Dietary patterns in the older New Zealand adult and their associations with cognitive function and metabolic syndrome: The Researching Eating, Activity, and Cognitive Health (REACH) study

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in
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Abstract

Background: The global population is ageing. Ageing and poor diet are common risk factors for cognitive decline and metabolic syndrome which reduce functionality in later years. A dietary pattern approach considers the full complexity of the diet. Dietary patterns in an older New Zealand context have not been identified nor their associations with cognitive function or metabolic syndrome.

Aims and objectives: This thesis, referred to as the REACH (Researching, Eating, Activity, and Cognitive Health) study, explored associations between dietary patterns and cognitive function and metabolic syndrome in older New Zealand adults. To achieve the aim a food frequency questionnaire (FFQ) was assessed for reproducibility, relative validity, and its suitability to derive robust dietary patterns. Further, associations between these dietary patterns and their nutrient and energy intake; the socio-demographic and lifestyle factors of the participants; and cognitive function and metabolic syndrome outcomes were examined.

Method: Community-dwelling adults from Auckland, New Zealand were recruited (aged 65-74 years, 36% male, *n* 371). Dietary patterns were derived from a 109-item FFQ using 57 food groups and principal component analysis. Nutrient, energy, and alcohol intake were calculated using FOODfiles, the New Zealand Food composition database.

The REACH FFQ and its derived dietary patterns were assessed for reproducibility and relative validity in a sub-set of the REACH participants (*n* 294). Reproducibility was assessed using an identical FFQ (FFQ2) administered one month after the initial REACH FFQ. A 4-day food record (4-DFR), collected between FFQ administrations, assessed relative validity.

Cognitive function, covering six domains (global cognition, attention and vigilance, executive function, episodic memory, working memory and spatial memory), was assessed using COMPASS (Computerised Mental Performance Assessment System). Self-administered questionnaires collected health (medication and supplement intake), demographic and lifestyle [including sex, education levels, living status (alone or with someone), smoking status, physical activity levels, address (for Index of Multiple Deprivation)], and physical activity (International Physical Activity Questionnaire) data. A fasted blood sample was collected for measuring genetic [Apolipoprotein E -ε4 (*APOE* -ε4)] and biochemical markers (triglycerides, high- and low-density lipoprotein cholesterol). Blood pressure and anthropometric measures [weight, height, waist circumference, and body fat % (using dual X-ray absorptiometry)] were collected. Metabolic syndrome was defined by the National Cholesterol Education Program Adult Treatment Panel III.

Statistical analyses performed: Reproducibility and relative validity of the REACH FFQ (food group intakes) and its derived dietary patterns (scores) were assessed using Spearman correlation coefficients (acceptable correlation rho=0.20-0.49), weighted kappa statistic (κ_w) (acceptable statistic $\kappa_{w=}$0.20-0.60), and Bland-Altman analysis including mean difference, limits of agreement, plots, and slope of bias. The similarity between dietary pattern loadings were assessed using Tucker's congruence coefficient.

Linear or logistic regression were used to examine associations between dietary patterns and their nutrients; socio-demographic and lifestyle factors; and health outcomes. Confounding adjustments included age, sex, education, index of multiple deprivation, energy intake, *APOE*-ε4, and physical activity.

Results: In the validation study, the FFQ food groups showed good reproducibility (mean correlation coefficient = 0.69, mean κ_w = 0.62) and acceptable relative validity (mean correlation coefficient = 0.45, mean κ_w = 0.38) though Bland Altman plots showed bias and mean differences significantly different to zero in some food groups. Three similar dietary patterns were identified from each dietary assessment tool: 'Mediterranean style', 'Western', and 'prudent'. Congruence coefficients between factor loadings ranged from 0.54 to 0.80. Correlations of dietary pattern scores ranged from 0.47 to 0.59 (reproducibility) and 0.33 to 0.43 (validity) (all P<0.001); weighted kappa scores from 0.40 to 0.48 (reproducibility) and 0.27 to 0.37 (validity); limits of agreement from ± 1.79 to ± 2.09 (reproducibility) and ± 2.09 to ± 2.27 (validity); a slope of bias was seen in the 'prudent' pattern for reproducibility and validity (P<0.001).

From the full REACH dietary data set, three valid dietary patterns were derived explaining 18% of the variation in the diet. The '**Mediterranean style**' pattern (salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs; cheese; tomatoes; and all other fruit) was associated with higher levels of beta-carotene equivalents, vitamin E, and folate intake (all P<0.001, all $R^2 \geq 0.26$), along with being female, having a higher physical activity level, and higher education (P<0.001, R^2 = 0.07). The '**Western**' pattern (processed meat; sauces and condiments; cakes, biscuits and puddings; meat pies and chips; processed fish; confectionery; vegetable oils; beer; chocolate; salad dressings; cheese; and sweetened cereal) was associated with higher daily energy intake (P<0.001, R^2 = 0.43), along with being male, having a higher alcohol intake, living with others, and a secondary education (males only) (P<0.001, R^2 = 0.16). The '**prudent**' pattern (dried legumes; soy-based foods; fresh and frozen legumes; whole grains; carrots; and

spices) was associated with a higher fibre and carbohydrate intake (both $P<0.001$, both $R^2 \geq 0.25$), along with higher physical activity and lower alcohol intake ($P<0.001$, $R^2 = 0.15$).

Neither the 'Mediterranean style' nor 'prudent' patterns were associated with either cognitive function or metabolic syndrome. The 'Western' pattern was not associated with cognitive function, but was positively associated with metabolic syndrome [odds ratio = 1 .67 (95% CI 1.08, 2.63)] ($P=0.02$).

Being younger ($P<0.05$), female ($P<0.001$), having a higher education ($P<0.01$) or no *APOE*-ε4 allele ($P<0.05$) were associated with better cognitive function. Higher deprivation ($P<0.001$) was associated with metabolic syndrome.

Conclusion: A novel and robust study with valid tools did not find any associations between dietary patterns and cognitive function in older adults living in New Zealand. Age, sex, education, and the *APOE*-ε4 allele were more predictive of cognitive function than the dietary patterns.

A 'Western' dietary pattern and higher deprivation were predictive of metabolic syndrome. To reduce the odds of metabolic syndrome, actions should aim to improve deprivation, and shift people's dietary intake away from the 'Western' dietary pattern.

Acknowledgements

The support of supervisors (and others) makes or breaks the PhD candidate. My supervisors, Kathryn Beck, Cathryn Conlon, Pamela von Hurst, and Beatrix Jones offered invaluable support and guidance. I often fell into rabbit holes and appreciate the many times they pulled me out. Thank you.

My PhD journey was conducted via the REACH study. My co-authors had already spent hours conceiving the study, applying for ethics and funding, and getting the wheels rolling. These co-authors entrusted me to take the study through its journey. I collected, analysed and wrote about the data but I was not alone, other students and colleagues helped with the data collection, the data entry of the food diaries, collecting blood, running cognitive testing sessions, and the myriad of tasks involved in this study. Thank you.

The input of the REACH study participants was incredible. Their enthusiasm for the project was gratifying. I appreciate each and everyone who gave their time to contribute to an early morning start and a challenging intellectual morning. Thank you.

Also invaluable were my student colleagues who supplied constant encouragement, companionship, and sporadic entertainment.

My thesis was also a writing journey. Massey University has an extraordinary team of people who helped to develop these skills through workshops, bootcamps, one to one consultation or writing sessions online with fellow students. Other Massey opportunities included the StrengthsFinder workshop. While I still have strengths to develop, I now understood my working style. A Massey University doctoral scholarship funded me through this journey for which I am grateful.

I have sacrificed time with loved ones during this process and am very eager to get into catch up mode once this thesis is completed.

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List of Abbreviations

4-DFR	Four-day food record
APOE-ε4	Apolipoprotein E -ε4
BMI	Body mass index
CI	Confidence interval
COMPASS	Computerised Mental Performance Assessment System
DASH	Dietary Approaches to Stop Hypertension
FFQ	Food frequency questionnaire
FFQ1	The first REACH food frequency questionnaire
FFQ2	The second REACH food frequency questionnaire (completed 1 month after the first)
FR	Food record
HR	Hazard ratio
kJ	Kilojoule
KMO	Kaiser-Meyer-Olkin test
MET	Metabolic equivalent of a task
MJ	Mega joule
MIND	Mediterranean-Dietary Approaches to Stop Hypertension (DASH) Intervention for Neurodegenerative Delay
MMSE	Mini-Mental State Examination
MoCA	Montreal Cognitive Assessment
NCEP-ATP III	National Cholesterol Education Program Adult Treatment Panel III (a metabolic syndrome definition)
OR	Odds ratio
PR	Prevalence ratio
REACH	Researching Eating, Activity, and Cognitive Health
SD	Standard deviation

List of manuscripts, conference presentations, and other contributions

Manuscripts (published, submitted, or to be submitted)

These listed manuscripts have been included in the thesis in manuscript format.

