in a laid down position, to measure percentage total body fat for the purpose of this thesis project. This was done at the T-0 phase and T-10 phase to measure changes in percentage total body fat over the course of the intervention.

Anthropometric measurements were height, weight, and BMI. Height and weight were measured using the A&D High-Capacity Personal Scale (HW-PW-200-FG) to measure weight in kilograms, and a free-standing stadiometer to measure height in centimetres. The BMI was then calculated simply using the BMI equation of $\frac{weight\ (kg)}{height^2(m^2)}$. All measurements were repeated at the T5 phase and T10 phase to evaluate changes in anthropometric measurements over the course of the intervention. All anthropometric measurements were done twice, then averaged, to ensure accuracy of the measured data.

3.2.7 Measuring Psychological Characteristics

The psychological characteristics of interest were measured through questionnaires at screening (T-2 phase). Questionnaires that were used to measure psychological characteristics in this thesis project were: the self-efficacy questionnaire, three factor eating questionnaire (TFEQ) (Stunkard & Messick, 1985), the Depression Anxiety Stress Scales-Short form (DASS-21) (Crawford & Henry, 2003), the WHO-Five Well-Being Index (WHO 5) (Topp et al., 2015), and the Positive Eating Scale (Sproesser et al., 2018). A summary of details for all the measured psychological variables has been outlined in Table 2.

Table 2. Components and Scoring of Psychological Variables for Participants in the Predition Trial

Variable	Measuring Method	Score Range	Details of Questionnaires
Self-Efficacy	Self-Efficacy Questionnaire	0 to 40	Eight questions with five-point scale ranging from “not confident at all” to confident.”
Eating Behaviours	TFEQ	0 to 100 (%)	A higher score indicated greater disordered eating patterns.
Depression (D), Anxiety (A) and Stress (S)	DASS-21	D: 0 to 42 A: 0 to 42 S: 0 to 42	A higher score indicated greater levels of depression, anxiety and stress.
State of Wellbeing	WHO-5	0 to 100	A higher score indicated a greater state of wellbeing.
Positive Eating	PES	1 to 4	A higher score indicated more association with positive eating.

3.3 Data Extraction

3.3.1 Compliance

In this thesis project, the term “compliance” was defined as both adherence to the dietary reporting and adherence to dietary intervention simultaneously. For example, a participant that adhered to dietary intervention but did not adhere to dietary reporting was considered not compliant to the study. Adherence to dietary reporting was assessed by how well the participants adhered to the instructions to provide food images and to provide text description, and meeting the minimum requirements for recording each week. Adherence to the dietary intervention was defined as whether participants abstained from consuming other meat beyond what was provided during the intervention, and whether participants consumed all serves of the protein provided each week (‘Flexitarian’ or ‘Vegetarian’). To measure adherence to dietary reporting, a reporting compliance score was developed. To measure adherence to dietary intervention, an adherence compliance score was developed. To measure compliance, the reporting compliance score and adherence compliance score were combined and weighted to create a composite compliance score.

Given the scarcity of robust compliance scores available in the literature, the compliance scores defined below were based on a Mediterranean-Style Dietary Pattern Score (MSDPS) developed by Rumawas et al. (2009) (Rumawas et al., 2009). The MSDPS scored a total of

thirteen food groups from a range of 1 to 10 based on the recommended intakes in the Mediterranean diet pyramid (Willett et al., 1995). In this thesis project, adherence to dietary reporting and dietary intervention followed a similar scoring pattern as the MSDPS.

3.3.2 Adherence Compliance Score

A score of 1 was received by the participant if they abstained from consuming other meat beyond what was provided during the intervention, and a score of 0 if they did not. A further score of 1 was received by the participant if they consumed all serves of the protein provided each week, and a score of 0 if they did not. The theoretical maximum points that a participant may receive was 20 points across the 10-week intervention. Adherence to dietary intervention was determined using a 0-100 scale, where the actual sum was divided by the theoretical sum of 20 points across the 10-week intervention, and multiplied by 100.

3.3.3 Reporting Compliance Score

A score of 1 was received by the participant if they adhered to the instructions to provide food images and/or to provide text description, and a score of 0 was received if they required text reminders for clarity of recording. Participants had been instructed to provide food images for five days and enter food using the EDD application database for two days as previously described. A further score of 1 was received by the participant if they met the minimum requirements for recording each week, and a score of 0 was received if they did not meet the minimum requirements. The theoretical maximum points that a participant may receive was 20 points across the 10-week intervention. Similar to above, adherence to dietary recording into the EDD application was determined using a 0-100 scale, where the actual sum was divided by the theoretical sum of 20 points across the 10-week intervention, and multiplied by 100.

3.3.4 Composite Compliance Score

A composite compliance score was developed to determine both adherence to dietary reporting and adherence to dietary intervention. Both the adherence compliance scores and reporting compliances scores were combined (4 scores in total), to produce a composite compliance score. The total theoretical maximum points that a participant may receive was 40 points across the 10-week intervention. The composite compliance score was determined

using a 0-100 scale, where the actual sum is divided by the theoretical sum of 40 points across the 10-week intervention, multiplied by 100.

Additionally, the composite compliance score was used to create a weighted score according to the total frequency of recording into the EDD application. The total frequency of recording was defined as the number of meal occasions and snack occasions recorded, as a percentage of the total opportunities of recording available. For example, the composite score of a participant that reported 80% of the total recording opportunities, was multiplied by 0.8.

3.3.5 Investigating Trends Between Intervention Groups

Specific trends in adherence to dietary reporting and adherence to dietary intervention were explored. Trends in adherence to dietary reporting was measured as the percentage of participants who did not adhere to dietary reporting at each weekly interval over the duration of the trial. Trends in adherence to dietary intervention was measured as the percentage of participants who did not adhere to dietary intervention at each weekly interval over the duration of the trial. Trends in compliance was measured as the total number of participants that adhered to both dietary reporting and dietary intervention simultaneously at each weekly interval over the duration of the trial. All trends that were analysed in the study were compared between intervention groups.

3.4 Data Analysis

Distribution of variables were graphically assessed prior to statistical analysis, and logarithmically transformed to achieve approximately normal distributions if needed. All statistical analyses were performed using R 4.0.3 statistical software, with alpha set at $P<0.05$.

Differences in compliance scores (adherence, reporting, and composite) and baseline participant characteristics (sociodemographic, anthropometric, psychological, lifestyle) according to intervention groups was assessed by a paired t-test.

Multiple linear regression analyses were performed to identify participant characteristics which were associated with adherence to dietary reporting, adherence to dietary intervention and adherence to both dietary reporting and dietary intervention. Adherence compliance

scores, reporting compliance scores, and composite compliance scores were set as the dependent variable in separate linear regression models, with psychological and lifestyle characteristics considered as independent variables in unadjusted and adjusted models. The sociodemographic variables were included as a covariate in adjusted regression models if they were associated with adherence compliance scores, reporting compliance scores and composite compliance scores ($p<0.20$). All statistical analysis were performed by nutrition researcher and registered dietitian, Nicola Gillies.

4 Results

80 participants were required to report dietary intake for 70 days in total while enrolled in a 10-week dietary intervention. 40 participants of the full 80 participants recruited, were involved in this thesis project due to ongoing COVID disruptions and limited data availability. The average number of days of reporting anything into the EDD application was 68.4 days out of the 70 days for the 40 participants analysed in this thesis project, 68.9 days out of 70 days for the red meat intervention group (n=20), and 68.0 days out of 70 days for the vegetarian intervention group (n=20). 52.5% of the participants were female and the average age of the 40 participants was 26.15 years. The majority of participants had a university level of education (n=25). Baseline characteristics of the participants are presented in Table 3.

Table 3. Baseline Characteristics of Participants in the Predition Trial

		Red meat (n=20)	**Vegetarian (n=20)**
Sociodemographic Variables	Age	27.4 ± 4.1	24.9 ± 5.0
	Gender, female	19 (%)	21 (%)
	Level of education		
	No qualification	1 (0.05%)	1 (0.05%)
	Secondary school	1 (0.05%)	8 (40.0%)
	Post-secondary school	1 (0.05%)	3 (15.05%)
	University	17	8
Anthropometric variables	BMI (kg/m²)	23.2 ± 2.4	24.6 ± 3.2
	Body composition (total % body fat)	24.8 ± 8.1	28.5 ± 9.9
Lifestyle Variables	Sleep	8.14 ± 1.30	7.88 ± 0.83
	Exercise	7857 ± 2557	8916 ± 3472
	Diet	65.5 ± 14.1	67.0 ± 13.3

4.1 Objective 1: Measuring Adherence to Dietary Reporting and Dietary Intervention

Adherence compliance scores, reporting compliance scores and composite compliance scores are presented in Table 4. All scores were scored from 1 to 100, where a higher adherence compliance score indicated higher adherence to dietary intervention, a higher reporting

compliance score indicated higher adherence to dietary reporting and a higher composite compliance score indicated higher compliance to the study. The adherence compliance score and composite compliance score were statistically significant between intervention groups (adherence; $p<0.001$, composite; $p=0.001$) (Table 4). Overall, adherence to dietary intervention was relatively high, ranging from 65 to 100 in adherence compliance scores. Compliance to the study was also relatively high, ranging from 55.5 to 100 in composite compliance scores. Reporting compliance scores were not statistically significant between intervention groups ($p=0.16$) (Table 4).

Table 4. Difference in Adherence Compliance Scores, Reporting Compliance Scores and Composite Compliance Scores Between Intervention Groups

	Red Meat (n=20)	**Vegetarian (n=20)**	***p* value**
Adherence Compliance Scores	96.8 ± 4.38	83.5 ± 9.75	<0.001*
Reporting Compliance Scores	94.5 ± 15.7	87.0 ± 16.3	0.146
Composite Compliance Scores	91.8 ± 11.1	78.0 ± 13.0	0.001*

* Statistically significant association between intervention groups (*$p<0.05$*)

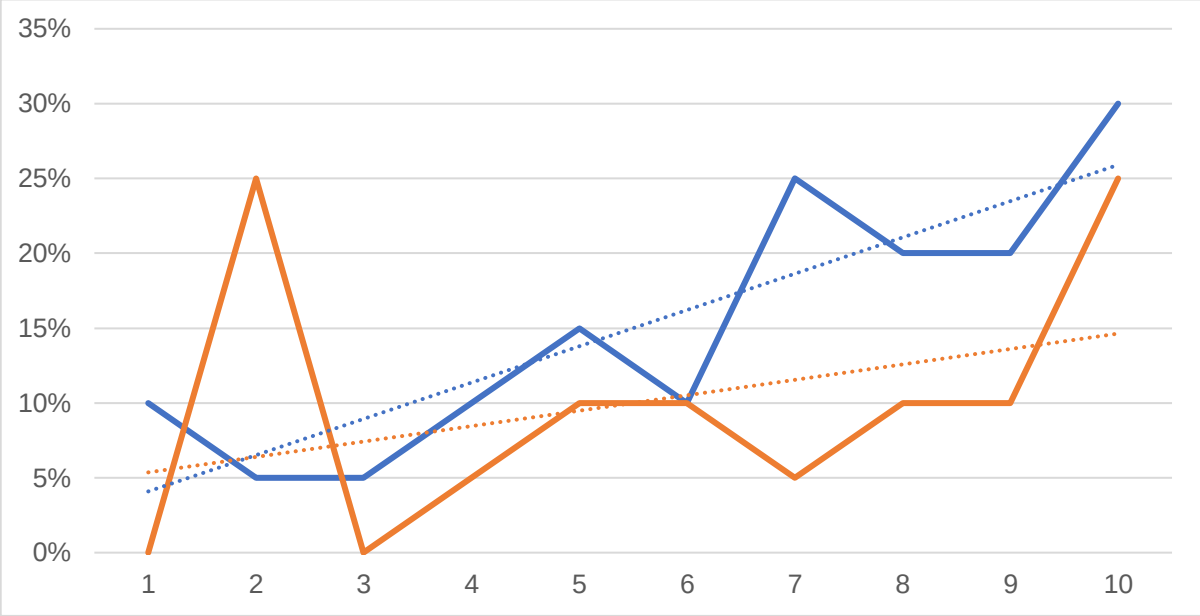
4.2 Objective 1a: Did Participants Adhere with Reporting Their Dietary Intake?

Trends in adherence to dietary reporting, adherence to dietary intervention, and compliance to the study (both adherence to dietary reporting and dietary intervention simultaneously) were analysed at weekly intervals to understand adherence rates throughout the duration of the trial. The red meat intervention group had higher adherence rates for all investigated trends: adherence to dietary reporting, adherence to dietary intervention, and compliance to the study. The percentage of participants that did not adhere to dietary reporting was the highest at week 10 of the trial, with 25% of the red meat intervention group not adhering to dietary reporting, and 30% of the vegetarian intervention group not adhering (see Figure 2). The percentage of participants that did not adhere to dietary intervention was also highest at week 10 of the trial, with 20% of the red meat intervention group not adhering to dietary intervention, and 70% of the vegetarian intervention arm not adhering to dietary intervention

(see Figure 3). This demonstrated that the vegetarian group were significantly less adherent to dietary intervention when compared with the red meat intervention group.

The trend in compliance was presented in Figure 4 as the total number of participants that were compliant to the study each week. The trend showed decreasing compliance to the study in both intervention groups, with compliance starting to drop from week four in both intervention groups. The compliance continued to drop as the study progressed. The red meat intervention arm showed overall higher compliance to the study throughout all 10 weeks, when compared with the vegetarian intervention arm. At week 6 of the trial, both groups showed that 75% of participants were compliant to the study and 25% of participants were non-compliant to the study. In both intervention arms, compliance to the study was lowest at week 10, with only 35% of participants complying in the vegetarian arm, and 70% of participants complying in the red meat intervention arm.

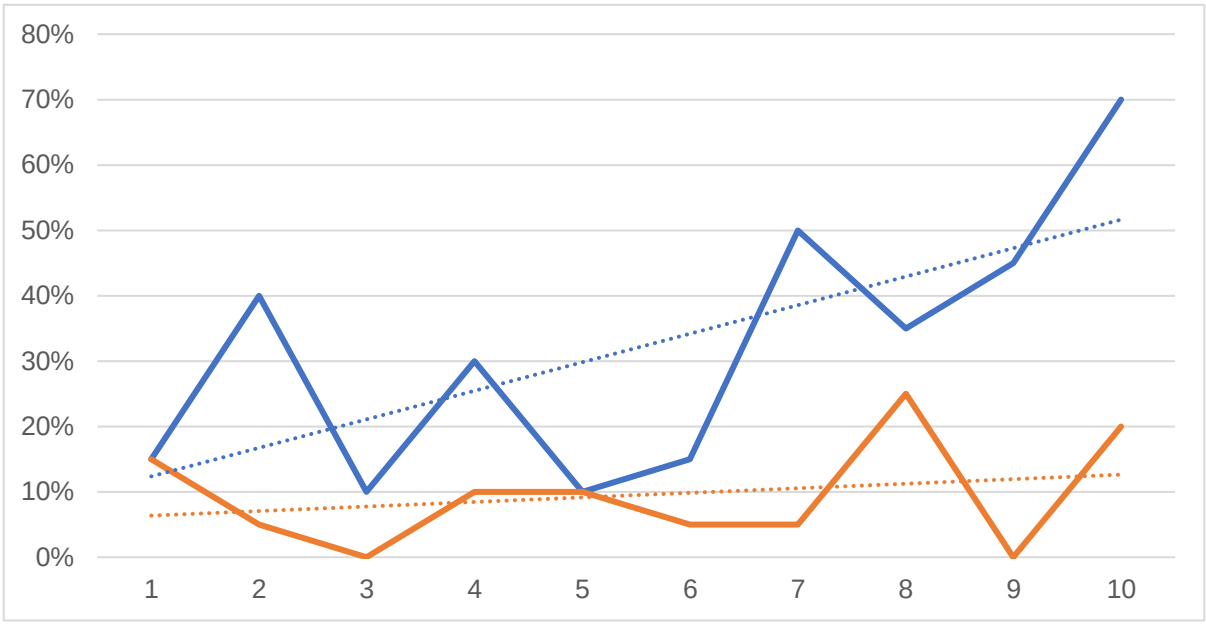
Figure 2. Percentage of Participants that Did Not Adhere to Dietary Reporting Between Intervention Groups Over the Duration of the Trial



Blue solid line: Vegetarian intervention arm, **Orange solid line:** Red meat intervention arm

Blue dotted line: Line of best fit of the vegetarian intervention arm, **Orange dotted line:** Line of best fit of the red meat intervention arm.

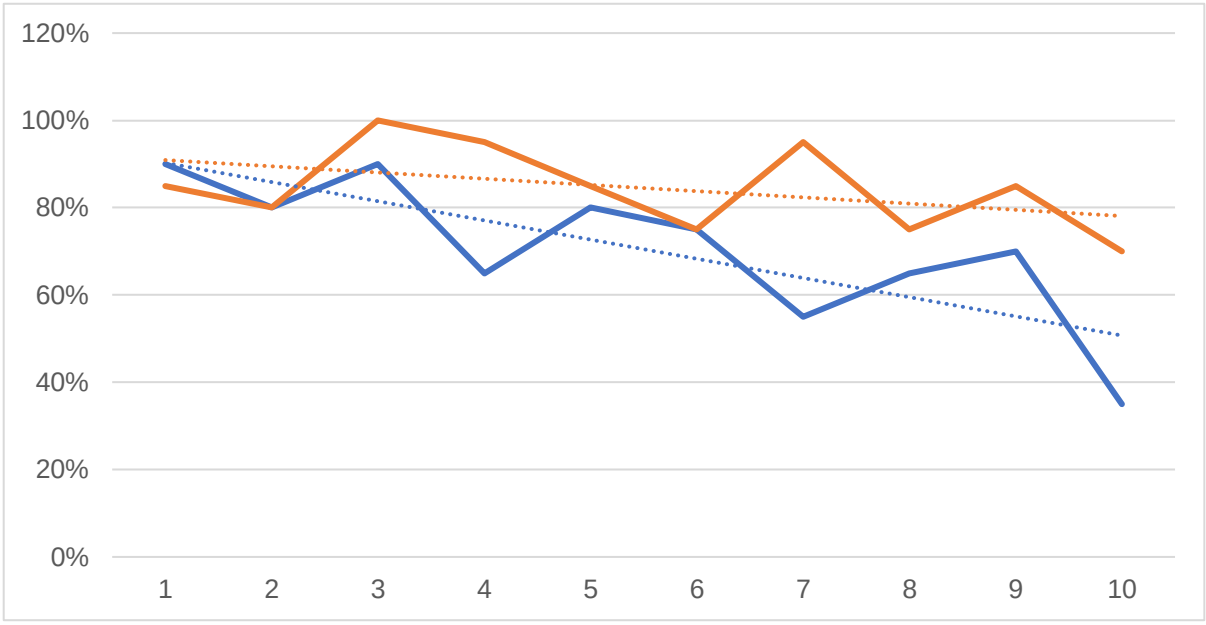
Figure 3. Percentage of Participants that Did Not Adhere to Dietary Intervention Between Intervention Groups Over the Duration of the Trial



Blue solid line: Vegetarian intervention arm, **Orange solid line:** Red meat intervention arm

Blue dotted line: Line of best fit of the vegetarian intervention arm, **Orange dotted line:** Line of best fit of the red meat intervention arm.

Figure 4. Percentage of Participants that Did Not Comply to the Study Over the Duration of the Trial



Blue solid line: Vegetarian intervention arm, **Orange solid line:** Red meat intervention arm

Blue dotted line: Line of best fit of the vegetarian intervention arm; **Orange dotted line:** Line of best fit of the red meat intervention arm

4.3 Objective 2: Investigating Barriers to Dietary Reporting Using the "Barriers to Recording" Questionnaire (Questions 1 to 7)

A four-point Likert scale ranging from "strongly disagree" to "strongly agree" was used for questions 1 to 7 for the Barriers to Recording questionnaire. The pilot groups (n=20) were invited to complete the questionnaire; however, one participant did not respond to the questionnaire. Therefore, 19 participants completed the questionnaire. The results of the questionnaire found that most participants agreed or strongly agreed that recording with a pair or partner was helpful (question 3), the text messages were helpful (question 4), and participants felt well supported by the research team (question 7). 47% of participants "strongly agreed" with question 3, 47% of participants "strongly agreed" with question 4, and 53% of participants "strongly agreed" with question 7. The mean and standard deviation of the scores for questions 1 to 7 are found in Table 5.

Table 5. Average Scores from Questions 1 to 7 in the Barriers to Recording Questionnaire

Question	**Score (n=19)**
I find the Easy Diet Diary mobile app difficult to use (1)	2.37 ± 0.68*****
The difficulties with the app prevent me from recording in the app more often (2)	1.79 ± 0.71
I find it helpful to record with a pair/partner undergoing the study with me (3)	3.37 ± 0.68
I find the text messages helpful for remembering to record appropriately and accurately into the app (4)	3.42 ± 0.61
I would like to receive more text messages to remind me to record more frequently into the app (5)	2.11 ± 0.74
I think that my current eating habits are 'unhealthy' so I don't record as much as I could into the app (6)	1.58 ± 0.51
I am well supported by the research team to record sufficiently on the app and meet study requirements (7)	3.53 ± 0.51

***Mean** ± **SD.** 1= strongly disagree, 2=disagree, 3=agree, 4=strongly agree*

4.3.1 Qualitative Analysis

All participants responded to questions 8 and 9 of the questionnaire (Table 6). Four themes emerged from the qualitative analysis of participant responses: 1) Lack of functionality with the EDD application, 2) More regularity with text message reminders, 3) Not having the time or forgetting to record, and 4) Recording inaccuracies. Each theme will be discussed in detail below.

Table 6. Questions 8 and 9 in the Barriers to Recording Questionnaire

Please comment on what could be done better to support you to record sufficiently on the app?	*Please comment.*
What could be done to better support you to record sufficiently on the app and comply with the study requirements?	*Please comment.*

Theme 1: Lack of Functionality with the EDD Application

(Red Meat Intervention Arm: n=7, Vegetarian Intervention Arm: n=3)

Most participants reported difficulties with recording because of technical aspects of the EDD application. A common response was that the EDD application had a limited database.

"Not all foods are in the app so sometimes is hard to record, i.e., if you get sourdough bread it isn't in there."

(Red Meat Intervention Arm, Female, 27)

"Technical aspects. App isn't the most intuitive."

(Red Meat Intervention Arm, Female, 30)

"…and the limited database of the Easy Diet Diary app."

(Red Meat Intervention Arm, Male, 30)

"Requires too much manual entry, cannot share recipes, very small database."

(Red Meat Intervention Arm, Male, 30)

"…lack of my food items on the app so have to enter it in manually and take photos of the nutrition level etc. so it's annoying but have been just putting in similar items."

(Red Meat Intervention Arm, Female, 27)

"It's hard to get the foods that match."

(Vegetarian Arm, Female, 29)

Some participants suggested changing a different software, My Fitness Pal.

"Change to My Fitness Pal app."

(Red Meat Intervention Arm, Male, 30)

"My Fitness Pal app is better but I'll keep going anyways."

(Red Meat Intervention Arm, Female, 27)

"Limited database in finding the food items. Would be nice if we can enter in food that isn't in the database (I think you can do this on My Fitness Pal)."

(Vegetarian Arm, Female, 26)

A limitation noted by participants was the image-based entries could only be taken in real-time using the camera function of the mobile phone. This meant that photos from the mobile phone's photo gallery could not be uploaded later.

"I think photos should be able to be uploaded to the app from your phone's photo reel rather than just using the camera. I might be able to find a photo on google of what I was eating or get a photo sent to me from a friend."

(Vegetarian Arm, Female, 24)

Theme 2: More Regularity with Text Message Reminders

(Red Meat Intervention Arm: n=2, Vegetarian Intervention Arm: n=4)

The reported feedback from some participants was that extra text message reminders would have been helpful with maintaining good compliance to dietary recording.

"Extra text messages. Especially on Tuesday morning when we switch back to photo taking."

(Red Meat Intervention Arm, Female, 27)

"Some more text reminders would be nice every now and then but otherwise it's fine."

(Red Meat Intervention Arm, Female, 21)

"Reminders if I've missed a meal or day."

(Vegetarian Arm, Male, 24)

"More reminders, knowing that the recording of foods doesn't need to be perfect."

"Not remembering to record my meals at some times."

(Vegetarian Arm, Female, 26)

"I'm recording almost everything I eat. Maybe more text reminders."

(Vegetarian Arm, Male, 35)

"Can the app send reminders? "You haven't entered today."

(Vegetarian Arm, Female, 32)

Theme 3: Not Having the Time or Forgetting to Record

(Red Meat Intervention Arm: n=3, Vegetarian Intervention Arm: n=5)

Some participants reported that entries into the EDD application were rushed as they did not have much time to record sufficiently.

"Time, lots of ingredients, shared meals." (Reported barriers)

(Red Meat Intervention Arm, Female, 26)

"Sometimes I forget to take photos because I'm eating out or in a rush."

(Red Meat Intervention Arm, Female, 21)

"When in a rush, it's the last thing I think about (recording). Also, when I'm really hungry I remember a bit too late."

(Red Meat Intervention Arm, Female, 23)

Some participants reported that they simply forget to record meals.

"Not remembering to record my meals at some times, or when going out to eat, not remembering exactly what was in the meals to record."

(Vegetarian Arm, Female, 26)

"I forget to take a photo, so I just write them in."

(Vegetarian Arm, Female, 29)

"Just remembering when having a snack, easy for main meals but not for snack times."

(Vegetarian Arm, Female, 32)

Forgetting to record was often also related to time constraints.

"Just forgetting due to a lack of time especially during workday."

(Vegetarian Arm, Male, 29)

"…some days I may forget to photograph or not get a change to write in straight away, but I always make sure to catch up on that fairly quickly."

(Vegetarian Arm, Female, 26)

Theme 4: Recording Inaccuracies

(Red Meat Intervention Arm: n=3, Vegetarian Intervention Arm: n=3)

A commonly described barrier was quantifying food items with the EDD application, especially with shared or split meals.

"Difficulties quantifying food and the limited database of EDD app."

(Red Meat Intervention Arm, Male, 30)

"Quantifying food, lack of my food items on the app so have to enter it in manually and take photos of the nutrition level etc. so it's annoying but have been just putting in similar items."

(Red Meat Intervention Arm, Female, 27)

"I may take a photo of the type of food I was eating, but not everything was shown in the photo. i.e., I'll take a photo of a bag of chips but not eat all the chips in the bag."

(Vegetarian Arm, Female, 24)

"Difficulties quantifying food, especially if at a restaurant."

(Vegetarian Arm, Male, 24)

"Quantifying food is probably the most difficult especially when you make a meal and then split it multiple ways."

(Vegetarian Arm, Female, 26)

One participant recorded altering their habitual dietary intake to simplify recording, therefore influencing the accuracy of their dietary intake.

"We do sometimes eat simpler foods on Sundays and Mondays than we otherwise would because the prospect of entering 15 ingredients in manually can seem daunting."