Chapter Three: published	Mumme, K., von Hurst, P. R., Conlon, C. A., Jones, B., Haskell-Ramsay, C. F., Stonehouse, W., Heath, A.-L. M., Coad, J. & Beck, K. L. (2019) Study protocol: Associations between dietary patterns, cognitive function and metabolic syndrome in older adults – a cross-sectional study. *BMC Public Health*, 19, 535. DOI: 10.1186/s12889-019-6900-4
Chapter Four: in press	Mumme, K., Conlon, C., von Hurst, P. R., Jones, B., de Seymour, J., Heath, A. L., Stonehouse, W., Coad, J., Haskell-Ramsay, C. & Beck, K. L. (2021) Relative validity and reproducibility of a food frequency questionnaire for assessing dietary patterns and food group intake in older New Zealand adults: The REACH study. *Journal of the Academy of Nutrition and Dietetics*, DOI: 10.1016/j.jand.2021.05.022
Chapter Five: published	Mumme, K., Conlon, C., von Hurst, P., Jones, B., Stonehouse, W., Heath, A.-L. M., Coad, J., Haskell-Ramsay, C., de Seymour, J. & Beck, K. (2020) Dietary patterns, their nutrients, and associations with socio-demographic and lifestyle factors in older New Zealand adults. *Nutrients*, 12, 3425. DOI: 10.3390/nu12113425
Chapter Six: under review	Mumme, K., Conlon, C., von Hurst, P., Jones, B., Haskell-Ramsay, C., de Seymour, J., Stonehouse, W., Heath, A.-L. M., Coad, J., Mugridge, O., Slade, C., Gammon, C., & Beck, K. (2021) Dietary patterns and cognitive function in older New Zealand adults: the REACH study. *European Journal of Nutrition*
Chapter Seven: under review	Mumme, K., Conlon, C., von Hurst, P. R., Jones, B., de Seymour, J., Stonehouse, W., Heath, A. L., Coad, J., Haskell-Ramsay, C., Mugridge, O., Slade, C., & Beck, K. L. (2021) Dietary patterns and metabolic syndrome in older New Zealand adults: the REACH study. *British Journal of Nutrition.*

Conference (and other) presentations

During my PhD I had opportunities to present my work as either a presentation or poster at the following conferences.

Nov 2018	Postgraduate and Early Career Nutrition Conference Auckland Oral presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L., Coad, J., Slade, C., Mugridge, O., Gammon, C., Beck, K. **Study Protocol: Associations between dietary patterns, cognitive function and metabolic syndrome in older adults – a cross-sectional study**.
Nov 2019	Postgraduate and Early Career Nutrition Conference Napier Oral presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L., Coad, J., de Seymour, J. & Beck, K. **An insight into the REACH dietary patterns and their nutrients in the older New Zealand adult**.
Nov 2019	Nutrition Society of New Zealand Annual Scientific Meeting Napier Oral presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L., Coad, J., de Seymour, J. & Beck, K. (2019) **Dietary patterns and associations with socio-demographic factors in older New Zealand adults: The REACH study**. Proceedings, 37, 40.
Nov 2019	Nutrition Society of New Zealand Annual Scientific Meeting Napier Poster presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L., Coad, J., de Seymour, J. & Beck, K. (2019) **Dietary patterns and their nutrients in older New Zealand adults**. Proceedings, 37, 38.
Dec 2020	Nutrition Society of Australia Annual Scientific Meeting Online oral presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L., Coad, J., de Seymour, J., Gammon, C., & Beck, K. **Dietary patterns were not associated with cognitive function in older New Zealand adults: The REACH study.**
Feb 2021	Massey University Oral presentation	Presentation of the REACH study results to REACH participants
Sept 2021	World Congress of Epidemiology Online oral presentation	Mumme, K., Conlon, C., von Hurst, P. R., Jones, B., de Seymour, J., Heath, A. L., Stonehouse, W., Coad, J., Haskell-Ramsay, C. & Beck, K. L. **Reproducibility and relative validity of dietary patterns in older New Zealand adults.**
Sept 2021	New Zealand Association of Gerontology / Age Concern conference – Vision for ageing in Aotearoa Oral presentation	Mumme, K., Conlon, C., von Hurst, P., Jones, M. B., Haskell-Ramsay, C., de Seymour, J., Stonehouse, W., Heath, A.-L., Coad, J., Mugridge, O., Slade, C., Gammon, C., & Beck, K. **Dietary patterns and their association with cognitive function and metabolic syndrome in older New Zealand adults.**

Other contributions

Conference organising committee	Postgraduate and Early Career Nutrition Conference (2016-2019) Nutrition Society of New Zealand Annual Scientific Conference (2019)

Candidate's contribution to the REACH[1] study

The leadership team for the REACH study are Associate Professor Kathryn Beck[2], Associate Professor Cathryn Conlon[2], Professor Pamela von Hurst[2], Dr Beatrix Jones[3], Dr Crystal Haskell-Ramsay[4], Dr Welma Stonehouse[5], Professor Jane Coad[2], and Associate Professor Anne-Louise Heath[6]. The candidate's contributions to this study and this thesis are included in listed below.

Task	Task Detail	Candidate's contribution
Trial preparation	Food frequency questionnaire	Reviewed and revised food frequency questionnaire.
		Primary input in creating the food groups for data analysis.
Recruitment (as part of study team)	Advertising	Prepared and monitored Facebook targeted advertising.
	Handling queries and screening	Assisted with study enquires (by email) and screening of participants (by telephone).
Collecting data on study days (as part of study team)	General	Candidate was part of data collection team and attended most study days.
	Anthropometry	Measured height, weight, waist and hip circumference as part of study team.
	Blood processing	Measured fasted blood glucose, lipids, HbA1c. Aliquoted plasma and serum for further sample analysis. Created and maintained register of blood samples. A primary role of candidate.
	MoCA[7] administration	MoCA to participants as part of study team.
	Questionnaire overview	Reviewed the questionnaires (health/demographic/lifestyle and physical activity data). Entered data into Excel and followed up on queries. A primary role of candidate.
	Primary cognitive testing	Assisted main administrators as required.

[1] Researching Eating, Activity, and Cognitive Health
[2] Massey University
[3] University of Auckland
[4] Northumbria University
[5] Commonwealth Scientific Industrial Research Organisation
[6] University of Otago
[7] Montreal Cognitive Assessment

Task	Task Detail	Candidate's contribution
Data clean for analysis (primary role of candidate)	Health/demographics/lifestyle and MoCA scores	Checked all data, data tables created including a data dictionary.
	Physical activity	Checked and scored all data and created data tables.
	Food frequency questionnaire	Data checked, missing data imputed, calculated g/day for each food item for each participant, data table prepared.
		Using the New Zealand nutrient database, calculated energy and nutrient intakes. Prepared data tables for both FFQ1[8] and FFQ2[9] as full data or in food groups.
	4-day food record	Entered food record data into FoodWorks (minor role).
		Checked final data quality by preparing tables/graphs to find errors and discrepancies.
		Moved FoodWorks data into required data tables e.g., apply food grouping, transforming of recipe data.
	Cognitive data from COMPASS	Cleaned and scored data. Checked data, standardised and grouped into domains.
Analysis of the data (primary role of candidate).	Participant characteristics	Prepared and analysed participant characteristics for all studies. Created tables.
	Identify dietary patterns	Created dietary patterns for all studies.
	Apply statistical analysis (dietary pattern and health outcomes)	Analysed and interpreted all data in the dietary pattern studies
	Apply statistical analysis (Validation of dietary patterns)	Analysed and interpreted all data in the validation studies
Prepare manuscripts for publication (A primary role of candidate).		Wrote manuscript text, submission letters to journal editors. Prepared tables and figures. Submitted manuscript to journals. Edited and revised manuscripts. A Statement of Contribution (DRC 16) for each published or submitted manuscript is included in the Appendix 9.1.
Communication with participants		Prepared newsletters for the participants (Appendix 9.3)

[8] REACH first food frequency questionnaire

[9] REACH second food frequency questionnaire (completed one month after the first)

Chapter One: Introduction

This chapter introduces the rationale for the thesis. Following the aims and objectives, a thesis overview provides an outline of the individual chapters.

1.1. Introduction

Healthy ageing becomes more important as the global population ages. The global population, aged over 60 years, has doubled in the last 30 years and is expected to double again by 2050 (United Nations et al., 2017). New Zealand has a similar outlook: adults over 65 years will increase from 17 to 29% of the New Zealand population by 2048 (Statistics New Zealand, 2016). This is largely due to an increased lifespan through improved healthcare. However, an increased lifespan does not always correspond with good health (Associate Minister of Health, 2016, World Health Organization, 2015), as older people are often living with diseases such as dementia (World Health Organization, 2019) or cardiovascular disease (Christensen et al., 2009). Regrettably, in the older years several health issues come from non-communicable disease which may be prevented or delayed through healthy lifestyle behaviours (World Health Organization, 2015, Livingston et al., 2020).

Cognitive function and metabolic syndrome are the two health outcomes explored in this thesis and both are associated with vascular health (Mottillo et al., 2010, Leritz et al., 2011). Cognitive function allows people to easily undertake day to day activities and naturally declines with age. Metabolic syndrome is a combination of symptoms relating to insulin resistance, dyslipidaemia, hypertension, and obesity which markedly increases the risk of cardiovascular disease and type 2 diabetes mellitus (Ford et al., 2008, Gami et al., 2007, Mottillo et al., 2010). Despite evidence for the common vascular pathology, there are mixed findings regarding a direct association between cognitive function and metabolic syndrome (Assuncao et al., 2018, Atti et al., 2019). Nevertheless, these two outcomes have similar mechanisms e.g., inflammation, oxidative stress; and risk factors e.g., age, obesity, poor diet, low physical activity (Frisardi et al., 2010, Cooper et al., 2015, Norton et al., 2014).