(Red Meat Intervention Arm, Male, 31)

Similarities Between Themes

Many themes were interrelated within another. These were:

- Rushing records of dietary intake can also impact the accuracy of recording, therefore the theme of Lifestyle Barriers is also associated with the theme of Recording Inaccuracies.
    - *"Not remembering to record my meals at some times, or when going out to eat, not remembering exactly what was in the meals."*

(Vegetarian Arm, Female, 26)

- A limited database with the EDD application leads to participants finding similar food items, however, does not give the most accurate record of dietary intake and can become tedious.
    - *"Quantifying food, lack of my food items on the app so have to enter it in manually and take photos of the nutrition level etc. so it's annoying but have been just putting in similar items."*

(Red Meat Intervention Arm, Female, 27)

- Having limited time or being in a rush can lead to forgetting to record into the EDD application, prompting more text message reminders.
    - *"Sometimes I forget to take photos because I'm eating out or in a rush." (Reported barrier).*
    - *"Some more text reminders would be nice every now and then but otherwise it's fine." (Reported suggestion).*

(Red Meat Intervention Arm, Female, 21)

4.4 Objective 3: Investigating the Relationship Between Baseline Characteristics with Adherence to Dietary Reporting and Adherence to Dietary Intervention

4.4.1 Differences in Baseline Characteristics Between Intervention Groups

The majority of participants had a BMI within the healthy range and some participants had a BMI within the overweight range. No participants had a BMI within the underweight or

obese range (Table 7). This was expected as “less than BMI of 30kg/m²” was required as part of the participant recruitment criteria. Baseline level of education was the only sociodemographic variable that was statistically significant between intervention groups, where the red meat intervention arm were more educated than the vegetarian intervention arm ($p=0.021$).

All participants were required to complete the study as paired participants. The most common relationship between paired participants were “partners” in both the red meat intervention arm ($n=12$) and the vegetarian intervention arm ($n=14$) (Table 7). However, there was no statistically significant difference in the relationship between paired participants with different intervention arms. The baseline PES score demonstrated statistically significant differences between intervention arms ($p=0.029$). At baseline, the PES score was higher in the red meat intervention arm, when compared with the vegetarian intervention arm. All other psychological characteristics were not statistically significant between the different intervention groups.

Sleep was analysed as the average hours of sleep per week by all participants. The average reported sleep duration was similar in both the red meat intervention arm and the vegetarian intervention arm (Table 7). Exercise was analysed as the average number of steps per week by all participants. Diet was analysed using an adapted Healthy Eating Score developed by two research dietitians (NG, AW). All of the reported lifestyle variables were not statistically significant between intervention groups ($p>0.05$) (Table 7).

Table 7. Baseline Characteristics of Participants Between Intervention Groups, Including Psychological Variables

	Variables	**Red meat (n=20)**	**Vegetarian (n=20)**	***p* value**
Sociodemographic Variables	Age	27.4 ± 4.1	24.9 ± 5.0	0.093
	Gender, female	19 (%)	21 (%)	1.000
	Level of education			
	No qualification	1 (0.05%)	1 (0.05%)	0.021*
	Secondary school	1 (0.05%)	8 (40.0%)	
	Post-secondary school	1 (0.05%)	3 (15.05%)	
	University	17	8	
Anthropometric Variables	BMI (kg/m²)	23.2 ± 2.4	24.6 ± 3.2	0.142
	Body composition (total % body fat)	24.8 ± 8.1	28.5 ± 9.9	0.215
Psychological Variables	Relationship with partner (n)			
	Flatmate	4 (20.0%)	6 (30.0%)	0.208
	Partner	12 (30.0)	14 (70.0%)	
	Sibling	2 (10.0%)	-	
	DASS			
	Depression	4.50 ± 4.30	7.80 ± 7.11	0.085
	Anxiety	3.80 ± 2.89	4.90 ± 5.75	0.451
	Stress	10.2 ± 8.43	10.9 ± 7.66	0.785
	Other			
	Self-efficacy	37.0 ± 4.4	38.9 ± 2.0	0.109
	TFEQ	0.50 ± 0.07	0.50 ± 0.11	0.916
	PES	3.15 ± 0.36	2.88 ± 0.40	0.029*
	WHO-5	58.8 ± 13.8	61.6 ± 14.4	0.533
Lifestyle Variables	Sleep	8.14 ± 1.30	7.88 ± 0.83	0.853
	Exercise	7857 ± 2557	8916 ± 3472	0.279
	Diet	65.5 ± 14.1	67.0 ± 13.3	0.731

* Statistically significant association between intervention groups ($p<0.05$)

4.4.2 Predictors of Adherence to Dietary Reporting and Dietary Intervention Using the Adherence Compliance Score, Reporting Compliance Score and Composite Compliance Score

Adherence compliance scores were positively associated with baseline PES scores (p=0.001), and inversely associated with baseline DASS-Depression scores (p=0.021) in unadjusted models. Education was the only sociodemographic variable that was included as a covariate in adjusted regression models, and was only included in adjusted regression models for reporting compliance scores and composite compliance scores ($p<0.20$). No sociodemographic characteristics were associated with adherence compliance scores, and adjusted models were not performed (Table 8).

Reporting compliance scores were not significantly associated with baseline anthropometric, psychological or lifestyle variables in unadjusted regression models or models adjusted for education ($p>0.05$).

Composite compliance scores were positively associated with baseline PES scores ($p=0.004$), diet ($p=0.045$), and inversely associated with DASS-Depression scores ($p=0.034$) (Table 8) in unadjusted models. When adjusted for education (secondary school; $p=0.034$, university; $p=0.034$), baseline PES scores remained positively associated with composite compliance scores ($p=0.004$). Diet was no longer associated with composite compliance scores and DASS-Depression was not inversely associated with composite compliance scores in adjusted models (Table 8).

Table 8. Relationship Between Anthropometric, Psychological and Lifestyle Characteristics with Compliance Scores (Adherence, Reporting and Composite) According to Multiple Linear Regression Models

		Adherence Compliance Scores				**Reporting Compliance Scores**				**Composite Compliance Scores**			
		Unadjusted		Adjusted[1]		Unadjusted		Adjusted[2]		Unadjusted		Adjusted[2]	
Domain	**Variable**	*β*	*p*	*β*	*p*	*β*	*p*	*β*	*p*	*β*	*p*	*β*	*p*
Anthropometric Variables	BMI	-0.833	0.121	-	-	-0.802	0.383	-0.770	0.378	-1.428	0.064	-1.309	0.086
	% body fat	-0.286	0.089	-	-	-0.223	0.441	-0.185	0.513	-0.380	0.118	-0.430	0.081
Psychological Variables	<u>Relationship with partner</u>												
	Partner	5.750	0.103	-	-	4.429	0.468	5.735	0.319	5.947	0.248	6.601	0.186
	Sibling	12.00	0.105	-	-	13.00	0.313	15.29	0.206	14.79	0.173	12.60	0.229
	<u>DASS</u>												
	Depression	-0.578	0.021*	-	-	-0.764	0.076	-0.555	0.185	-0.770	0.034*	-0.702	0.055
	Anxiety	-0.102	0.767	-	-	-0.839	0.146	-0.783	0.163	-0.273	0.584	-0.358	0.477
	Stress	-0.170	0.381	-	-	-0.282	0.395	-0.209	0.526	-0.189	0.505	-0.244	0.401
	<u>Other</u>												
	Self-efficacy	-0.389	0.389	-	-	0.244	0.742	0.022	0.975	-0.142	0.831	-0.234	0.723
	PES	12.48	0.001*	-	-	11.81	0.067	9.633	0.121	15.51	0.004*	15.38	0.004*
	TFEQ	-5.472	0.758	-	-	-42.44	0.153	-35.21	0.264	-25.07	0.325	-12.19	0.665
	WHO-5	0.129	0.246	-	-	0.094	0.621	-0.047	0.813	0.148	0.356	0.153	0.380
Lifestyle Variables	Sleep	-2.695	0.189	-	-	-3.496	0.318	-4.553	0.112	-4.744	0.108	-3.517	0.167
	Exercise	0.001	0.249	-	-	0.001	0.204	<0.001	0.697	0.001	0.125	0.001	0.264
	Diet	0.194	0.086	-	-	0.245	0.204	-0.008	0.969	0.325	0.045*	0.219	0.232

* Statistically significant association ($p<0.05$)

[1] Adjusted models were not performed as education was not associated with adherence compliance scores.

[2] Adjusted linear regression models were adjusted for education.

5 Discussion

5.1 Overarching Aim of the Study

The overarching aim of the Predition randomised controlled trial was to explore differences between the dietary intervention of red meat versus red-meat alternatives as part of a healthy plant-based diet; on the effects of health and wellbeing. Vegetarian diets have been in existence for a long time, however flexible versions of moderate red meat diets are rising in popularity. The term ‘flexitarian’ refers to a flexible vegetarian, a diet that predominantly consists of plant-based foods, and meat and fish in moderation. Global trends suggest that flexitarian eating is on the rise (Deliens et al., 2021; Derbyshire, 2017).

The subset of data included in the current thesis is based off 40 participants, as covid related delays to the main trial have resulted in the exclusion of the final 40 participants. The Predition trial consisted of recruiting free living individuals to participate in an intervention conducted in a free-living environment, hence the need for monitoring of adherence. My thesis focused on adherence to dietary reporting and adherence to dietary intervention using a smartphone application, and how this differed between the vegetarian and meat consuming groups, what barriers prevented participants from achieving optimal dietary reporting, and whether baseline characteristics were associated with adherence to dietary reporting and dietary intervention.

5.1.1 A Summary of Findings

A total of 40 participants were analysed in this thesis project. The average days of dietary reporting into the EDD application (any amount of recording into the application) was 68.4 days out of the maximum 70 days for the total 40 participants. The average days of dietary reporting into the EDD application was 68.9 days in the red meat intervention group (n=20) and 68.0 days in the vegetarian intervention group (n=20). The baseline characteristics in both intervention groups were relatively similar, except for level of education, where the red meat intervention group were more educated (85% of participants in the red meat intervention group had a university level of education, 40% of participants in the vegetarian intervention group had a university level of education).

Adherence compliance scores, reporting compliance scores, and composite compliance scores were developed to measure how well participants adhered to dietary intervention

(adherence compliance score), adhered to dietary reporting (reporting compliance score), or adhered to both dietary intervention and dietary reporting simultaneously (composite compliance score). Both adherence compliance scores and composite compliance scores were higher in the red meat intervention group when compared with the vegetarian intervention group, and was statistically significant between intervention groups. The composite compliance score showed how complaint participants were to both aspects of adherence in the study, and the composite compliance score from the total 40 participants ranged from 55.5 to 100.

When investigating trends in adherence rates throughout the trial, the percentage of participants that did not adhere to dietary reporting, and the percentage of participants that did not adhere to dietary intervention increased over time in both intervention groups. When investigating the trend in compliance rates throughout the trial, the percentage of participants that were compliant to both aspects of adherence in the study decreased over time. The vegetarian group were much less adherent to dietary intervention when compared with the red meat intervention group, with 70% of participants in the vegetarian group not adhering to dietary intervention by week 10, compared with 20% of participants in the red meat group not adhering to dietary intervention by week 10.

The thesis project aimed to optimise dietary reporting into the EDD application, therefore it was important to understand barriers that participants faced with achieving optimal dietary reporting. The Barriers to Recording Questionnaire was conducted in the pilot groups (n=19) to gain feedback from participants and further support adherence to dietary reporting for the following groups (Appendix 3). Overall, 100% of participants reported feeling well supported throughout the trial, but also provided insightful information on barriers experienced with adhering to dietary reporting using the EDD application. Eighty nine percent of participants reported it was helpful to undergo the trial with a household pair/partner and 94% of participants reported it was helpful to receive text message reminders. Four themes appeared from the thematic analysis of participant responses to the questionnaire: 1) Lack of functionality with the EDD application; 2) More regularity with text message reminders; 3) Not having the time or forgetting to record; 4) Recording Inaccuracies.

All recruited participants were generally healthy, based on the exclusion criteria previously described. Differences in baseline characteristics between intervention groups were analysed

to account for statistical significance between intervention groups. All anthropometric variables and lifestyle variables were not statistically significant between intervention groups. All sociodemographic variables were not statistically significant between intervention groups, except for level of education, where the red meat intervention group was more educated when compared with the vegetarian intervention group ($p=0.021$). All psychological variables were not statistically significant between intervention groups, except for the PES score, which was higher in the red meat intervention group when compared with the vegetarian intervention group ($p=0.029$).

Lastly, the adherence compliance scores, reporting compliance scores and composite compliance scores were used to investigate associations between adherence to dietary intervention, adherence to dietary reporting and compliance to the study. Composite compliance scores were positively associated with baseline PES scores ($p=0.004$) in adjusted models. PES scores and diet scores were positively associated and DASS-Depression scores were inversely associated with composite compliance scores in unadjusted models, but diet scores and DASS-Depression scores were no longer associated in adjusted models. PES scores remained positively associated with composite compliance scores in adjusted models, suggesting that positive eating was associated with compliance to the study.

5.2 Adherence to Intervention

All recruited participants were omnivorous, however, were required to adhere to a dietary intervention of either a largely plant-based or fully plant-based diet for 10 weeks. Results of the study found that the red meat intervention group had a higher adherence compliance score ($p<0.001$) and higher composite compliance score ($p=0.001$), when compared with the vegetarian intervention group. One possible explanation for the differences observed could be related to the vegetarian group having to make larger changes to their current dietary lifestyle. As participants were all previously meat consumers, it may have been harder for participants in the vegetarian group to adapt to a dietary lifestyle that required abstinence from meat for 10 weeks. Making changes to the diet is essentially making changes to a habit. The literature shows that it is difficult to change dietary habits and studies have explored strategies that can be implemented to make habitual dietary changes less challenging (Burke et al., 2017; Fehér et al., 2020; Haas et al., 2017; Tassell & Flett, 2005). Therefore, multiple

strategies to support adherence to the dietary intervention were implemented prior to and during this thesis project.

5.2.1 How Much of A Shift Is Appropriate For Implementing Successful Dietary Changes

In this thesis project, adherence to dietary intervention decreased over time, demonstrating that there were barriers with adhering to dietary intervention in our study. The evidence around how much of a shift in dietary lifestyle or dietary behaviours are needed to support long-term change, has been poorly investigated. However, the literature has explored barriers to making dietary changes and factors that were more likely to promote making dietary changes. Many of these factors were related to individual self-belief, self-efficacy, adequate social support and motivation to change (Castro-Sánchez & Ávila-Ortíz, 2013; Fehér et al., 2020; Koikkalainen et al., 1999; S. E. Moore et al., 2018; Tassell & Flett, 2005).

Switching from an omnivorous diet to a vegetarian or vegan diet can be a difficult change. As there is an increasing population of vegan and vegetarian consumers, there has been increasing research conducted on the conversion to different dietary lifestyles (Brunton, 2019). When looking specifically at the conversion from an omnivorous diet to a vegetarian or vegan diet, a 2020 review found that common barriers include taste factors, convenience, social barriers, mental health concerns and the enjoyment or satisfaction of eating meat (Fehér et al., 2020). The "enjoyment of eating meat and difficulty abandoning it" was seen as one of the largest barriers to converting to a plant-based diet, followed by nutrient deficiency and other health concerns (Fehér et al., 2020). Based on the review of the literature conducted by Fehér et al. (2020), the findings from this thesis project were logical, as a higher adherence to dietary intervention was observed in the red meat intervention group and this was likely due to the vegetarian intervention arm having difficulty with abstaining from meat. An NZ study investigated difficulties related to making dietary changes (decreased fat consumption and increased fruit and vegetable consumption) in 111 Māori women, and found that the stages of readiness to change were associated with making dietary changes (Tassell & Flett, 2005). As participants were moved along the continuum based on the stages of change model, they were more ready for change, and therefore demonstrated higher self-efficacy and were more likely to make these dietary changes (Tassell & Flett, 2005). This

suggests that behaviour change can be influenced by multiple intrinsic factors such as self-efficacy, self-belief and readiness to make changes.

5.2.2 Supportive Measures

An example of a support strategy implemented in this thesis project was the "Predition Trial Cookbook" that was developed by the researchers (LL, NG, AW). The cookbook included education on basic cooking knowledge, label reading advice and recipe ideas for cooking with vegetarian and meat-alternative products. Recipe books have been a commonly used resource tool to support participant adherence to healthier dietary lifestyles. Much of the literature categorised recipe books or recipe ideas under "educational resources" (Davis et al., 2015; Moore et al., 2018; Saslow et al., 2020). In the Predition Trial, the cookbook was not just seen as an education resource for cooking methods, but also a supportive tool for assisting participants with adhering to dietary intervention. The rationale behind developing the cookbook was to target support for participants that may struggle with transitioning to a largely plant-based diet. As all participants previously consumed meat, the research team felt that it would be beneficial to provide further support on vegetarian cooking methods and recipe ideas. There was no feedback on the usefulness of the cookbook, however 100% of participants felt well supported based on the Barriers to Recording questionnaire.

Moore et al. (2018) explored participant attitudes towards a Mediterranean diet in a Northern Irish population at risk of cardiovascular disease (Moore et al., 2018). Common barriers to adhering to a Mediterranean diet were limited knowledge and lack of cooking skills. The study suggested that providing quick and easy to prepare recipes and meal ideas were important for integrating healthy changes in habitual dietary patterns (Moore et al., 2018). A study investigated three intervention strategies; text messages, gifts, and urine ketone self-monitoring, to improve health outcomes for individuals with Type 2 Diabetes (Saslow et al., 2020). In this study, cookbooks and recipe ideas were seen as a gift, to motivate individuals to adhere better to dietary intervention. A 2015 dietary intervention trial tested the feasibility of adhering to a Mediterranean diet for more than two weeks in elderly Australians (Davis et al., 2015). The intervention included supportive resources such as healthy eating guidelines, a seven-day sample menu, and a recipe book. The study found that most participants used the recipe book throughout the intervention phase, and no participants felt that any recipes should be removed. An interesting observation from this study was that participants suggested more

education for special occasions and dining out. Similarly, one participant in our study reported difficulties with dietary reporting in social situations in the Barriers to Recording Questionnaire, stating *"difficulties quantifying food, especially if at a restaurant (male, 24 years)."* This statement was related to difficulties with adhering to dietary reporting, but nonetheless suggested that further support strategies to improve adherence in dietary intervention trials could include education around social settings and restaurant dining, to prepare participants for all types of eating environments.

A study explored how individuals living with Type 2 Diabetes perceived and acted on changes to their diet (Castro-Sánchez & Ávila-Ortíz, 2013). Some reported difficulties were; consistently controlling their appetite, limiting the pleasure of eating, foods lacking flavour, reduced amounts of enjoyable foods, hard to control the urge to eat (Castro-Sánchez & Ávila-Ortíz, 2013). Participants in the vegetarian intervention arm of the Predition Trial may have experienced similar difficulties, such as being limited from the pleasure of consuming foods with meat. Another explanation to non-adherence with dietary advice was reported in a study identifying difficulties with changing diet in patients with coronary heart disease (Koikkalainen et al., 1999). The most frequently reported barrier to dietary advice in this study was related to eating in social situations, such as: *"positive decisions about diet are forgotten while eating in company"* and *"I eat like other people in my company without thinking about what I eat."* Once again, this demonstrated that adherence to dietary intervention becomes particularly challenging in social settings, where individuals are likely to be influenced by the eating environment and food choices from other individuals. In relation to the Predition Trial, participants in the vegetarian intervention arm may have experienced similar difficulties in social settings where the people around them decide to order meals containing meat. Barriers to adhering to dietary intervention specifically, was not measured in the current thesis project but findings from the literature suggest multiple feasible explanations to difficulties with adhering to dietary intervention that may be relevant in our study (Castro-Sánchez & Ávila-Ortíz, 2013; Koikkalainen et al., 1999; S. E. Moore et al., 2018). Feedback collated from the Predition Trial on how participant's perceived the change in dietary lifestyle for 10 weeks, is collected 3 months post intervention and not available at the time of thesis completion.

5.3 Adherence to Dietary Reporting

In this thesis project, the reporting compliance scores were not statistically significant between intervention groups. However, the average reporting compliance score was higher in the red meat intervention group (94.5 ± 15.7), when compared with the vegetarian group (87.0 ± 16.3) (p=0.146), and the composite compliance scores were statistically significant between intervention groups and higher in the red meat intervention group. This suggests that overall adherence to dietary reporting was higher in the red meat intervention group. The research team aimed to measure and support adherence to dietary reporting using the most appropriate, practical and optimal methods for participants and researchers. Therefore, eHealth was integrated and the smartphone dietary recording application "Easy Diet Diary" was used as an incentivising approach to improving adherence to dietary reporting. To further support participants with using the EDD application, an instructional email handout developed by the dietetic student (LL) outlining how to navigate the EDD application was sent to participants at screening (T-2 phase), followed by a verbal face-to-face rehash of the instructional email handout at the first clinic visit (T-0 phase). The aim of providing guidance to using the EDD application was to make dietary reporting easier, more convenient, more time-efficient, and to reduce participant burden. This was developed as studies had shown that a common reported barrier to dietary self-monitoring using mHealth and eHealth approaches, was difficulty with understanding how to use the proposed software (Vo et al., 2019; Zhang et al., 2014).

There is increasing availability of dietary self-monitoring tools and devices that extend beyond pen and paper methods, creating more opportunities for researchers to improve adherence to dietary reporting in dietary intervention studies. The user feasibility and efficacy of using mobile applications to record dietary intake has become more well accepted, effective, easy and enjoyable (Parwati et al., 2020; Spring et al., 2018). A recent study (PEARS study) explored the acceptability of a smartphone application to improve exercise and nutrition in overweight and obese pregnant women (Greene et al., 2021). Using the smartphone application was significantly associated with more enjoyment, more acceptability and responses of usefulness and helpfulness to the PEARS study (Greene et al., 2021). A 2016 study recruited 146 volunteers to participate in an exercise and nutrition program that measured adherence to the program using a mobile phone application "Fittle," and in either teams or as a solo participant (Du et al., 2016). The findings of the study found that teamed

participants using the Fittle application were more adherent to the exercise and nutrition program and had a more positive attitude to the program. Therefore, much of the literature supports the appropriateness of using mHealth approaches to assess adherence to dietary reporting in our thesis project.

However, mobile phone applications did not always improve adherence in dietary intervention trials. A 3 month trial conducted in Spain investigated adherence to the Mediterranean diet, with half of participants in the counselling group, and half of participants in the counselling and application use group (Recio-Rodriguez et al., 2016). The results of this study found that adherence to the Mediterranean diet increased in both groups, and printed resources further improved adherence, but the mobile application was not associated with increasing adherence (Recio-Rodriguez et al., 2016). However, the participants in this trial had an average age of 51 years, whereas a younger cohort, such as the Predition Trial reported mostly received positive feedback with using a mobile application. Age seems to be a potential influence to mHealth familiarity, and one study found that younger cohorts who had university education were most likely to favour mHealth interventions, which was reflected in this thesis project (Granger et al., 2016).

The researchers consistently supported participants with using the EDD application through mobile phone text message reminders. This enabled researchers to get in touch quickly and conveniently, and prompt participants to stay adherent to either dietary intervention or dietary reporting. Table 9 shows examples of text message reminders from the three categories of text messages used throughout the trial. The text message reminders were used to support both adherence to dietary reporting and adherence to dietary intervention. In our study, the combination of using an mHealth approach along with providing support through text message reminders have shown to be successful in measuring and supporting adherence to both dietary reporting and dietary intervention based on feedback from the Barriers to Recording Questionnaire. This will be discussed further below (Section 5.5).

Table 9. Examples of Text Message Reminders in the Predition Trial.

Category	Text Message Examples
Recording	*Have you entered all food and drink into the Easy Diet Diary, #firstname#? Tomorrow you can start taking photos instead of manually inputting your food :)*
Clarification	*Hi #firstname#, we need more clarification from your data entry for [meal occasion] on 00/00. Could you please text back more detail about this meal.*
Adherence to Dietary Intervention	*Hi #firstname#. Please enter at least ONE full day of food into the Easy Diet Diary by 09/08 and ALWAYS write when you eat your protein in the notes section.*

5.4 Trends in Adherence to Dietary Reporting and Adherence to Dietary Intervention

The percentage of participants that did not adhere to dietary reporting over the duration of the trial increased in both intervention groups. By the end of the trial, 30% of participants in the vegetarian intervention arm did not adhere to dietary reporting and 25% of participants in the red meat intervention arm did not adhere to dietary reporting. A larger difference was seen between intervention groups in adherence to dietary intervention, with 70% of participants not adhering to dietary intervention in the vegetarian intervention arm and 20% of participants not adhering to dietary intervention in the red meat intervention arm by the end of the trial (week 10). Similarly seen in other dietary intervention trials, adherence to dietary reporting and adherence to dietary intervention is subject to decline as the study progresses (Morris & Schulz, 1992; Mummah et al., 2016; Spring et al., 2018).

This thesis project was particularly interested in measuring and supporting adherence to dietary reporting and dietary intervention. This was achieved through monitoring the use of the EDD application. It is important to acknowledge that adherence to dietary intervention was also measured through participants' reporting abilities into the EDD application. This meant that participant's ability to record well into the EDD application was an important contributor towards measuring adherence to dietary intervention, suggesting that proper recording into the EDD application affected both adherence to dietary reporting and adherence to dietary intervention. Therefore, the trends in adherence to both dietary reporting and dietary intervention at each weekly interval over the course of the trial was explored to

fully appreciate and understand how well participants were able to record their dietary intake. The trend in compliance to both aspects of adherence at each weekly interval over the course of the trial was also explored.

The literature currently shows that compliance rate drops about 40% to 50% in long-term clinical and dietary interventions (Crichton et al., 2012; Wilhelmsen & Eriksson, 2019; Yu et al., 2015). The drop in compliance to both aspects of adherence in this thesis project was not as high as what was seen in the literature. 35% of participants in the vegetarian intervention group were not compliant to both aspects of adherence by the end of the trial, and 15% of participants in the red meat intervention group were not compliant to both aspects of adherence by the end the trial. This was a plausible finding as the Barriers to Recording Questionnaire suggested that participants generally felt well supported throughout the trial. Despite this, there was still a progressive decline observed in the Predition Trial in adherence to dietary intervention and dietary reporting overtime.

Many studies explore adherence to intervention or adherence to dietary reporting individually, however our study explored these aspects of adherence individually and together. Therefore, when reviewing the literature, it was difficult to find studies that measured both aspects of adherence to dietary intervention and dietary reporting collectively. There was also more research conducted on adherence to other health interventions, such as medication and treatment, and less so in dietary intervention studies (Morris & Schulz, 1992). A review article on medication compliance found that compliance to long term medication therapy would eventually drop to 50% regardless of the medication or type of illness, and ranged from 33% to 94% in the reviewed articles (Morris & Schulz, 1992). When exploring adherence to dietary reporting, a 12 month study by Mummah et al. (2016) found a downward trend in the frequency of reporting into the diet recording application, which demonstrated decreased adherence to dietary reporting (Mummah et al., 2016). During week one of the 12 month trial, participants recorded an average of 0.8 times per day into the application, and by the end of the trial, 80% of participants recorded 0 times per day for more than 3 days in a row (Mummah et al., 2016). In our study, the decline in adherence to dietary reporting was less dramatic than the decline seen in the study by Mummah et al. (2016), which was likely due to our study being of a shorter duration.