Ageing occurs at a cellular level where damage to DNA and a constant inflammatory state results in a gradual loss of function e.g., cognition or mobility, possibly disease, and death (World Health Organization, 2015, Chow and Herrup, 2015, Aridi et al., 2017). Older adults value quality and independence in a longer life (Blazer et al., 2015) and declining functional abilities can reduce capacity and independence. For example, impaired cognitive function or dementia is a key predictor for admission into residential care (Luppa et al., 2010). The ability of older people to age safely, independently and comfortably in their own home is favourable for the older person, their families,

and has substantial savings in health-care expenditure (World Health Organization, 2015). Hence, there are significant reasons for preserving independence in the older adult for as long as possible through maintaining cognitive function and being free from disease including metabolic syndrome (or disturbances).

One way to facilitate healthy ageing is to understand known risk factors. These may be either fixed or modifiable. Age is one fixed risk factor for cognitive decline and metabolic syndrome; sex and genetic elements are also fixed risk factors (Blazer et al., 2015, Zafar et al., 2018, Pucci et al., 2017, Wisdom et al., 2011). Socio-demographic factors are not fixed but can be difficult to modify (Moore et al., 2017, World Health Organization, 2015, Park and Strauss, 2020). Other modifiable risk factors affecting cognitive function and metabolic syndrome include the diet, physical activity, smoking, midlife hypertension and obesity, and type 2 diabetes mellitus (Norton et al., 2014, Saklayen, 2018). The effect of lifestyle and diet on cognitive decline and chronic disease, such as metabolic syndrome, is well-recognised (Cooper et al., 2015, Jayedi et al., 2020) and provides a starting point in preventing, delaying or reducing the impact of cognitive decline and metabolic syndrome in older adults.

Examining the relationship between the diet and health outcomes or disease has traditionally been undertaken using single nutrients or food groups, but this approach may have outcomes confounded by the overall complexity of the diet (Hu, 2002). Therefore, a complementary dietary pattern approach where the complete diet characterises the health outcome may be more meaningful (Slattery et al., 1998). The *a posteriori* dietary pattern approach can reduce the complexity of the whole diet into a manageable data set based on the unique eating patterns of the study population (Newby and Tucker, 2004). However, a common criticism concerning *a posteriori* dietary patterns is the subjective decisions required to derive the dietary patterns limiting the effective use of the pattens (Edefonti et al., 2019). Consequently, dietary patterns should be assessed for consistency (reproducibility and relative validity) before exploring relationships between the dietary pattern and health outcome. Assessing the consistency of a dietary pattern involves examining the ability of the dietary assessment tool, usually a food frequency questionnaire (FFQ), to derive dietary patterns. The dietary patterns from the test FFQ are typically compared to dietary patterns derived from a second administration of the test FFQ (to assess reproducibility) and a food record (to assess relative validity).

Despite the limited number of dietary patterns being assessed for consistency (Edefonti et al., 2019), dietary patterns have been associated with cognitive function and metabolic syndrome in older adults. Some evidence suggests dietary patterns with healthy food groups are beneficial for

cognitive function, slowing cognitive decline or reducing dementia outcomes in the older population (Milte and McNaughton, 2016, Chen et al., 2018, van de Rest et al., 2015) and may reduce the risk of metabolic syndrome in the general population (Fabiani et al., 2019, Jayedi et al., 2020, Rodriguez-Monforte et al., 2017). Conversely, dietary patterns with unhealthy food groups may increase the risk of metabolic syndrome in the general population (Fabiani et al., 2019, Jayedi et al., 2020, Rodriguez-Monforte et al., 2017). The above results look promising, but the evidence for metabolic syndrome is low to moderate and with a possibility of publication bias (Jayedi et al., 2020). With regards to cognitive health, there is high heterogeneity in the methods including the measurement of cognitive function and the selection of confounders used in the statistical analysis (Milte and McNaughton, 2016, Chen et al., 2018, van de Rest et al., 2015). More conclusive evidence is required to create targeted and detailed guidelines to maintain cognitive and metabolic health in older adults (van de Rest et al., 2015, Jayedi et al., 2020).

Dietary patterns are useful in public health as people can more easily comprehend and apply the food groups of a dietary pattern rather than single nutrients (Slattery, 2010). Also, by describing dietary patterns according to socio-demographic population groups and lifestyle behaviours, dietary interventions can be targeted towards the identified and at-risk population groups. Further, dietary patterns can be described based on their associated nutrients which may be useful in understanding any observed relationships between the dietary pattern and health outcome or disease (Hu et al., 1999).

A posteriori dietary patterns are specific to the study cohort; therefore, it is important to derive dietary patterns from many populations and sub-population groups (Hu, 2002). Researchers have not yet identified dietary patterns or explored the associations between dietary patterns and cognitive function and metabolic syndrome in the older New Zealand adult.

1.2. Study aim and objectives

The aim of the REACH (Researching Eating, Activity, and Cognitive Health) study is to examine associations between dietary patterns and cognitive function, and dietary patterns and metabolic syndrome in older New Zealand adults. Objectives are to:

1. Use a food frequency questionnaire to derive dietary patterns in the older New Zealand adult and calculate the nutrient and energy intake to determine their associations with each dietary pattern.

2. Examine the reproducibility and relative validity of both the food frequency questionnaire and the derived dietary patterns to ensure the food frequency questionnaire can derive robust dietary patterns.
3. Examine associations between dietary patterns and cognitive function.
4. Examine association between dietary patterns and metabolic syndrome.
5. Examine associations between dietary patterns and socio-demographic and lifestyle factors.

1.3. Overview of the thesis

This overview gives an outline of the individual chapters in this thesis. The first chapter, Chapter 1 – **Introduction**, provides the basis of the study and the context in which the study fits. This chapter introduces dietary patterns and health outcomes. The aims and objectives are detailed for the thesis and the REACH (Researching, Eating, Activity, and Cognitive Health) study.

The second chapter, Chapter 2 – **Review of the literature**, contains six sections. The first section discusses the **exposure; dietary patterns** – what are they, why dietary patterns should be used and how dietary patterns are created. The second section discusses the **outcomes; cognitive function and metabolic syndrome** – what they are, how they are defined and how they are measured. The third section examines the literature behind the **reproducibility and relative validity** of dietary assessment tools used to determine dietary patterns to ensure they are robust. The fourth section covers literature on the relationship between **dietary patterns and socio-demographic and lifestyle factors**. The fifth section details the literature on associations between **dietary patterns and cognitive function/cognitive decline** in older adults. The final section explores current literature on **dietary patterns and their association with metabolic syndrome**. Where relevant all literature has a focus on the older adult.

Chapter 3 – Study protocol, covers the **methodology** and is presented as the published protocol manuscript. The chapter contains data collection methods for dietary, demographic, health, and biochemical data and also includes the method to derive the dietary patterns. Methods for collecting health outcome data is explained. Finally, statistical methods used for exploring the associations between the dietary patterns and health outcomes are outlined.

The manuscripts of several outcomes from the REACH data are included in chapters 4 to 7. These each include some background, methodology, results, and discussion section. Chapter 4 examines the **relative validity and reproducibility** of the dietary assessment tool used to collect the dietary data and the resulting dietary patterns. Chapter 5 introduces the REACH dietary patterns according to their food groups and nutrient content. This chapter also describes the associations between the

dietary patterns and socio-demographic and lifestyle factors. Chapter 6 addresses the main aim of the REACH study. Here, associations between the **dietary patterns and cognitive function** are detailed. Chapter 7 covers the second aim of the REACH study and explores associations between **dietary patterns and metabolic syndrome**.

The final chapter, Chapter 8 – **Discussion and conclusions**, brings the contents of the thesis together. It reviews the initial rationale behind the study, discusses the overall results, strengths and limitations and the implications of these results. The final chapter determines what the next step is in this area of research.

To close the thesis, the **appendix** includes sections related to the completion of this thesis. For example, the dietary assessment tool, questionnaires and the REACH newsletter.

Chapters 3, 4 and 5, are stand-alone peer-reviewed, published academic journal articles, whereas Chapters 6 and 7 are currently under peer-review. Due to the nature of these Chapters, there may be some repetition of background, methodology or discussion points.

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Chapter Two: Review of the literature

The second chapter contains six sections. The first two sections give an outline on dietary patterns, cognitive function, and metabolic syndrome. The third section reviews the literature on the validation of dietary patterns. The fourth section looks at the literature regarding dietary patterns and their associations with socio-demographic and lifestyle factors. Finally, the literature is reviewed on associations between dietary patterns and both cognitive function and metabolic syndrome.

2.1. Dietary patterns, their construction, and the assessment of dietary intake

This section explores dietary patterns: what they are and how they are derived. It describes the different dietary pattern analysis methods before delving into dietary pattern construction including collecting the dietary data and the subjective decisions made to turn complex data into useful and meaningful information in order to be able to explore dietary pattern and health outcome associations.

2.1.1. Why we have dietary patterns

The dietary pattern or eating pattern is described as "foods as they are actually consumed in various characteristic combinations" (Schwerin et al., 1982), providing an overview of the total diet and eating behaviour (Jacobs and Steffen, 2003). It is a 'top-down' approach in nutritional science, an alternate and complementary approach to the traditional 'bottom-up', single or grouped foods, macro- or micro-nutrients approach (Jacobs and Steffen, 2003).

KEY POINTS

- Dietary patterns can be used to explore associations between diet and health outcomes or disease.
- The *a posteriori* approach to dietary patterns requires several subjective decisions.
- Guidelines are required to improve methods and establish consistent methodology.

While the traditional 'bottom-up' approach makes a valued contribution to nutritional science, there are limitations to this method. A dietary pattern can address these limitations by acknowledging:

- the complexities of dietary intake and their associated biochemical interactions as important (Milte and McNaughton, 2016, Hu, 2002),
- people consume a diet consisting of many foods, not isolated nutrients (Jacobs et al., 2009),
- correlations between nutrients or foods can make it difficult to separate their effects e.g., potassium and magnesium (Lee et al., 1988),
- the effect of a single nutrient may be too small to detect but the cumulative effect of many nutrients found in a diet may be sufficiently large to be detected (Sacks et al., 1995, Appel et al., 1997),
- the interactions between nutrients may amplify or nullify the initial effect of a single nutrient (Sacks et al., 1995),

- an unknown food combination may have an effect on the outcome (Sacks et al., 1995),
- statistical analysis of many nutrients may find association by chance, whereas reducing dietary intake into a few dietary patterns removes this 'chance' (Hu, 2002),
- multicollinearity is apparent with many nutrients or food groups, but this is an advantage in dietary pattern analysis (Hu, 2002), and
- the single nutrient or food group approach may have outcomes confounded by the overall complexity of the diet (Hu, 2002).

The ability of the dietary pattern to characterise the relationship between diet and health outcomes or disease may surpass that of the individual nutrient or food groups (Slattery et al., 1998, Mozaffarian, 2016). To date, dietary patterns have examined associations with many health outcomes including: chronic disease (Jayedi et al., 2020), cardiovascular disease (Rodriguez-Monforte et al., 2015), type 2 diabetes mellitus (Jannasch et al., 2017), metabolic syndrome (Fabiani et al., 2019a, Rodriguez-Monforte et al., 2017), cognitive function and/or risk of dementia (Liu et al., 2020, van de Rest et al., 2015, Chen et al., 2018), bones and fracture risk (Fabiani et al., 2019b), and sarcopenia (Bloom et al., 2018). This conceptual understanding of the diet is useful in public health (Newby and Tucker, 2004) as a dietary pattern is more easily translated to the public and is less prescriptive to follow (Slattery, 2010, Dietary Guidelines Advisory Committee, 2015b) compared with eating based on nutrient intake recommendations.

This section explores the differences in methods used to determine dietary patterns and reviews dietary assessment methods for collecting dietary data. The construction of *a posteriori* (empirical or data-driven) dietary patterns, methodological issues and validation are discussed with a focus on dietary patterns derived using principal component analysis. The limitations of the *a posteriori* dietary pattern are presented and finally, a conclusion discusses and suggests further research in this area.

2.1.2. Methods to derive dietary patterns

An individual's diet is diverse, synergistic, and dynamic (Reedy et al., 2018). The idea of simplifying this complex array of foods can be overwhelming. Dietary pattern analysis turns many lines of dietary data into dietary information which can be used in nutritional research or more specifically, studies investigating associations between diet and health outcomes or disease. Those 'lines of dietary data' may come from older studies (Oh and No, 2018) where dietary pattern analyses can add depth and value to existing research. Dietary patterns are derived by one of three methods – *a priori, a posteriori*, and hybrid methods. These three methods are discussed below followed by their strengths and weaknesses.

2.1.2.1. A priori – guided by the research

A priori dietary patterns are based on current nutritional knowledge where a dietary index is created. The index ranks an individual's adherence to dietary guidelines (e.g., US dietary guidelines) or a dietary pattern (e.g., the Mediterranean Diet Index) or a diet specific to disease prevention e.g., Dietary Approaches to Stop Hypertension (DASH) (Sacks et al., 2001). This method relies on a good understanding of the relationship between the diet and the health outcome or disease which, in some instances, may not represent the best or current available evidence (Hu, 2002).

2.1.2.2. A posteriori – guided by the dietary data

A posteriori dietary patterns are not predefined nor limited by current knowledge but are extracted from the specific dietary data of the study population to provide a better understanding of eating behaviours and a unique view of dietary intake (Newby and Tucker, 2004). A statistical approach is applied to the complex dietary data with an aim to reduce a larger data set into easily comprehensible dietary patterns (Newby and Tucker, 2004). Two common approaches used are factor analysis which groups the variables (e.g., food groups) based on a pattern of variation and cluster analysis which groups the individuals into homogenous sub-groups. The methods are exploratory and hypothesis generating rather than hypothesis confirming.

Factor analysis

Factor analysis includes principal component analysis and exploratory (or common) factor analysis (Hu, 2002, Jannasch et al., 2018, Edefonti et al., 2019). The difference between the two methods is subtle and hidden in the maths but both methods aim to reduce the data (Field, 2018). Overall, factor analysis is suitable for linear regression and capable of detecting associations between dietary patterns and health outcomes (Tucker, 2010).

Exploratory factor analysis is only interested in the common variance among the food groups and finds linear combinations of latent (hidden) patterns (Agnoli et al., 2019). On the other hand, principal component analysis includes all variances (unique, common and error) in the analysis. Principal component analysis identifies linear combinations (factors) of food groups or nutrients which can account for the largest variation, between individuals, in the diet (Agnoli et al., 2019). Despite their slight differences the factors derived from the two techniques are similar (Michels and Schulze, 2005, Guadagnoli and Velicer, 1988), though principal component analysis is the preferred *a posteriori* method (Edefonti et al., 2019).

Cluster analysis

Cluster analysis, using either *k*-means or Ward's clustering methods (Smith et al., 2011), produces dietary patterns based on differences between the study participants. Ward's method is designed to

minimise the variation within each cluster and *k*-means aims to maximise the variation between the clusters. Each participant belongs to only one homogenous cluster based on similar eating patterns (Smith et al., 2011) and the dietary pattern score is categorical.

2.1.2.3. Hybrid methods

Hybrid methods combine both *a priori* and *a posteriori* methods by using the known knowledge of a response variable, e.g., known nutrient, anthropometry measurement or biomarker, associated with a health outcome to identify patterns, using statistical analysis, in a specific study population (Ocké, 2013). By building on *a priori* knowledge the health outcome can be explored in relations to its aetiology (Ocké, 2013). However, incomplete knowledge can be a limitation so the response variable should be causal rather than predictive (Ocké, 2013). The most used hybrid method is reduced rank regression which finds linear combinations of the food groups with a focus to explain the greatest variation from a set of response variables related to a health outcome (Agnoli et al., 2019, Hoffmann et al., 2004), e.g., plasma carotenoid to explain cognitive decline (Kesse-Guyot et al., 2014). Another, less popular, hybrid method is partial least squares regression, similar to reduced rank regression except the patterns aim to explain maximally the variation in both the response and the dietary variables (Ocké, 2013).

2.1.2.4. The strengths and limitations of the main dietary patterns

Each dietary pattern method has strengths and weaknesses. These are summarised in Table 2.1.

Table 2.1: Strengths and limitations of the main dietary pattern methods

	A priori	*A posteriori* Factor analysis	*A posteriori* Cluster analysis	Hybrid Reduced rank regression
Strengths	• Pre-defined and simple to calculate. • Index is based on available knowledge. • Many indices are validated. • Can be used with individuals or a large population. • Easily comparable. • Indices are translatable and can be applied to public health messaging.	• Not limited to current knowledge. • Unique view of a populations eating patterns. • Pattern can be described by food groups or nutrients. • A nutrient pattern may help determine mechanisms of any association. • Each participant receives a score for all dietary patterns.	• Not limited to current knowledge. • Based on differences between individuals of the study population. • Clear description of each pattern (cluster) including mean intake (if available).	• Patterns consider both diet (food groups or nutrients) of study population and known biomarkers and variables associated with disease outcome (response variables). • Variation in the diet can be explained by both the dietary data and the chosen response variables. • Predicting variable based on known scientific knowledge thus supporting study of biological pathway.
Limitations	• Index may be based on out-dated knowledge. • Full complexity of diet may not be captured where foods and food groups are limited. • Foods or food groups chosen (or not) by index may introduce bias.	• Statistical modelling needed. • Bias may be introduced by analytical decisions in deriving patterns. • Patterns are specific to a study population and not always easy to compare. • May only explain a small segment of the total variation within the diet.	• Statistical modelling needed. • Clusters are mutually exclusive - participants will belong to one cluster only. • Large sample size required as mutually exclusive groups may reduce statistical power. • Patterns are specific to a study population and not always easy to compare. • Sensitive to outliers and minor changes.	• Statistical modelling needed to create and validate pattern. • Requires a reasonable sample size.