Dietary intervention studies have investigated how adherent participants were to dietary intervention by the end of the trial, however, the adherence rate throughout the trial is less commonly explored. The 'Make Better Choices 2' RCT investigated two methods of promoting dietary change: simultaneously targeting physical activity recommendations with dietary intervention, or sequentially targeting physical activity recommendations then adding the dietary intervention. The 9 month RCT incorporated mHealth approaches, by using a smartphone application to monitor and track dietary intake. Reporting into the application decreased overtime, from 96.3% of days at baseline to 54.6% of days at 9 months ($p<0.001$) (Spring et al., 2018). Data presented in the current thesis project showed an average of 68.4 days out of 70 days (97.7%) of dietary reporting of any food item into the EDD application. The high adherence to dietary reporting in this thesis project is a logical finding, once again due to being a shorter duration, but also due to the ease of use of the EDD application and helpful text message reminders reported by participants in the Barriers to Recording questionnaire. Very little research has been conducted on personnel support requirements to maximise participant reporting, however, the current thesis utilised 0.75 full time equivalent (LL) allocated to measuring adherence to dietary reporting and adherence to dietary intervention. This is possibly higher than many RCT investigations. Some other common barriers to adhering to dietary intervention studies found in the literature were high costs of healthy foods, more availability of fast foods, limited time and limited knowledge (Abdelhafez et al., 2020). Similarly, in this study, commonly reported barriers to optimal dietary reporting included being too busy and not having enough time to report into the EDD application succinctly.

The trends showed higher adherence to dietary intervention, adherence to dietary reporting and compliance to both aspects of adherence in the study in the red meat intervention group. A possible explanation for this was the statistically significantly higher baseline level of education observed in the red meat intervention group. Socio-demographic variables have shown to be poor predictors of adherence in some studies, and strong predictors in other studies (Greco et al., 1997; Hulka, 1979; Kyngäs & Lahdenperä, 1999; Morris & Schulz, 1992; Razali & Yahya, 1995). A study investigated factors that influenced adherence to a raw vegan diet and found that participants with more years of education at baseline were more likely to adhere to the diet, and sufficient knowledge and time were facilitators to the participant's ability to adhere (Link & Jacobson, 2008). Similarly, in an Australian study investigating dietary behaviour changes over a four year period, a low socioeconomic status

and low levels of education at baseline were predictors of poor dietary behaviours, and non-smokers, meeting physical activity recommendations, and avoiding weight gain were found to be predictors of positive dietary changes (Thorpe et al., 2019). Thorpe et al. (2019) hypothesised that perhaps having a higher level of education was associated with promoting other healthy lifestyle behaviours. Therefore, if an individual has limited nutrition education, there is less understanding of why making a dietary change is necessary, and therefore less motivation to want to make a change. Unsurprisingly, the evidence around the association of education levels on adherence to dietary reporting in particular, is scarce. Despite this, as some of the literature shows that education can be related to better adherence to dietary intervention, and the baseline characteristics of our study found the red meat group was more educated, this could potentially explain the higher overall compliance observed in the red meat intervention group of this thesis project.

5.5 Barriers to Achieving Optimal Dietary Reporting

To understand how to further support optimal dietary reporting in future studies, it was important to understand the barriers that participants experienced with dietary reporting in the current thesis project. Therefore, the Barriers to Recording Questionnaire was developed and used by the pilot groups in the Predition Trial (n=19). The participants provided valuable feedback on their experiences with dietary reporting and how to further support adherence to dietary reporting in the questionnaire. The majority of responses received from participants were positive, with high levels of agreement reported for helpfulness of text message reminders and feeling well supported by the research team. Forty seven percent "strongly agreed" that the text message reminders were helpful," 53% "strongly agreed that they felt well supported by the research team to meet study requirements, and 47% of participants who completed the questionnaire "strongly agreed" that it was helpful to undergo the study with a pair or partner. Interestingly, other studies have also observed that team participation with dietary reporting showed better adherence when compared with solo participation (Du et al., 2016; Wing & Jeffery, 1999).

The literature suggests that text message reminders are an effective method of improving adherence in nutrition and clinical trials (Chen et al., 2017; Partridge et al., 2015; Vervloet et al., 2012). However, there remains ambiguity around the most effective type of text messages and the most appropriate frequency of text messages to maximise adherence. More regular

text message reminders in the Predition Trial may have further improved adherence to dietary intervention and adherence to dietary reporting. Eighty nine percent of participants in the pilot groups (n=19) found the text message reminders helpful. Participants commented that text message reminders such as when they had missed a meal or a day of recording would have helped to improve dietary reporting. Based on the literature, the optimal frequency of text message reminders can be hard to determine as some individuals prefer more text message reminders, whilst others may prefer less text message reminders (Dennison et al., 2013). The SMARTER pilot study was a 12 week weight loss trial conducted in 39 individuals, who were randomised into three weight loss intervention groups (Burke et al., 2017). One group used a weight loss smartphone application, one group used the weight loss smartphone application and received 1 to 4 daily message reminders, and one group used the weight loss smartphone application, received 1 to 4 daily message reminders and were involved in group behavioural weight loss sessions. The authors reported the text message reminders were helpful with improving adherence to dietary self-monitoring of the smartphone application, however, there still remains mixed opinions on the frequency of text message reminders (Burke et al., 2017). When comparing to the current thesis project, mixed opinions on the frequency of text message reminders was also observed, as some participants commented that more text message reminders would be helpful, and a mix of "strongly disagree," "disagree," and "agree" were reported to the suggestion of more text message reminders.

Some participants suggested more text message reminders throughout the trial or text message reminders on days they had forgotten to record. For example, one participant suggested a text message reminder on the days they did not record into EDD application. The average number of days that participants recorded anything into the EDD application was 68.0 days out of 70 days in the vegetarian intervention group, and 68.9 days out of 70 days in the red meat intervention group. This suggests relatively high levels of daily dietary reporting in the Predition Trial, therefore, no changes were made with the method of sending text message reminders for the following groups. Some of the responses were related to the technical aspects of the EDD application and time constraints with a busy lifestyle, which hindered dietary recording quality. The EDD application allows image-based entries using only the camera function of the mobile phone. This meant that participants must take a photo of the food item in "real-time" and cannot upload photos through their mobile phone album or gallery. To support the remaining participants with this barrier, the researchers gave ideas,

such as taking a photo of a photo, or finding a similar meal online and taking a photo of the similar meal. Only three participants (17%) reported that they "agreed" that difficulties with the EDD application prevented better recording, whilst the remainder of participants "disagreed" or "strongly disagreed" with this statement.

Unsurprisingly, research shows that despite technological approaches to make dietary reporting more convenient and easy to use, participants still find this burdensome, although much less than traditional paper-based methods (Turner-McGrievy et al., 2019). This means that further strategies need to be implemented to make reporting, tracking and self-monitoring of dietary behaviours more engaging and convenient for users. It was expected that technology would not resolve all the barriers with achieving optimal dietary reporting, but it is anticipated to continue to improve and reduce participant burden.

In this study, adequate dietary reporting was defined as either three meal occasions per day, or two meal occasions and one snack per day, within each adherence check-up period. The literature shows that other studies have also aimed to define adherence to mobile and technology assisted dietary reporting (Payne et al., 2018; Turner-McGrievy et al., 2019). Turner-McGrievy et al. (2019) explored two 24-week weight loss intervention trials that used mHealth approaches, with the aim of defining adherence to mobile dietary self-monitoring. The mHealth approaches used in the two intervention trials included a photo meal application, bite counter device (counts how many bites of food taken based on wrist-controlled action), and two calorie tracking applications. Seven methods of defining self-monitoring adherence were used. Examples of methods used in this study were total number of meal occasions, total number of days that any food item was tracked, and number of days that at least 800 kcal were tracked (Turner-McGrievy et al., 2019). When comparing the different mHealth approaches, the study found that the most effective predictor of weight loss was defined as the total number of days that participants reported at least two meal occasions. This was similar to the current thesis project's method of measuring adherence to dietary reporting, where participants were adherent if they had completed one full day of recording within a check-up point, otherwise were prompted with a text message reminder. Interestingly, in the study byTurner-McGrievy et al. (2019), participant adherence was defined after the completion of the trial (Turner-McGrievy et al., 2019), whereas participant adherence was defined prior the trial in this thesis project. The strength of defining adherence to dietary reporting prior to the intervention allowed our researchers to develop appropriate

prompting methods to support adherence as participants progressed throughout the trial. Monitoring of adherence during the trial requires significant personal investment when compared with post trial assessment.

The Barriers to Recording Questionnaire demonstrated valuable feedback on how to further support adherence to dietary reporting. As seen in some studies, adherence to dietary self-monitoring can begin to drop around weeks three to five of intervention (Yu et al., 2015), which corresponds to the time that the questionnaire was given to participants in the Predition Trial. Therefore, having a questionnaire at the end of the study after potential decline in adherence may be more representative of participant experiences with the full trial and experiences with dietary reporting. Due to feedback on how participant's perceived the change in dietary lifestyle not being available at time of thesis completion, this was not analysed. Furthermore, feedback on the usefulness of resources such as the Predition Trial Cookbook would help future researchers develop the most optimal resources for participants and further understand aspects of adherence to dietary reporting and dietary intervention.

5.6 Relationship Between Baseline Characteristics and Adherence to Dietary Reporting and Dietary Intervention

As mentioned in the review of the literature, there is little to no research conducted on the association between baseline characteristics and adherence to dietary reporting in nutritional studies. There were no studies that specifically explored the relationship of baseline sociodemographic variables, anthropometric variables and psychological variables and how this might affect adherence to reporting dietary intakes. For example, no study investigated whether baseline levels of education would influence adherence to dietary reporting. Adherence to dietary reporting was more strongly influenced by supportive methods that were provided prior to the study beginning, such as instructions on how to report adequately, and supportive methods provided during the study, such as continuous text reminders. As a result, most of the following discussion around baseline characteristics have been explored in association with adherence to dietary intervention, as this was more commonly seen. This thesis project explored both adherence to dietary reporting and adherence to dietary intervention, therefore attempts to highlight the association between baseline characteristics and adherence to dietary reporting have been made, despite this being scarce in nutritional research.

5.6.1 Baseline Sociodemographic Characteristics

In this thesis project, baseline level of education was statistically significant between intervention groups, and the red meat intervention group was more educated than the vegetarian intervention group. The red meat intervention group had a higher adherence compliance score and a higher composite compliance score, when compared with the vegetarian intervention group, therefore education levels may potentially explain this observation. As mentioned above, no studies in the literature investigated whether baseline education levels would influence adherence to dietary reporting in nutrition research. However, the red meat group were more educated and had better compliance in this thesis project, which suggests that higher educated individuals may be more understanding of the importance of adhering to dietary reporting for the purpose of the trial, therefore showing better adherence to dietary reporting.

Studies that have investigated education levels in association with adherence to dietary intervention found that individuals who were more educated were more likely to better adhere to dietary intervention (Wangberg et al., 2008; Yuksel & Bektas, 2021). This was because educated individuals were more informed and aware of healthy lifestyle practices, therefore were more likely to partake in the dietary intervention (Wangberg et al., 2008; Yuksel & Bektas, 2021). In relation to this thesis project, it may be possible that participants in the red meat intervention group demonstrated better adherence to dietary reporting as they were more educated and therefore more likely to be aware of the benefits of adhering to dietary reporting for the purposes of the trial. In other studies, education was implemented as an intervention strategy to improve adherence to dietary intervention. Providing education was related to improved adherence to dietary intervention in many studies because the complexity and barriers to adhering to healthy dietary behaviours became more easy to overcome once participants were more knowledgeable (Arcand et al., 2005; Ayele et al., 2018). Based on higher education levels demonstrating better adherence to dietary intervention in the literature, the findings from our study were reasonable to suggest that better education was related to better adherence to dietary reporting and dietary intervention in the Predition Trial.

5.6.2 Baseline Lifestyle Characteristics

Both intervention groups of the Predition Trial promote a healthy dietary lifestyle, therefore all literature being discussed explored for adherence to a healthy dietary lifestyle or otherwise to clinical intervention. The baseline lifestyle factors of interest in the Predition Trial were: sleep duration, exercise levels and diet quality. None of the baseline lifestyle factors were associated with adherence to dietary reporting, adherence to dietary intervention or compliance in the current thesis project. However, some of the literature shows a relationship between lifestyle factors and adherence to the dietary intervention (Danes & Whinder, 2013; Imaki et al., 2002; Kant & Graubard, 2014; Stamatakis & Brownson, 2008; Theorell-Haglöw et al., 2020).

Young adults have shown to have varied sleep schedules and irregular sleeping patterns, which are typically associated with influencing eating habits. A study by Theorell-Haglöw et .al (2020) investigated the relationship between sleep duration and adherence to a healthy diet and regular meal pattern in adults (aged 45 to 75 years old) (Theorell-Haglöw et al., 2020). Sleep duration was measured using an online questionnaire, and dietary information was gathered using a modified Mediterranean diet (mMED) score and Healthy Nordic Food Index (HNFI) score. Participants who had both short sleep durations (defined as 6 hours or less per night) and poor sleep quality, showed lower adherence to a healthy diet and regular meal patterns, when compared with normal sleepers (Theorell-Haglöw et al., 2020). This was similarly observed in other studies, which saw higher energy intakes coming from snack foods rather than proper meal occasions (Kant & Graubard, 2014), higher intake of carbohydrates and processed sugars (Danes & Whinder, 2013), and lower intakes of fruit, vegetables and fibre (Imaki et al., 2002; Stamatakis & Brownson, 2008). The National Sleep Foundation recommends 7 to 9 hours of sleep for adults up to the age of 65 (Hirshkowitz et al., 2015). In the Predition Trial, the average hours of sleep throughout the intervention was 8.14 hours in the red meat intervention group and 7.88 hours in the vegetarian intervention group. The adequate hours of sleep reported in the analysis was likely the reason that there was no identified association between sleep duration and any aspects of adherence in the Predition Trial. A limitation to the accuracy of measuring sleep in the Predition Trial was that participants may not have worn the watch every day throughout the trial. However, it is important to note that all recruited participants of the study were intended to be healthy young adults exhibiting healthy lifestyle patterns, therefore extremely irregular sleep duration or sleeping patterns were not expected. In our study, no associations were found between

sleep and any aspects of adherence, and sleep duration and lack of sleep were not reported as barriers with adhering to dietary reporting in the Barriers to Recording Questionnaire.