2.1.3. Obtaining the dietary data

There are many methods to assess dietary intake. Awareness of the strengths and limitations of each method reduces the challenges when choosing the appropriate dietary assessment tool (Dao et al., 2019). The main method for collecting dietary data, for dietary patterns, is the food frequency questionnaire (FFQ) (Jannasch et al., 2018, Rodriguez-Monforte et al., 2017, Milte and McNaughton, 2016, Chen et al., 2018) although other methods are also used, for example, 24-hour recalls (Oh and No, 2018), food records (Kesse-Guyot et al., 2014) or a retrospective FFQ – Lifetime Dietary Questionnaire (Hosking et al., 2014). The best method for a study will depend on the cost, the particular dietary components studied e.g., whole diet or nutrient intake, precision required, participant's life stage, resources available and level of participant burden (Cade et al., 2017). Four common dietary assessment tools are discussed below.

2.1.3.1. Food frequency questionnaire

The FFQ was developed in the 1950's. The use of the FFQ waned over the following decades but regained popularity in the 1980's to become a primary tool to assess longer term dietary intake in epidemiologic studies (Willett, 2012b). The concept behind the FFQ is to capture a 'generic' view of the longer-term diet as opposed to a precise 'episodic' view of a specific number of days. The FFQ is suitable for studies where ranking of participants is required rather than absolute nutrient values (Willett, 2012b). The FFQ achieves this through a questionnaire containing a list of foods (with or without serving size) where participants indicate the frequency of consumption over a specified period. The FFQ period, perhaps one year or one month, should be based on the outcome being studied. For example, a one-month time frame is suitable for plasma high density lipoprotein cholesterol because the change in this blood lipid can be observed over a short period (Willett, 2012b). However, a short period may not take into account seasonal variation (Thompson and Subar, 2017).

Ideally, an FFQ needs to be developed and validated for the specific population group for which it is intended. It can be arduous to design a new FFQ for every study, thus modifying a current validated questionnaire can save time and resources (Cade et al., 2002). Modifications to the original FFQ should consider the differences between the original and the new population group, e.g., differences in ethnicity and age. The dietary data required in the new group may be different to the original population so changes to the food list, frequency, and time covered may need attention. Indeed, all FFQ's should be reviewed regularly as dietary preferences and food availability change.

The main considerations for the design of an FFQ are the food list, clarity of the questions, and the format of the response section. The food list should cover foods eaten by the population being

studied and contain sufficient foods to target any nutrient(s) or food group(s) of interest. A diverse food list will allow adequate ranking of the FFQ data and should be sufficiently meaningful depending on the objectives of the study (Willett, 2012b), for example is 'milk' sufficient or would 'low-fat milk', 'high-fat milk' be more meaningful? A comprehensive food list is preferred with the aim of capturing a significant array of foods without losing the focus of the study participants – 130 food items is considered a reasonable limit (Willett, 2012b). With a comprehensive food list, energy intake may be calculated and used to determine misreporting or as an adjusting factor. An additional final open-ended question allows the capture of any additional foods (Beck et al., 2020). There may be exceptions where the whole diet is not the focus and a short FFQ may be suitable e.g., screening for a specific nutrient intake (Willett, 2012b).

Questions (food items) in the FFQ should be clear. Some foods are used in many ways e.g., milk in hot drinks and on cereal. Here, the serving size may vary between one tablespoon to half a cup and the frequency may vary between four times a day for milk in hot drinks to once a day for cereal. While serving sizes can add clarity, if the question is not clear participants may ignore the serving size and select a frequency to suit their perceived serving size (Cade et al., 2002).

Depending on information required, FFQ response categories can be dichotomous (consumed, not consumed) or a frequency over a period (once a week, twice a day, etc). The number of frequency responses is important. Five frequencies may be too few, missing useful information, but too many frequencies may distort values (particularly with foods eaten once or several times per day) when calculating daily nutrient or food group intake (Willett, 2012b, Cade et al., 2002). The response categories should allow for accurate collection for high frequency foods (e.g., coffee) and less frequently consumed foods (e.g., liver) (Willett, 2012b).

The FFQ may minimise day to day variability errors, but this will be replaced by errors of estimation and averaging intake over longer time periods. Bias will be introduced through an incomplete list of foods and errors in estimating frequency and serving sizes. The bias from an FFQ can be minimised through clear instructions and question wording, providing examples (e.g., answered question samplers or pictures of serving sizes), and protocols for trained administrators to follow (Willett, 2012b). Pilot testing an FFQ provides feedback on clarity of the questions. The effectiveness of the FFQ should be tested for reproducibility and validity or the degree to which the FFQ measures the true dietary intake with multiple 24-hour recalls or a food record on a subset of the population (Cade et al., 2002). Nutritional databases used to calculate energy intake and nutrient values from all dietary assessment methods have limitations (Willett, 2012c), however extra measurement error

may occur with the use of an FFQ because the values used rely on serving sizes and a suitable representative food for nutrient and energy values.

2.1.3.2. Food records

The concept behind the food record is to record actual food and serving sizes at the time of consumption. The food record is suitable in studies where absolute values of nutrient and energy intake are required (Willett, 2012a) e.g., comparing a populations nutrient intake with Nutrient Reference Values. With adequate participant training this method has the potential to collect accurate, quantifiable information as foods are consumed, thus eliminating memory issues, and recording more accurate quantities than an FFQ. If there is an opportunity for a researcher to review the record at collection time, errors can be reduced further by probing questions about items that are often missing, such as butter, salt added to vegetables or cooking methods (Thompson and Subar, 2017).

The number of days a food record covers is a fine balance between a participant staying motivated and collecting enough variety in the diet to minimise errors. Four to five days is considered a reasonable compromise between scientific rigour and participant practicality (Willett, 2012a). Eating over consecutive days is not independent of the previous day, for example, leftovers may be eaten over several days (Thompson and Subar, 2017). This day-to-day variability can be a source of error in food records and specific associations may be undetected (Sempos et al., 1985).

Logging a food record is burdensome. The food record may not accurately reflect the true eating behaviour as participants may change their eating behaviour to simplify the process; or choose to eat socially acceptable foods e.g., a salad sandwich rather than a pizza; or change their diet due to an awareness of what is eaten (Thompson and Subar, 2017). The use of scales increases the burden further and can result in a poor response rate. However, a weighed food record is more accurate: an estimated food record may result in underreporting of around 20% (Willett, 2012a). Under reporting can be reduced by providing verbal and written instructions to participants, emphasising timely reporting and the importance of accuracy for quality research (Willett, 2012a).

There are costs associated with processing food records and quality control e.g., probing is required for accurate data and entering the data is time consuming. Technological approaches can reduce this burden where mobile apps or wearable cameras record participants' food choices concurrently, however images still need to be analysed and connected to a food database (Willett, 2012a, Thompson and Subar, 2017).

2.1.3.3. 24-hour diet recall

The concept behind the 24-hour recall is to collect data on foods and drinks consumed in a 24-hour period and provide absolute values for nutrient and energy intake (Willett, 2012a). Dietary data from the 24-hour recall is collected by interview either in person, by telephone or via computer questionnaire which significantly reduces costs. For example, the ASA24® dietary assessment tool is an automated, self-administered 24-hour recall with prompts, serving sizes and a link to the USDA (United States Department of Agriculture) nutrient database (Thompson and Subar, 2017). Person to person interviews (20 – 30 minutes) require a skilled researcher to collect the data. The interviewer will ask probing, usually open-ended questions to gather detailed information on foods eaten and their preparation method (Thompson and Subar, 2017). A 24-hour recall relies on the participant's ability to accurately recall foods and the serving sizes eaten in the last 24 hours. Errors can be minimised by using techniques to assist recall such as a multiple pass method to set the stage by enquiring briefly about what was eaten in the last 24 hours; enquiring about any missing foods; asking about time and consumption of foods; and probing for specific details to complete the picture (Thompson and Subar, 2017). Further errors can be minimised by using food models, photographs, and household measures to quantify serving sizes (Thompson and Subar, 2017). To truly capture a representation of the participant's diet and maximise day to day variation between participants, 24-hour recalls should be collected on random days (Thompson and Subar, 2017, Willett, 2012a).

A single 24-hour recall is appropriate where an estimate of the population mean intake of a nutrient or food group is required. The sample size should be sufficiently large and represent all days of the week. In contrast, multiple 24-hour recalls are required to estimate the distribution of individual intakes e.g., where the proportion of individuals below a reference point for recommended intake of a nutrient or food group is required.

2.1.3.4. Diet history questionnaire

A diet history questionnaire, like the FFQ, collects dietary data retrospectively. Not only does this questionnaire collect food frequency data but also details on foods typically eaten over the course of a day, including food preparation methods. The questionnaire may be automated and self-administered or collected by a trained interviewer. Regardless, this meal-based approach was once popular in the 1990s but used to a lesser extent now (Thompson and Subar, 2017). It is often used in the clinical setting.

2.1.3.5. Other considerations

Dietary assessment tools may need to be modified where a participant has: a cognitive or memory impairment; poor dentition, hearing, or vision impairment; or a chronic illness and requires a special

diet (Thompson and Subar, 2017). Here, dietary assessment methods may need to be flexible by combining methods, probing more with regards to methods to prepare or consume foods, or using a suitable proxy such as a caregiver (Saldiva et al., 2017, Thompson and Subar, 2017). For the older, physically, and mentally healthy adult usual methods of dietary assessment are still appropriate (Volkert and Schrader, 2013).

Missing values may occur with FFQs. Dietary pattern analysis using a FFQ requires a complete dataset. There are several approaches for dealing with missing values. The missing values can be imputed as zero, a median value, or through a multiple imputation technique (Parr et al., 2008, Abellana Sangra and Farran Codina, 2015). Multiple imputation is better than null imputation where missing values are a low percentage of the data (Ichikawa et al., 2019). Imputing anything other than zero, will increase nutrient and energy intake suggesting imputing null values will underestimate dietary intake (Parr et al., 2008). When dietary data is collected digitally, the occurrence of missing values can be controlled with validation rules i.e., a rule which does not allow a question to be skipped (Abellana Sangra and Farran Codina, 2015).

Collecting dietary data is fraught with errors, therefore all new and modified FFQs should be validated. To confirm reasonable accuracy of the dietary data, the FFQ must be examined for reproducibility and relative validity in a sub sample of the study population. Reproducibility refers to repeating the measurement of dietary intake and understanding the conditions will be different to some extent at each administration (Willett, 2012e). Whereas the measure of relative validity ensures the FFQ is actually measuring what it is supposed to by comparing it with another dietary assessment tool (e.g., food record) which has independent errors to the FFQ (Willett, 2012e).

2.1.3.6. The strengths and limitations of dietary assessment methods

Each dietary assessment tool has strengths and weaknesses. These are summarised in Table 2.2.

Table 2.2: Strengths and limitations of dietary assessment methods

	Food frequency questionnaire	Food record	24-hour recall	Diet history questionnaire
Strengths	• Self-administered and low burden on participants and administrators. • Online questionnaires are cheaper, eliminate processing steps, reduce missing data, and edit checks during data entry. • Covers the diet retrospectively. • Eating behaviour is not affected.	• Does not rely on memory. • Absolute values, rather than relative, are produced. • Allows any food, food source, or preparation method. • Sensitive to many distinct groups e.g., ethnic or age group.	• Smaller participant burden compared with food record. • Eating behaviour is not affected. • Short recall window makes method available to a wider population sample. • Participant's literacy is not required if interviewer collects data. • Technological options available to automate data collection.	• Small participant burden. • Eating behaviour is not affected.
Limitations	• Food list is finite. • Provides a crude list of intakes suitable for ranking rather than absolute values. • Cooking methods and meal combinations not captured. • Bias may be present through choice of what to report and may be subject to under-reporting. • Relies on memory. • May be cognitively challenging to understand questions, serving size and frequencies.	• Sample selection is limited to motivated and literate participants. • Eating behaviour may change. • Increased participant burden. • Costs associated with entry of data. • May be subject to under-reporting.	• Relies on memory. • Method may be subject to selective and under-reporting. • Cost associated with interviewer and data entry. • One day not representative of an individual's intake.	• Relies on memory. • Cost associated with interviewer and data entry. • Not well standardised, difficult to reproduce and compare with other studies. • May be subject to under-reporting.

2.1.4. Constructing a dietary pattern using principal component analysis

Constructing dietary patterns from a dietary assessment tool involves many subjective decisions which can create bias and affect the type and number of patterns derived (Martinez et al., 1998). There are two stages in dietary pattern analysis. The first involves the preparation of the data and the second stage is the statistical analysis.

TERMINOLOGY

- Dietary pattern = factor.
- Input variable e.g., food groups = (factor) loadings.
- An **eigenvalue** is a measure of the variation explained by a pattern.

2.1.4.1. Decisions before construction

One pre-dietary pattern decision involves **quantifying the dietary data** prior to input into the analysis. There are several input options depending on the method for collecting the dietary data. The input variable can be a food, food group or nutrient and calculated as a continuous variable (g (or mg)/day, energy adjusted g/day, % of total energy contribution) or a categorical variable (frequency of consumption or consumed/not consumed).

The method used will depend on why the data were collected and the purpose of the dietary patterns. Categorical or dichotomous variables are used when food preference or diet diversity is the main concern. Moreover, when nutrients are the input variable, patterns are effectively characterised by the nutritional content of the diet and patterns are more comparable with each other by common nutrient groups (Allès et al., 2016). Using a '% of the total energy contributed' input variable means dietary patterns are in proportion to energy intake but foods with low energy are not well considered e.g., diet drinks, water, coffee, and tea (Newby and Tucker, 2004). Whether a continuous variable (regardless of energy adjustment) or a categorical variable is used, meaningful dietary patterns can be obtained through principal component analysis (Smith et al., 2013).

It is common to **group the food items**, from any dietary assessment tool, into food groups. The food groups are represented in the dietary pattern as factor loadings and the higher the loading the more correlated the food group is to the dietary pattern. The grouping of the food items is another subjective decision. Food groupings are typically based on similarities of food items in both their nutrients and culinary use as well as any expected links to the health outcome or disease being explored (Newby and Tucker, 2004) e.g., oily fish may be a separate food group to other fish when cognitive function is an outcome.

The number of food groups determines the amount of variation in the diet explained by the dietary patterns (% variation in the diet = eigenvalue/number of food groups). A systematic review of 38 dietary pattern studies reports a median of 31 food groups (Edefonti et al., 2019) but food groupings can range from 25 to 99 (Schulz et al., 2021). Less food groups in the dietary pattern will explain more of the variation in the diet, whereas more food groups will explain less variation in the diet but will retain more information and may determine more precise estimates of disease risk compared with dietary patterns derived from a smaller number of food groups (McCann et al., 2001, Ashby-Mitchell et al., 2015).

Dietary patterns can be difficult to compare due to the heterogeneity of the food groups (Dietary Guidelines Advisory Committee, 2015a). Food grouping will differ between ethnic and geographical regions. Care needs to be taken to group the food items equally so one food item is not over-represented. For example, in one study, from Botswana, the primary dietary pattern (eigenvalue >4) had four (out of 21) food groups containing beer. These four food groups had substantial loadings greater than 0.60 (Maruapula and Chapman-Novakofski, 2007).

Another subjective decision is whether the input variable should be **adjusted for energy intake** prior to analysis. Energy intake is normally adjusted for in studies examining the relationship between dietary intake and health outcomes. This reduces the variation in the dietary intake resulting from differences in body size, physical activity levels and metabolic efficiency (Willett, 2012d). Using a non-adjusted input variable and including energy as a confounder is an acceptable method (Willett, 2012d) but there is also an option for adjusting the input variable for energy intake prior to dietary pattern analysis.

There are arguments for and against an energy adjustment of the input variable. An energy adjusted input variable derives iso-caloric dietary patterns which may make dietary pattern comparison easier (Willett, 2012d) though patterns will be more represented by energy-dense food groups (Balder et al., 2003). Also, any outcome associations are more likely to be from the effect of food choices *per* se rather than the effect of food choices and energy intake (Bamia et al., 2005, Northstone et al., 2008, Willett, 2012d). On the other hand, dietary intake and energy are highly correlated and these correlations drive the factor analysis. Adjusting the input variable for energy prior to analysis reduces the correlations and the quality of the data for analysis (Northstone et al., 2008). By allowing for an energy adjustment later in the analytic process i.e., as a confounder, there is the opportunity to better assess the effect of energy intake (Smith et al., 2013). A recent systematic review reported similar outcomes for factor and cluster analysis patterns regardless of whether the input variables were energy adjusted or not (Edefonti et al., 2019).

Yet another decision is whether to analyse **males and females separately or together**. Males and females make different food choices (Hartmann et al., 2013) and it is often reported females are more likely to follow a healthier eating pattern than men (Newby and Tucker, 2004, Beck et al., 2018). The question arises whether dietary patterns should be created separately for each sex. Studies have used different approaches to derive dietary patterns with consideration of sex. Either the full data set is used to create one set of dietary patterns, or the data set is split to derive dietary patterns for males and females (Chen et al., 2020). Sometimes dietary patterns are created for each sex and if the patterns are similar, the full data set is used to derived dietary patterns (Andreeva et al., 2016, Judd et al., 2014, Eng et al., 2018, Park et al., 2005, van Dam et al., 2003, Bamia et al., 2005) otherwise, the sex-specific dietary patterns are retained for the analysis (Thorpe et al., 2016). Where the dietary patterns are constructed from the full data set, sex should still be accounted for in the statistical analysis either by stratification (Andreeva et al., 2016) or (more commonly) adjusting as a confounder and testing for sex interactions.

It is a similar for **ethnicity** where correlations between food groups can differ between ethnicities e.g., beans eaten with corn in people from Mexico. This may result in different dietary patterns between ethnicities. In the REGARDS study (Reasons for Geographic and Racial Differences in Stroke) (*n* 21,636), extra statistical tools were employed to determine the best method to derive dietary patterns based on race, gender, and region (Judd et al., 2014). The outcome was one set of dietary patterns which meaningfully described the study population. In the New Zealand context, the diets of Māori and non-Māori are often similar with some minor differences e.g., Māori consumed a higher percentage of energy from total fat than non-Māori (Ministry of Health, 2012). Where dietary patterns have been derived from a representative population of New Zealanders, a 'healthy' pattern was more likely to be followed by 'New Zealand European and other' but no differences between ethnicity were seen with a 'traditional' pattern (Beck et al., 2018). While ethnicity in dietary patterns requires further research, ethnicity should always be considered as a confounder.