Exercise was monitored through the Smartwatch by average daily number of steps that participants achieved during the duration of the Predition Trial. The Smartwatch had an additional feature of measuring exercise which was called "Workout mode." There were 11 workout modes to choose from (examples: indoor cycle, rowing machine, outdoor walking). The researchers decided to exclude the "Workout mode" feature of measuring exercise for the Predition Trial due to increased researcher burden and complications with standardising exercise measurements. The limitation to this method of measuring accuracy was that researchers were relying solely on the average number of steps as the level of exercise that participants engaged in. This could lead to an inaccurate measure of physical activity, as participants may have engaged in exercises that do not require many steps, but were of moderate or strong intensity. A study by Gillman M. et. al (2001) explored the relationship of levels of physical activity with dietary behaviours and habits in adults (Gillman et al., 2001). Results of the study found that individuals who had a sedentary lifestyle consumed smaller intakes of fruits, vegetables, vitamin A, vitamin C, vitamin E, calcium and fibre, when compared with more active individuals (Gillman et al., 2001). The results of this thesis project found that exercise was not significant with adherence to dietary reporting, adherence to dietary intervention or compliance in the study, which was appropriate, as the measurement of exercise was not representative of all levels of exercise. To further improve the measurement of exercise in future studies, intensity and duration of exercise may be a more accurate depiction of actual levels of exercise in individuals.

The baseline diet quality of participants in the this research project were measured using an adapted Healthy Diet Score (HDS) developed by two research dietitians (NG, AW). The average HDS score in the red meat intervention group was 65.5, and the average HDS score in the vegetarian intervention group was 67.0. However, baseline diet quality was not associated with adherence to dietary reporting, adherence to dietary intervention, or compliance in the study. To our knowledge, the quality of an individual's baseline diet is rarely explored in relation to adherence with dietary reporting and dietary intervention. Therefore, the importance of incorporating a high quality dietary lifestyle were explored in relation to this thesis project. A study in Turkey investigated the prevalence of childhood obesity and claimed that establishing healthy dietary habits similar to the Mediterranean diet

were helpful with reducing future diet-related disease risk (Sahingoz & Sanlier, 2011). The study measured adherence to the Mediterranean Diet Quality Index in adolescent Turkish individuals (aged 12 to 14 years). Results of the study found that individuals with more nutritional knowledge were more likely to exhibit healthy dietary habits and a higher quality diet. This suggested that by having better knowledge of nutrition and dietary wellness, individuals were more likely to adapt to a high quality dietary lifestyle. In relation to the Predition Trial, both intervention arms were in line with a healthy dietary lifestyle and perhaps participants with a lower baseline diet quality may have found it more difficult to adhere to a healthy dietary lifestyle when compared with participants with a higher baseline diet quality. However, as no significant differences were found in relation to baseline diet quality and adherence to dietary reporting, adherence to dietary intervention and compliance to the Predition Trial, this was an assumption made based on the literature.

5.6.3 Baseline Psychological Factors

PES scores were positively associated with adherence compliance scores and composite compliance scores in the Predition Trial ($p=0.004$). This suggested that there was a relationship between positive eating behaviours with adherence to dietary intervention and compliance in the Predition Trial, but no relationship with adherence to dietary reporting alone. All recruited participants were included if they did not show signs of disordered eating, were free of chronic health conditions, and did not use medications or recreational drugs. This means that all recruited participants had a generally good relationship with eating and were not prescribed with medications to treat psychological illnesses such as depression. Some variables were associated with adherence compliance scores and composite compliance scores in unadjusted models, such as DASS-Depression however, the associations disappeared after adjusting for other modifying factors such as education.

5.6.3.1 Positive Eating Behaviours

In this thesis project, the questionnaire used to create the PES score included questions that measured the level of enjoyment of eating, relationship with eating and emotions with eating (Appendix 6). Higher PES scores indicated higher levels of enjoyment with eating, a better relationship with eating, and positive emotions with eating, which were associated with higher adherence to dietary intervention and higher compliance in the Predition Trial. Similar findings were observed in other studies that explored the relationship of food with adherence

to dietary intervention trials (Appleton & McGowan, 2006; Dockendorff et al., 2012; Evers et al., 2018; Kuijer & Boyce, 2014; Vaillancourt et al., 2019; Westenhoefer & Pudel, 1993).

A study by Dockendorff et al. (2006) used an Intuitive Eating Scale (IES) to explore psychological trends in young adolescence (average age of 12 years) (Dockendorff et al., 2012). Intuitive eating is adopting a healthy attitude with eating and recognising the body's hunger and satiety cues (Denny et al., 2013). Dockendorff et al. (2012) explored four factors; Unconditional Permission to Eat, Eating for Physical rather than Emotional Reasons, Trust in Internal Hunger/Satiety Cues, and Awareness of Internal Hunger/Satiety Cues (Dockendorff et al., 2012). Results of this study found that individuals who reported higher scores for Unconditional Permission to Eat and Eating for Physical Reasons were less likely to internalise ideal appearances, weight loss and dieting, and reported more positive emotions and greater satisfaction with their bodies. Furthermore, individuals with higher scores of Trust in Internal Hunger/Satiety Cues were more likely to be of normal weight and report positive emotions such as happiness and confidence. Awareness of Internal Hunger/Satiety Cues was interestingly not related to any psychological trends in this study. The study was limited as only a narrow age group were analysed and therefore results were not representative of all age and population groups. Despite this, findings of the study suggested that factors of intuitive eating, such as eating for physical rather than emotional reasons, trust in internal hunger/satiety cues and unrestrained dietary behaviours promote positive emotions with eating and therefore better relationships with food. One study focused on intuitive eating effects in relation to the effect on health biomarkers and parameters. Individuals that participated in less social, emotional and environmentally triggered eating were more likely to have improved cardiovascular protection and positive blood lipid levels (Hawks et al., 2005). As such, triggers and cues can alter a participants food intake either positively or negatively. In the Predition Trial, the Three-Factor Eating Questionnaire (TFEQ) was used to measure eating behaviours which explores similar items to the PES questionnaire. The average baseline TFEQ score in both intervention groups was not statistically significant, but demonstrated low disordered eating patterns, with an average baseline TFEQ score of 0.50 ($p>0.05$) in both groups.

Eating is not only associated with survival, but also important to bringing pleasure in everyday life (Westenhoefer & Pudel, 1993). There are many factors that contribute towards the pleasure of eating including taste, eating environment, having adequate time and eating in

social and cultural settings (Westenhoefer & Pudel, 1993). Restricting food intake is associated with restricting the pleasures derived from consuming food, which may potentially affect adherence to healthy dietary patterns (Westenhoefer & Pudel, 1993). A study by Appleton and McGowan (2006) explored the relationship between restrained eating and poor psychological health (Appleton & McGowan, 2006). Anxiety was positively associated with restrained eating, and moderated by pleasure with eating. The authors suggest that experiencing pleasures normally associated with eating can moderate and improve the feelings of anxiety that are associated with restrained eating (Appleton & McGowan, 2006). Therefore, promoting the pleasures of eating may be a useful strategy to promote dietary changes and healthy eating. A study by Vaillancourt et al. (2019) aimed to compare pleasure-oriented messages with health-oriented messages to promote healthy eating in the adult population of Quebec City, Canada (Vaillancourt et al., 2019). Participants exposed to pleasure-oriented messages were most successful with increasing their perception that healthy eating can be pleasurable, when compared with participants exposed to health-oriented messages. The pleasure-oriented messages were displayed on an informational leaflet, with four section titles of the leaflet orientated to induce pleasure, such as "discover your new favourites," and "the pleasure of gathering together." This suggests that dietary behaviours are likely to be associated with individual perceptions and relationships with food.

Further exploring the association between dietary behaviours and the individual perception and relationship with food, more evidence emerged to support this finding. For example, the perception of "chocolate cake" as a guilt or celebration food was related to differences in attitudes, behaviours and intentions of healthy eating (Kuijer & Boyce, 2014). Guilt was related to lower levels of self-efficacy and less successful weight loss or weight maintenance. A possible explanation is that feelings of guilt with food results in avoidance of these foods and suppressing thoughts for those "guilt foods." As a result, the thoughts can become more intrusive and prominent, which can lead to cravings and less behavioural control (Rodgers et al., 2011). A 2018 meta-analysis analysed whether emotions such as feeling bad or feeling good with eating can affect food consumption (Evers et al., 2018). Individuals that were restrained eaters were more likely to increase food consumption in response to negative emotions (Evers et al., 2018). The meta-analysis found that there was conflicting evidence on the effects of emotional eating with predicting food consumption. Emotional eaters may eat to reduce negative emotions, for example: increased food consumption was associated with individuals who used eating to control negative emotions (Evers et al., 2018). However,

emotional eating did not directly affect eating behaviour, and emotional eating scales were found to be a poor predicter of food consumption according to Evers et al. (2018). This is because retrospective questionnaires will always pose the risk of potential recall bias and in the case of emotional eating scales, this can lead to under or overestimation of scale scores and therefore a poor predictor of emotional eating behaviours (Evers et al., 2009, 2018). In this thesis project, food guilt was not explored, however, one of the questions in the Barriers to Recording questionnaire investigated whether satisfaction with current dietary patterns was related to altering dietary behaviours to become more compliant. The question asks: "I think that my current eating habits are 'unhealthy' so I don't record as much as I could into the app." All participant responded "strongly disagree" or "disagree," which suggests that perception of current dietary patters was not related to adherence to dietary reporting. This was an interesting finding, as some studies have found that participants may alter dietary patterns due to feeling guilty about what they were eating, or to demonstrate a "healthier" dietary pattern, therefore hindering the accuracy of the recorded dietary intakes (Egele et al., 2021). Once again, the participants in the Predition Trial exhibited a generally healthy relationship with food, which may explain why food guilt was not reported as a barrier to adherence in the trial.

5.6.4 Depression and the Relationship to Healthy Eating and Compliance

In this thesis project, the baseline DASS-Depression score was used to analyse symptoms of depression in participants of the Predition Trial. DASS-Depression scores were inversely associated with adherence compliance scores and composite compliance scores in unadjusted models, but these associations were not observed in adjusted models. However, it is still worth exploring whether symptoms of depression may influence adherence to dietary intervention and dietary reporting in the Predition Trial. As the DASS-Depression score is not a diagnostic tool, it was unknown to what extent a participant had symptoms of or was experiencing depression during the trial. However, no participants were taking prescribed medications to help improve symptoms of depression. The WHO definition of depression is: *"Characterised by persistent sadness and a lack of interest or pleasure in previously regarding or enjoyable activities. It can also disturb sleep and appetite."*(World Health Organization, 2022a).

The average baseline DASS-Depression score in the red meat intervention group was 4.50, and the average baseline DASS-Depression score in the vegetarian intervention group was 7.80. DASS-Depression scores of less than 9 are considered normal, so both baseline values for red meat and vegetarian groups, while different from each other, were normal (Gomez, 2016). To our knowledge, there is little research conducted on the relationship between depression and adherence to dietary intervention or adherence to dietary reporting. However, there is substantial research on the incidence of depression in vegetarian versus meat eating consumers. Therefore, studies that have explored the incidence of depression between different dietary lifestyles will be explored. Studies that have investigated depression in association with adherence to medication or a healthy dietary lifestyle will also be analysed. This is because medication that is used to treat or aims to improve the symptoms of depression, requires the individual to adhere to the intervention. Additionally, the intervention of this study also adheres to a healthy dietary lifestyle, therefore it is reasonable to compare with studies that have explored the relationship between depression and adherence to a healthy diet.

From the NZ 2018 Mental Health Survey, 18 to 24 year olds reported experiencing moderately severe to severe depression more than other age groups (Wilson & Nicolson, 2020). The WHO reports about 5% of adults affected with depression globally, making this a common mental health disorder (World Health Organization, 2021b). Therefore, it is of significant importance to acknowledge and understand dietary behaviours of individuals with symptoms of depression, to promote healthy dietary lifestyles and support good mental health. There is emerging evidence supporting adequate nutrition in maintaining good mental health (Bailly et al., 2015; Jacka et al., 2011; Popa & Ladea, 2012). The Mediterranean diet is an often discussed standard of a healthy dietary lifestyle. Some studies have suggested that adhering to a Mediterranean diet was associated with a lower prevalence of depression, whereas higher consumption of processed foods were found to increase the prevalence of depression (Popa & Ladea, 2012). It is important to remember that the relationship between depression and nutrition is complicated as depression can be caused by multiple social, environmental and physical factors. Some studies reported a lack of pleasure with eating as a common symptom of depression (Bailly et al., 2015; Silverstein, 1999). The lack of pleasure consequently led to less desirable food choices, such as higher intakes of processed foods and irregular meal patterns, therefore becoming less adherent to a healthy dietary lifestyle (Bailly et al., 2015).

A study by Strine et. al (2018) used telephone based methods to analyse the association of perceptions of life satisfaction in relation to quality of life (Strine et al., 2008). The study found that with decreasing levels of life satisfaction, there were higher reports of mental distress, depressive symptoms, pain, obesity and heavy drinking (Strine et al., 2008). Vegetarian diets and plant-based foods have long been associated with a healthy dietary lifestyle, decreasing the risks of cardiovascular disease, hypertension, type 2 diabetes and obesity (Appleby & Key, 2016; Papier et al., 2019). However, vegetarian diets have also been shown to have an association with depression or result in higher depression scores (Ocklenburg & Borawski, 2021). This evidence is conflicted and must be further explored, as other studies reported the complete opposite, showing that vegetarian diets were inversely associated with depression (Daneshzad et al., 2020). Meanwhile, a study by Wirnitzer et al. (2018) compared the health status of vegan, vegetarian and omnivorous runners and found no association between diet and mental health (Wirnitzer et al., 2018). As seen similarly in the Predition Trial, no association between depression and adherence to dietary reporting, adherence to dietary intervention and compliance to the study was observed. Therefore, this area of research is unsettled as the complexity of depression cannot rule out other potential confounding factors that play a role in depression. Therefore, a vegetarian diet alone may not necessarily predict a higher incidence of depression but may be a potential risk factor in some individuals.

A 2018 study conducted on 9668 men found that men with vegetarian diets had higher depression scores after adjusting for potential confounding factors and socio-demographic factors (Hibbeln et al., 2018). The study proposed that nutrient deficiencies were a possible explanation for the higher depression scores seen in the vegetarian cohort as low nutrient intakes have been a common issue in vegetarian and vegan consumers (Howe et al., 2007; Lim et al., 2016). When exploring nutrient related deficiencies, vegetarian and vegan consumers were more likely to have vitamin B12, omega-3, zinc and iron deficiencies (Iguacel et al., 2021; Phillips, 2005; Saunders et al., 2013). In the case of nutrient deficiencies, the evidence for risk of developing mental health disorders and depressive symptoms was stronger (Iguacel et al., 2021). Therefore, being a vegetarian or vegan consumer does not necessarily directly relate to depressive symptoms, however, becoming nutrient deficient which occurs more commonly in vegetarian and vegan consumers, can increase the risk of developing mental health issues. Additionally, other studies have found that vegetarian diets were associated to increased depressive symptoms, but this was related

to the psychological reasons for adopting a vegetarian diet, such as unhealthy weight controlling behaviours, abnormal eating attitudes, low self-esteem, and anxiety, rather than nutritional deficiencies (Baş et al., 2005; Perry et al., 2001). This correlates to the findings in our study, as the baseline DASS-Depression scores were relatively low in both intervention groups and when adjusted for education, were no longer inversely associated with composite compliance scores in the study.

5.7 Strengths

Overall, the results from the study suggest that measuring and supporting adherence to dietary reporting and dietary intervention was successful in the Predition Trial. 100% of participants reported feeling well supported by the research team and there were no drop-outs, which demonstrate success in providing supportive resources and education to participants. Participants completed this study in pairs living in the same household. This was a successful implementation based on the Barriers to Recording questionnaire, where 89.5% of participants "agreed" or "strongly agreed" that they found it helpful to record with a pair or partner. As seen in other dietary intervention studies, social support, team participation and group sessions positively influenced adherence to dietary intervention by providing therapeutic benefits to participants (Armstrong et al., 2011; Dennis, 2003; Jacka et al., 2011; Paul-Ebhohimhen & Avenell, 2009; Sparks et al., 2019; Watanabe-Ito et al., 2020). In this thesis project, two aspects of adherence were measured; adherence to dietary reporting and adherence to dietary intervention. This was a time consuming and complicated procedure, therefore it is understandable that the current literature rarely measures more than one aspect of adherence. However, this was a strength in our study as the utmost detail was dedicated to measuring adherence and a variety of components that can influence adherence in dietary assessment trials were understood. For example, adherence to dietary intervention was measured through recording into the EDD application, however, if participants did not report dietary intakes adequately into the EDD application, then adherence to dietary intervention could not be measured. Therefore, this thesis project recognised that adhering to dietary intervention required a certain degree of adherence to dietary reporting into the EDD application, therefore focused on both aspects of adherence to optimise outcomes in the Predition Trial. As seen in the results, the average drop in adherence rates were less significant in our thesis project, at around 25% to 30%, whereas the average drop in

adherence rates from a scope of the literature was around 40% to 50% (Carter et al., 2013; Chen et al., 2017; Crichton et al., 2012; Jimoh et al., 2018; Simpson et al., 2017).

The use of a smartphone application to measure adherence to dietary reporting and dietary intervention has been successful for both participants and researchers. As seen in the literature, mobile diet recording applications allow researchers to access real time data coding, providing more accuracy to data collection and early detection of adherence issues that can be communicated to participants immediately (Sharp & Allman-Farinelli, 2014). Similarly seen in this thesis project, monitoring of adherence to dietary reporting and dietary intervention were completed twice a week, and issues with adherence were recorded, then notified directly to participants with a text message reminder. Participants would then immediately be able to clarify or make changes to their current actions. This demonstrated that the eHealth approach to measuring and supporting adherence in the Predition Trial was successful due to improved time efficiency and convenience to both participants and researchers.

5.8 Limitations

Participants were responsible for adhering to a "flexitarian" or "vegetarian" dietary lifestyle with the support of researchers. Adherence to dietary intervention was monitored through the EDD application for three serves of red meat per week in the "flexitarian" intervention, or three serves of meat alternatives per week in the "vegetarian" intervention. There were potential inaccuracies that could results from this method of monitoring adherence. Participants may have eaten additional serves of animal protein, but concealed this to researchers by not reporting this into the EDD application. Ultimately, the researchers would trust the reported dietary intake from the EDD application as they cannot monitor dietary intake through any other method. This demonstrates that the accuracy of measurement in adherence to dietary intervention may have been impaired in the Predition Trial. Some studies have used wearable micro-camera devices to improve accuracy of dietary reporting, including exposure to other environmental factors and cooking methods (Pettitt et al., 2016; Sun et al., 2010). However, this was not deemed appropriate for this study due to the low feasibility of wearing this device for a long period of time and difficulties with image based data analysis.

One of the themes recognised from qualitative analysis was a lack of functionality of the EDD application. This was a limitation to supporting adherence to dietary reporting for the participants as it increased participant burden and therefore hindered the quality of dietary reporting. Three participants suggested the "My Fitness Pal" mobile phone application as a more intuitive dietary reporting application (MyFitnessPal Inc, 2022). Similar to the EDD application, My Fitness Pal is a mobile phone application that is used to track food and drink intake. However, My Fitness Pal has their own database that continues to grow based on the user information, creating over 5 million different food items. The EDD application has an Australian food database, limiting the variety of food items available for consumers to select (Xyris Pty Limited, 2020). The application also has the options of both manual text entry and image-based entry. However, the advantage of My Fitness Pal when compared with the EDD application, is that My Fitness Pal enables individuals to use the camera function of their mobile phone to take photos of food, and additionally import photos from their mobile phone album. The EDD application was only able to use the camera function to take photos of food in "real time." The limited functionally of the EDD application was a disadvantage to dietary reporting as responses from the questionnaire identified that being unable to upload image-based entries from their photo album reduced dietary reporting quality.

Another challenge with the EDD application was the limited food and drink database. An example from one participant was that 'sourdough bread' was not in the EDD food database. This consequently made the process of dietary reporting more difficult, as participants would need to find other ways to report the food item, increasing burden of time. The EDD application uses the Australian Food Composition Database (Xyris Pty Limited, 2020, 2022). As the Predition trial was conducted in New Zealand, this may have affected the recording of food items for participants as food items closer to New Zealand cultural foods may not be programmed into the application. An example of a common New Zealand staple food is kumara, which was not a part of the food and drink database on the EDD application. Participants were still able to overcome this limitation by reporting similar foods such as "sweet potato," or using the "notes" section to inform researchers of this limitation. However, the process of providing clarity in the "notes" section with each food item can become laborious and time consuming throughout the 10 weeks of the trial. Additionally, reporting similar foods in the database as an alternative to the actual food item means less accuracy with reported dietary intakes.

Several participants reported aspects of difficulty when providing accuracy to dietary reporting. An example of this was difficulty with quantifying ingredients and meals. This can be especially difficult when meals are ordered from restaurants because participants were unaware of the ingredient make-up of the meal. Some participants also reported difficulty with quantifying ingredients when food was made in bulk, and then shared into many meals. Additionally, image-based entries of food items were assumed as 100% consumed, unless otherwise quantified in the "notes" section by the participant. When measuring adherence to dietary intervention, this can be an inaccurate measurement as a participant may not have all the provided protein displayed in the photo, but the researcher would assume that the participant had consumed 100% of the protein. For this thesis project, quantifying the protein provided for the dietary intervention was the only relevant measurement required. Therefore, most of the limitations with quantifying food portion sizes were not significant to this analysis.

As mentioned in the strengths, the majority of participants reported that having a pair or partner to complete the trial was helpful, as this was one of the successful behaviour strategies incorporated into the research design. Whilst this was a positive finding, this thesis project did not take into account the dependency of the pairs or partners, and how this may have influenced the outcomes. All data were analysed as individual data for this thesis project. Nesting or consideration of hierarchal aspects of paired individuals were not accounted for, and nesting of paired individuals were not accounted for between other pairs in the study. This was a limitation to the study as influences that study pairs may exert on each other were not analysed, creating some confounding effects to the study outcomes.

Lastly, this thesis project was impaired due to ongoing COVID-19 disruptions. As mentioned in the results, 80 participants took part in the Predition Trial, however, only 40 participants' results were able to be analysed within the timeframe of completing the current thesis project. Therefore, there was a smaller sample size and a lack of data. Consequently, results for all objectives of the thesis project were incomplete and stronger associations with particular variables were not observed. For example, DASS-Depression was inversely associated with composite compliance scores in unadjusted models, but associations disappeared after being adjusted for education. As the research demonstrates that adherence to a healthy diet can be related to improved symptoms of depression, the lack of data may have caused this thesis project to not have observed this result.

5.8.1 Participant Burden

Participant burden remains a challenge in mHealth dietary intervention trials. From the literature (Carter et al., 2015; Chen et al., 2017; Crichton et al., 2012; Daugherty et al., 2012), reported examples of participant burden with smartphone dietary reporting include:

- Mobile application issues itself
- Difficulty with using technology
- Delay of meal consumption to capture images
- Accessibility of phones during mealtimes
- Time consuming efforts of application use

As society becomes more technology-reliant, limitations such as time and knowledge related to learning the technological systems should gradually improve (Bonilla et al., 2015).

In the Predition trial, participants were made aware at the beginning of the study that all reported "skipped meals" into the EDD application were marked as a meal occasion. "Skipped meals" were included as meal occasions because participants acknowledged and initiated the action of logging a meal occasion. A challenge that emerged with this was that some participants would report one proper meal per day, and report two "skipped" meal occasions for the remainder of the day. This became difficult to interpret as it did not seem logical to consistently have only one meal each day. As a result, the researchers communicated through this issue by monitoring participants with this pattern of dietary reporting, and would send a text-message reminder when deemed appropriate. Another limitation of counting "skipped meals "as meal occasions was the possibility of participants recording "skipped meal" to make dietary reporting easier and faster, despite potentially having a proper meal occasion. One participant in this study reported that they purposely ate simpler foods on days where manual text entry were preferred, to reduce the burden of recording multiple ingredients. Some participants reported an adequate number of meal occasions for each day, however this could be extremely minimal. For example, one participant only reported "anchovies" for a dinner occasion, which was difficult for the researchers to deem as an adequate meal occasion. Therefore, the limitations observed in this thesis project demonstrates that participant burden was still prevalent in the Predition Trial, despite efforts to minimise the effect.

5.8.2 Researcher Burden

As expected, researcher burden was observed in this thesis project. A Canadian study found researcher barriers to electronic dietary records included misinterpretation of participant data, unfamiliarity with electronical methods, and additional time required for researchers to analyse results (Bonilla et al., 2015). In relation to this thesis project, this was particularly prevalent when participants did not adhere to certain aspects of the trial. When participants did not adhere, the researchers used text messages to contact participants and ensure they kept adhering. Some participants clarified reasons for not adhering, some participants became adherent after communicating with researchers, and some participants remained non-adherent. The researcher responsible for checking adherence through the EDD application would then need to check through the application once again, and correct changes where necessary. This increased the burden of time for the researchers involved. However, the thorough monitoring and support that was provided in this thesis project ensured that the results of the findings were accurate and detailed, which was an overall benefit to the trial. Despite this, the findings from our thesis project indicates that researcher burden remains a challenge in dietary intervention studies, however, we believe that the eHealth approaches significantly reduced this.

6 Conclusions

The current thesis project focused on measuring and supporting adherence to dietary reporting and dietary intervention in the Predition Trial, using the Easy Diet Diary smartphone application. Using the Easy Diet Diary to measure adherence to dietary intervention improved time efficiency for the researchers, as real-time data could be accessed and analysed with convenience. Supportive measures such as text message reminders could then be facilitated early on within the trial to minimise adherence issues-this was also an advantage reported by other studies (Sharp & Allman-Farinelli, 2014). Other strategies to support adherence to dietary intervention, such as the Predition Cookbook and complimentary weekly meal-kit deliveries were believed to support success in adhering to intervention. Participant feedback with adjusting and adhering to dietary intervention were not available at the time of this thesis completion. However, similar studies have found that providing educational resources and gifts were helpful with adhering to intervention (Crichton et al., 2012; Davis et al., 2015; S. E. Moore et al., 2018; Saslow et al., 2020). Adherence to dietary reporting and dietary intervention decreased as the trial progressed, with 70% of participants in the vegetarian intervention arm not adhering to dietary intervention by week 10. This was not a surprise and followed similar trends to findings from the literature, demonstrating that more research and supportive measures were necessary to improve adherence (Morris & Schulz, 1992; Simpson et al., 2017; Wilhelmsen & Eriksson, 2019).