One last step before dietary pattern analysis is to assess the **adequacy of the dietary data for analysis**, that is, are there adequate correlations between the input variables to produce dietary patterns representative of the data set. At this point, the dietary data undergoes correlation analysis to become a correlation matrix. The suitability of the correlation matrix can be measured with two tests. The Kaiser-Meyer-Olkin measure of sampling adequacy (usually abbreviated as KMO) measures the relative compactness of the correlations (Kaiser, 1970) and the Bartlett's test of sphericity measures whether the correlations within the matrix are significantly different to a matrix with nil correlations (Tobias and Carlson, 1969).

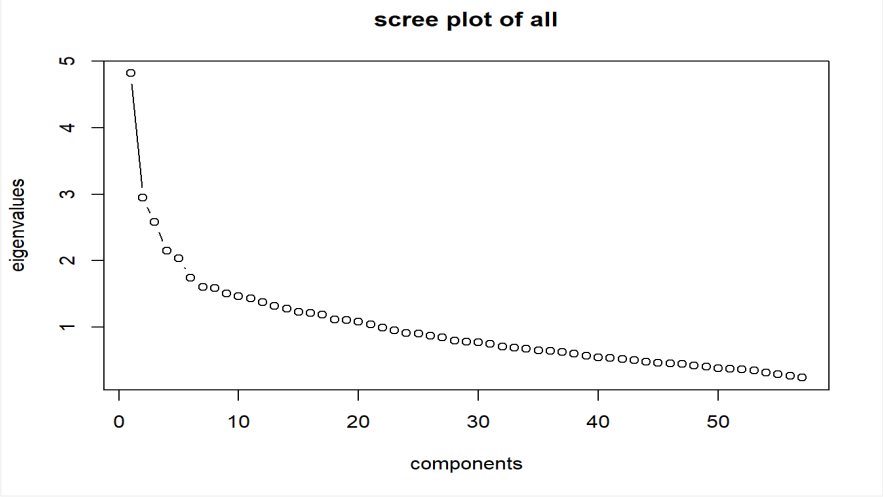
2.1.4.2. Decisions during construction

Principal component analysis will create a factor (dietary pattern) for every input variable (e.g., food group) to explain 100% of the variation in the diet. It is not always practical to include all the factors in the analysis, so the number of factors is specified to improve results. The first subjective decision in analysis is deciding how many **factors to retain** and is based on:

- eigenvalues >1, where an eigenvalue is a measure of the variation explained by a pattern. The variance explained is the eigenvalue divided by the number of food groups (Field, 2018).
- a scree plot (Cattell, 1983) (Figure 1) where eigenvalues are plotted for each factor. The elbow of the eigenvalues distinguishes between relatively larger and smaller eigenvalues.
- interpretability of the factors e.g., minor factors may have less food groups loaded.

Figure 1: An example of a scree plot

A scree plot from a dietary pattern analysis of 57 food groups (x-axis). Three dietary patterns can be selected from this scree plot as dietary patterns #4 onwards represents less and less of the variation in the diet.



The second subjective decision is if to and how to '**rotate**' the factors. 'Rotating' the factors improves the interpretability of the factor by allowing loadings to be maximised on the factor to which they correlate best, resulting in food groups (or nutrients) favouring one dietary pattern over another (Michels and Schulze, 2005). There are two methods of rotation - orthogonal and oblique. Orthogonal or varimax rotation is commonly used and assumes the underlying factors are independent of each other, whereas oblique rotation is used when the factors are related. A comparison study between dietary patterns rotated using varimax and oblique rotation reported no differences in outcomes (Qin et al., 2015, Shakersain et al., 2016).

The third subjective decision is the **naming** of the dietary pattern. There are two common dietary pattern naming conventions. Either, by the food groups with the highest factor loadings or by a conventional name such as 'prudent', 'healthy', 'Western' or 'traditional' which aims to characterise the dietary pattern. These names give a general insight into what the dietary pattern contains. 'Prudent' and 'healthy' are likely to contain high loadings of fruits, vegetables, poultry, fish, whole grains, olive oil, nuts, and seeds (Fabiani et al., 2019a, Rodriguez-Monforte et al., 2017) and 'Western' and 'traditional' are likely to contain red and processed meats, refined grains, animal fat, sweetened beverages, and convenience foods (Slattery et al., 1998, Rodriguez-Monforte et al., 2017, Fabiani et al., 2019a). However, there are discrepancies where food groups may be considered healthy in one dietary pattern but unhealthy in another e.g., cheese, wine, potatoes, rice, or milk (Rodriguez-Monforte et al., 2017). Therefore, methods to rank or grade the food groups (healthy to unhealthy) needs to be considered possibly 'based on world-wide recommendations' (Rodriguez-Monforte et al., 2017).

2.1.4.3. Can the dietary patterns be used in studies with confidence?

As discussed earlier, using valid dietary data is necessary for generating robust dietary patterns, but the analysis needs to go further. The dietary assessment tool also needs to be assessed for its capability to produce robust dietary patterns. This way, the dietary patterns can be used with confidence when exploring associations with health outcomes. While principal component analysis is the preferred analytical method (Edefonti et al., 2019) other *a posteriori* methods have been validated e.g., cluster analysis (Bountziouka et al., 2011), reduced rank regression (Appannah et al., 2014), and confirmatory factor analysis (Ryman et al., 2015, Togo et al., 2003). The method to assess if a dietary assessment tool is capable of producing reproducible and relatively valid dietary patterns is discussed later.

2.1.5. Furthermore …

Dietary patterns have been used in science for several decades, though more evidence is required to account for variations in geographical regions and other health outcomes (Jayedi et al., 2020, Fabiani et al., 2019a). Dietary pattern methodology tends to lack a standardised approach to creating dietary patterns (Reedy et al., 2018). The many available methods can create hurdles rather than boosting the concept of examining the totality of the diet (Reedy et al., 2018). Indeed, the ability to pool studies in meta-analyses, though done, is difficult due to heterogeneity of the multiple measures of input variables; choice of dietary pattern methodology (Milte and McNaughton, 2016); choice of food groupings (Rodriguez-Monforte et al., 2017, Dietary Guidelines Advisory Committee, 2015a);

and methods to control for energy intake (Jannasch et al., 2018). Gaps in dietary pattern methodology have been identified and need addressing (Reedy et al., 2018). These include:

- evaluating the effect of measurement error in dietary patterns,
- considering the dietary pattern over the short term e.g., a meal,
- considering the changing food choices through the life course and the influence on disease risk,
- developing pattern tools based on both associations to health outcomes and aetiology,
- standardising dietary pattern methods,
- improving dietary assessment tools to capture context and life scope, and
- sharing a conceptual framework.

The improvement of current methods is required but concurrently, new methods are also emerging. Developing new analytical methods may help address the limitations in current dietary pattern analysis and provide improved results and interpretations (Zhao et al., 2021). For example, research that incorporates metabolome or gut microbiome data could help sketch the underlying mechanisms that govern the relationship between the diet and health outcomes (Schulz et al., 2021). However, new analytical methods will not address all limitations e.g., the heterogeneity of food groupings and their comparability are likely to remain a problem regardless of the analytical approach. Nor will new analytical methods necessarily improve current methods e.g., actually verifying the suitability of dietary data for factor analysis. Still, emerging methods in dietary pattern analysis requires future research to evaluate their ability to identify health outcomes (Zhao et al., 2021).

2.1.6. Concluding items

Dietary pattern analysis has been used extensively to explore the relationships between diet and disease or health outcomes. The *a posteriori* dietary pattern approach considers the diet is greater than the sum of its parts, but this approach has limitations because creating dietary patterns requires many arbitrary, though important, decisions e.g., grouping foods. Research has addressed some e.g., energy adjustment, but not all arbitrary decisions. Emerging analytical methods may address other, but not all, limitations of current methods e.g., a valid process exists to verify the adequacy of dietary data for factor analysis, but this is not often reported e.g., Kaiser-Meyer-Olkin measure of sampling adequacy and the Bartlett's test of sphericity. Still, emerging methods in dietary patterns require future research. In conjunction, guidelines are required to improve methodology e.g., how foods should be grouped to improve the comparability of dietary patterns

and to establish consistent use of current methods, perhaps through the application of best practice guidelines.

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2.2. Cognitive function and metabolic syndrome

This thesis explores dietary patterns in relation to two health outcomes: cognitive function and metabolic syndrome. This second section of Chapter 2 defines and discusses the measurement of these outcomes and how the outcomes are affected by ageing. The section goes further to discuss the similarities of cognitive function and metabolic syndrome through their risk factors and mechanisms.

2.2.1. Cognitive Function

2.2.1.1. What is cognitive function?

KEY POINTS

- Cognitive function and metabolic syndrome are connected through common vascular risk factors and mechanisms.
- Evidence for an association between cognitive function and metabolic syndrome is not conclusive.