The incorporation of an eHealth approach to measure and support adherence to dietary reporting also demonstrated success, where 100% of participants that completed the Barriers to Recording questionnaire felt well supported by the research team (47.5% of all participants completed the questionnaire) and 94% of participants felt that the text message reminders were helpful. The Barriers to Recording Questionnaire also successfully measured barriers that participants faced with adherence to dietary reporting in the Predition Trial. Based on this feedback, the thesis project recognised that application functionality, more text message reminders, not having time or forgetting to record, and the potential for inaccurate recording were major barriers to adequate dietary reporting. This was similar to findings from previous studies that have investigated adherence to reporting in dietary intervention studies (Chen et al., 2017; Crichton et al., 2012; Hooson (Jzh) et al., 2020; Jimoh et al., 2018; Thompson & Subar, 2017). Despite the successes in supporting dietary reporting in the Predition Trial,

commonly seen barriers in dietary reporting were still present in our study, and more research is necessary to overcome this.

Interestingly, the adherence compliance score and composite compliance score were statistically significant between intervention groups, and were higher in the red meat intervention group. In addition, the red meat intervention group were more educated and had a higher PES score at baseline, which could potentially explain the better overall compliance when compared with the vegetarian intervention group. When investigating the predictors of adherence to dietary reporting and dietary intervention, the baseline PES score was positively associated with composite compliance scores after adjusting for education. This suggested that having a positive relationship with food demonstrated better adherence to dietary intervention and better compliance (adherence to dietary reporting and dietary intervention simultaneously) in our study. Positive eating behaviours and positive relationships with food were associated with better adherence to healthy dietary behaviours in the literature, making this an appropriate finding (Appleton & McGowan, 2006; Dalen et al., 2010; de Leon et al., 2020; Dockendorff et al., 2012; Westenhoefer & Pudel, 1993). As mentioned previously, no studies had investigated whether baseline characteristics would affect adherence to dietary reporting, and unfortunately no direct associations between baseline characteristics and adherence to dietary reporting were found in our study.

Overall, this thesis project was successful with measuring and supporting adherence to dietary reporting and dietary intervention in the Predition Trial. The review of the literature found eHealth approaches to dietary intervention much more promising, and this was reflected in my thesis project, based on the positive participant feedback received and low participant and researcher burden. For future studies that wish to optimise adherence in dietary intervention studies, it is strongly recommended that an eHealth approach is used, in addition to other supportive measures prior and throughout the duration of the trial. As positive eating was positively associated with adherence to dietary intervention in this thesis project, upcoming studies may wish to integrate strategies to promote positive eating behaviours to improve adherence rates in dietary intervention.

Appendices

Appendix 1. Instructional Email on the Use of the EDD Application (in Electronic PDF Format)

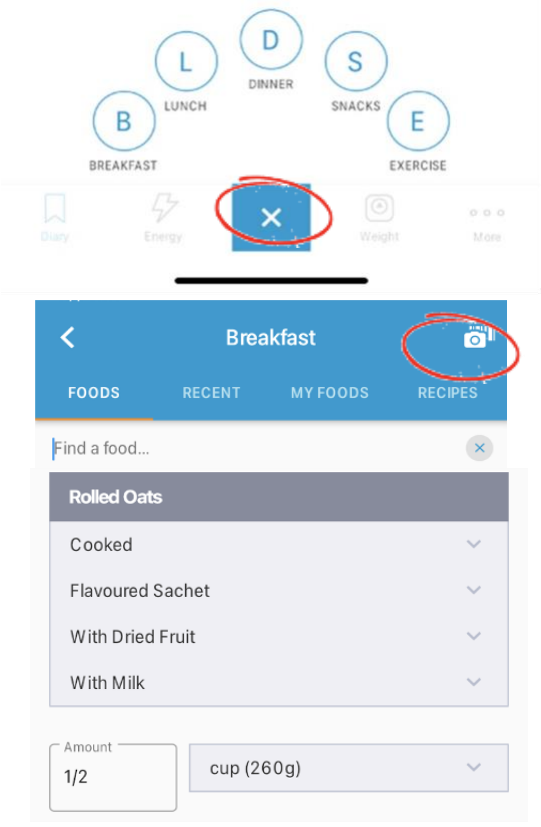
Using the Easy Diet Diary (EDD)

- Download and sign up for the EDD through the link we email you. This way we can check in on how you're going.
- Once downloaded, sign up for a new account. Follow the instructions and enter your name, date of birth, sex, and weight. When it asks you to enter a goal weight, please enter your current weight.
- Enter the suggested energy goal. *NB: We are not looking at your energy intake, rather your overall dietary pattern and adherence to eating your protein.*
- For exercise, select "Do Not Track". We are not worried about tracking exercise on this app as your Huawei Band will do this.

How to enter food and drink

To manually enter food and drink:

1. Select the meal occasion you are entering by tapping the name of it on the main screen, or tap the "+" and select the meal (e.g. breakfast, lunch, dinner or snacks).
2. Begin typing your food into the "find a food" box and select the closest option to what you are eating. Alternatively, tap the camera/barcode icon and use the barcode scanner to identify packaged food items (*NB: not all products are in the database so some products may not show up).*
3. Select your best estimate of the quantity and unit of your food item (see tips for estimating portions). Then tap "Add".
4. Continue to add all the foods for that meal or snack occasion.



(Xyris Pty Limited,2022)

To enter photos of food and drink:

1. Select the meal occasion you are having the meal at.
2. Tap the camera/barcode icon.
3. Make sure to tap the camera icon again once the picture appears.
4. Click the white button to take a photo of your food. The clearer, the better.

Note that photos cannot be uploaded later on- you must take a photo of your food through the app.

Tips

- **Skipping Meals**

  If you skip a meal then tap the Notes section (the box under Snacks and Drinks) and type "Skipped [meal occasion]". For instance, if you didn't eat breakfast type "Skipped breakfast" in the notes.

- **If you can't find a food**

  If you can't find a food, try searching an alternative name for it e.g. search 'sweet potato' instead of 'kumara'. Typing the specific brand help you to find a food. However, we are not too concerned with the exact brands- just choose the closest item to what you are eating.

- **Estimating Portions**

  Here are some helpful tips for estimating portions:

  -Liquids (e.g. milk): 1 cup = 250 ml = 250 g

  -1 handful of cooked vegetables = ½ cup = 80g

  -2 handfuls of salad = 1 cup = 80g

  If you are not weighing your food, if available enter your food in cups (or other option) rather than grams.

- **Faster Entering**
  - When entering food items you can tap the 'RECENT' tab to select foods that you have previously entered on those meal occasions.
  - If you cook a certain meal often you can enter this as a recipe by tapping: More (bottom right) > Recipes > +

What You Need to Do

During the 10-week intervention:

- Sunday and Monday: manually input everything you eat and drink

- Tuesday to Saturday: take a photo of (or manually enter) your main meals and snacks, especially those including your provided protein

Over the next two weeks, please take the opportunity to practice inputting at least one meal manually and one meal by taking a photo.

Appendix 2. Standard Operating Procedures for Measuring Adherence to Dietary Reporting and Dietary Intervention Using the EDD Application

Measuring Adherence

- LL to complete on Friday (for 3 days of recording, i.e., Tues, Wed, and Thurs) and Tuesday (for 4 days of recording i.e., Fri, Sat, Sun, and Mon) mornings.
- NG and AW to check on Friday and Tuesday afternoons and send text messages as needed.
- T-2 checks do not count towards a participant being 'non-adherent' but are used as a guide for AW and NG to discuss with participants.

Code for Excel Table

- Date completed: Enter the date that adherence was checked at each assessment period. This should be the same for all participants in the group, but it is good to keep track of this.

Adherence – Recording:

- Meal occasions: Have the participants entered at least 2 meals and a snack (or 3 meals) on a single day in the adherence period checked. Count the number of main meals entered in the adherence period. Do not pre-emptively enter adherence for this, as we need the total amount over either the 3- or 4-day period. Enter the TOTAL number the participant has consumed, do not divide it by the total opportunities – this will be done at a later stage.

  E.g., if a participant consumed 6 in adherence point 2a, record 6 not 6/9.
- All meal occasions that were reported as "skipped meals" were also considered as a meal occasion. E.g., "skipped breakfast," and pasta for lunch, would count as 2 meal occasions.

Adherence – Intervention:

- Red meat/veg serves: Record how many meals have been reported with either the red meat or the vegetarian alternative. Again, do not divide this by anything – just report the total number.
- At timepoint b-if total protein serves do not add up to 3, this will be recorded as non-adherent.

Text message required: Record yes or no

- Reason for text message: Record as one (or more) of the following choices
  - *Recording* (i.e., has not completed a full day)

- *Clarification* (i.e., cannot tell what a meal is which makes a difference to the participant's compliance)
- *Adherence* (i.e., not adhering to the intervention).

Please only use these three options, as we can easily filter and use this data at a later stage.

- Describe text message: Free text to give any relevant details e.g., for clarification and non-adherence please note down the date and meal occasion that requires further detail or that breaches dietary intervention. For the baseline data, note if participants need to take a manual entry, photo entry, or both, as well as if they need to still sign up for the EDD.

Appendix 3. Barriers to Recording Questionnaire Conducted in Pilot Groups at T5 Phase

Predition Barriers to Recording Questionnaire

Please indicate how strongly you agree with the following statements.

	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)
I find the Easy Diet Diary mobile app difficult to use (1)	○	○	○	○
The difficulties with the app prevent me from recording in the app more often (2)	○	○	○	○
I find it helpful to record with a pair/partner undergoing the study with me (3)	○	○	○	○
I find the text messages helpful for remembering to record appropriately and accurately into the app (4)	○	○	○	○
I would like to receive more text messages to remind me to record more frequently into the app (5)	○	○	○	○
I think that my current eating habits are 'unhealthy' so I don't record as much as I could into the app (6)	○	○	○	○
I am well supported by the research team to record sufficiently on the app and meet study requirements (7)	○	○	○	○

Q4 Please comment on what could be done better to support you to record sufficiently on the app?

Q5 Please comment on any other barriers that have made it hard for you to record into the Easy Diet Diary app (e.g. limited time, lack of instructions on how to use the app, technical difficulties, difficulties quantifying food).

Appendix 4. Thematic Analysis of Qualitative Outcomes Conducted By Larissa Li

Theme/Pattern	Participant Comments
Difficulty with technical aspects of the application	- Limited database, not enough food items in the EDD application - Image-based entries must be taken through the camera ONLY and in real-time ONLY - A few participants suggested the “My Fitness Pal” app instead
Text message reminders	- More text message reminders throughout the trial (Example: “you have not recorded today”) - Reminders on Tuesday have been helpful for switching from manual to image-based entries
Time constraints and forgetting to record	- Entering recipe ingredients can be time consuming - Eating simpler meals to reduce time to enter food items into the app - Forgetting to take photos or record into the app because of busy schedules or being in a rush
Accuracy of Reporting or Recording Inaccuracies	- Limited database of the EDD app makes it hard to find matching or similar food items - Difficulty quantifying food portions, especially if made in bulk, shared or ordered out - A photo of a food item does not tell the viewer the quantity being consumed, unless written in the “notes” section additionally.

Additional Note of Interest

The thematic analysis completed by Dr. Andrea Braakhuis identified the following themes:

- Theme 1: Easy Diet Diary app lacked functionality.
- Theme 2: Text message nudges to complete food diaries could have been more regular.

Appendix 5. Instructional Handout for the Use of the Huawei Band 4 Pro (in A4, Printed Format)

Huawei Band Participant Information

Set up

1. Charge your Huawei Band 4 Pro and select preferred language using the touch screen.

2. On your mobile phone, download the Huawei Health app from the app store.

3. Click to allow use of Bluetooth. It's up to you whether you allow access to your contacts and enable notifications. Accept the user agreement.

4. Click 'Register' for a new Huawei ID.

   Please use: **Your phone number** **Password: predition1**

5. Enter your details. When setting up your account **please agree to store data on the cloud.**

6. Choose whether you would like to allow your band data to update your phone Health data. Allow Huawei Health to use your location.

7. On the Huawei Health app, go to Devices > Add > Smart Band, and select your band's name.

8. Touch PAIR, and the Huawei Health app will start searching for the band. Then select the correct device name from the list of available devices, and it will start pairing automatically. Click the tick on the band, then click 'Pair' on the phone.

Usage Notes and Tips

- Please wear your band as much as possible and record your exercise using the band during the 2-week lead-in and the 10-week intervention. *NB: the band is waterproof and the battery lasts for around 3-5 days depending on usage.*

- To use your band: touch the Home key (bottom button) to wake the band when the screen is off. Swipe up or down to scroll through the features. Touch the screen to select any features. Swipe right on screens (other than the home screen) to return to the previous screen.

- Turn on Huawei TruSleep Function: Devices > select band > enable TruSleep.

Appendix 6. The Questionnaire Used to Create The PES Score

INSTRUCTIONS: Please answer the following questions about your eating experiences **over the past week**, using this four-point response scale from 1 'strongly disagree' to 4 'strongly agree'.

		Strongly Disagree	Disagree	Agree	Strongly Agree
		1	2	3	4
PES1	I eat in a way that makes me feel good.				
PES2	Eating is a pleasure for me.				
PES3	Overall, I am satisfied with my eating behaviour.				
PES4	I enjoy eating.				
PES5	I am relaxed about eating.				
PES6	Eating is fun for me.				
PES7	I have a good relationship with eating.				
PES8	Eating is something nice for me.				

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