Cognitive function describes the variety of brain-mediated abilities and processes that allow people to perceive, store, manipulate, evaluate, and respond to information from a vast array of sources e.g., the environment, memories, and thoughts (Schmitt et al., 2005). These functions are grouped into domains to help explain behaviours e.g., attention and memory domains. Cognitive functions can be further split into specific functions e.g., based on input such as visual or auditory. Even though the functions are grouped, the processes within and between the functions are interlinked as the efficiency of one function may rely on another function to complete a cognitive task e.g., the process of word recall requires attention to receive the input, through either a visual or auditory stimulus. Other cognitive processes for the word recall task are storing the words to memory and later retrieving the words. If one function is not working e.g., attention, it appears that memory is failing but, it is the attention domain which failed (Petersen, 2016). For this reason, many cognitive tests are needed to measure the required cognitive functions (Benton et al., 2005). Testing of cognitive function is discussed below but first an outline of the functions and domains is provided.

Attention and vigilance

Attention and vigilance are the ability to receive and process incoming stimuli. There are four aspects of attention - the ability to: concentrate and refrain from moving attention to other stimuli (focused attention); maintain concentration over a period (vigilance); focus on more than one task particularly where a task has multiple elements (divided attention); and the ability to move focus and tasks (alternating attention) (Lezak et al., 2012a).

Executive function

Executive function relates to the ability to be independent, self-directed, and to respond and adapt to new situations. This function is key to maintaining social connections, working independently, and providing satisfactory self-care (Lezak et al., 2012a) e.g., planning meals and weekly shopping. There are four components of executive function (Lezak et al., 2012b).

1. Volition is about intention, determining what is needed (or wanted) and setting goals and being motivated.
2. Planning and decision making is required to carry out an intention and involves conceptualising changes, deliberating alternatives, and making choices.
3. Purposeful action is the ability to initiate and follow through a sequence of events.
4. Effective performance is the ability to monitor, regulate, and self-correct.

Memory

Memory is the ability to access knowledge and is central to all cognitive functions (Lezak et al., 2012a). There are two major memory classifications – declarative and non-declarative (Lezak et al., 2012a).

Declarative memory

Declarative memory can be stated verbally and includes semantic (reflecting general knowledge), and episodic memory (personally experienced events). Episodic memory refers to memories which can be placed into time and space (spatial memory) and also involves the ability to recall e.g., words and picture recall, keys, and glasses. Episodic memory is often subject to 'memory complaints' in older people (Lezak et al., 2012a, Zimmermann and Eschen, 2017, Bolla et al., 1991). The framework around declarative memory has two stages – short-term and long-term memory. Short-term memory is the ability to receive and retain input for a short time e.g., four digits. The input may be placed in temporary storage and used further by other cognitive activities e.g., working memory or placed in long-term memory. Working memory is where this input may be further manipulated e.g., where four digits are repeated in backwards order. Long-term memory is the process of learning or consolidating new information, perhaps through reorganisation of held information (Lezak et al., 2012a).

Non-declarative memory

Non-declarative memory is the memory of skills learnt without conscious awareness e.g., the 'how to' memory, this includes walking, eating, and talking but also includes more specific skills such as reading or riding a bike.

Fluid and crystallised intelligences

Another method to group cognitive function is through the intelligences of which there are two categories - crystallised or fluid. Crystallised intelligence relates to accumulated factual knowledge, comprehension, reading, and vocabulary. Fluid intelligence relates to the capacity to do everyday tasks and the ability to learn new tasks requiring attention, reasoning, working memory, and long-term memory. Over the life span fluid intelligence will decline whereas crystallised intelligence will remain constant or even increase over time (Sanchez-Izquierdo and Fernandez-Ballesteros, 2021, World Health Organization, 2015). Crystallised and fluid intelligence should be measured separately so any changes in the intelligences do not off-set one another.

2.2.1.2. How is cognitive function measured?

As mentioned earlier many cognitive tests are required to accurately measure cognitive function. Batteries of tests have been designed to provide measures for specific purposes such as intelligence (Weschler, 2008) or following the progress of dementia (Morris et al., 1989). While some batteries are "fixed", it is more common to use a "flexible" or "tailored" battery assembled from a core set of tests (Lezak et al., 2012d). Generally, the selected tests come from current batteries in common use. The "tailored" batteries are designed specifically for research purposes and are useful, practical, and easy to administer (Lezak et al., 2012d).

A "tailored" battery of cognitive tests evaluates cognitive functions e.g., the global cognition domain; specific domains e.g., attention; or can track changes in cognition e.g., decline. While 'paper and pencil' tests offer mobility (Schmitt et al., 2005), computer-based testing has become more common for assessing cognitive function (Wild et al., 2008, Zygouris and Tsolaki, 2015). They offer standard administration and presentation of tests thereby, minimising examiner bias e.g., COMPASS (Computerised Mental Performance Assessment System) (Brain Performance and Nutrition Research Centre, 2019). Other advantages include the ability to minimise floor and ceiling effects, accuracy in measuring response times, and the efficiency in time and costs through reduced administration and data entry (Zygouris and Tsolaki, 2015). However, there are disadvantages where older adults may experience computer anxiety due to the technical environment, though most older adults are quickly becoming more familiar with this technology (Zygouris and Tsolaki, 2015).

Another category of cognitive tests are the mental test examinations used in clinical settings to produce an overall score for classifying cognitive impairment e.g., Mini-Mental State Examinations (MMSE) (Folstein et al., 1975) or Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). The MMSE and MoCA are not batteries but tools which are easy and quick to administer (10 minutes) to obtain a single global cognition score. The MMSE concentrates on semantic, episodic

memory, working memory, attention, and language. Semantic and language are crystallised intelligences and have a different age-related decline to the fluid intelligences, therefore the addition of the disparate measures to a single score is a criticism of the MMSE (Benton et al., 2005, Schmitt et al., 2005). The MoCA is more sensitive in detecting cognitive impairment than the MMSE as the MoCA contains more recall words, a longer delay before recall and less learning trials (Nasreddine et al., 2005). The MoCA focusses more on the domains likely to be impaired such as executive function, complex visuospatial processing, and higher-level language abilities (Nasreddine et al., 2005). Furthermore, the sensitivity of the MMSE to deduct subtle changes in cognition is limited when used in short term nutritional interventions (Schmitt et al., 2005).

2.2.1.3. Cognitive function naturally declines with age

Just like other organ systems, the brain also ages progressively. The ageing brain undergoes physical changes: reduced volume, and altered neurons and cellular mechanisms e.g., DNA replication errors and abnormal protein synthesis (Lezak et al., 2012c). A naturally ageing brain is different to a degenerative brain disease that has its own pathology (Heilman and Nadeau, 2019). **Age-related cognitive decline** is a normal part of ageing and characterised by slower thinking where reasoning and decision making become more difficult but do not interfere with daily activities (Petersen, 2016). Age-related cognitive decline does not naturally progress to the disease state but may progress to mild cognitive impairment (Petersen, 2016). **Mild cognitive impairment** is a borderline area between age-related cognitive decline and very early dementia (Petersen, 2016). Cognition function is slightly less than normal, there is no neurological disease and normal daily activities around memory, learning and decision making become more challenging. Some but not all mild cognitive impairment progresses to dementia (Petersen, 2016). **Dementia** describes disease that significantly alters the ability to perform daily activities by impairing cognitive function affecting memory, cognitive ability, language, perception, and thought. Alzheimer disease and vascular dementia are the most common forms of dementia (World Health Organization, 2015).

Normal cognitive function starts to decline relatively early, affecting various cognitive domains at differing rates of decline (World Health Organization, 2015, Salthouse, 2009). The decline may begin in healthy educated adults as early as the third decade (Salthouse, 2009). Crystallised intelligence (e.g., vocabulary, semantic knowledge, or other non-declarative memory tasks) will remain level or even increase until the seventh decade when it will start to decline (Salthouse, 2019, Benton et al., 2005) (World Health Organization, 2015). The fluid intelligences e.g., memory, reasoning, and the ability to learn new tasks will have a steady decline which may accelerate from 70 years old. For prospective memory (remembering to do something soon) and verbal episodic memory (tip-of-the-tongue events) the decline will accelerate before 70 years (Benton et al., 2005). The rate of decline

can be offset by knowledge and experience gained through a lifetime, physical activity, and mental training (World Health Organization, 2015).

2.2.1.4. Interventions to maintain cognition

Research has explored activities to minimise the rate of age-related cognitive decline e.g., physical activity and cognitive training. According to systematic reviews and meta-analyses, there is strong evidence physical activity slows age-related cognitive decline in healthy, older adults (Baumgart et al., 2015, Falck et al., 2019). Exercise must be regular and slightly vigorous though positive associations have been noted in regular walking and when healthy adults start exercise routines. Yoga-based interventions focussing on balance and flexibility have a potential to improve cognitive function in healthy older adults, but more robust research is required (Hoy et al., 2021). There is moderate evidence cognitive stimulating activities may slow the rate of age-related cognitive decline in healthy older adults (Lampit et al., 2014, Baumgart et al., 2015, Lezak et al., 2012c). With computerised cognitive training e.g., games with clear cognitive rationale, a meta-analysis found a group-based rather than a home-based approach was more effective and training more than three times per week was counter-productive (Lampit et al., 2014). Randomised controlled trials exploring interventions to slow cognitive decline using nutritional interventions found no or inconsistent effects of vitamins A, B, C and E; ginkgo biloba or omega-3 fatty acids in older adults (Plassman et al., 2010). A review of recent randomised controlled trials based on the Mediterranean Diet reported positive benefits in cognition and depression in both impaired and cognitively healthy older adults (Klimova et al., 2021)

2.2.1.5. Cognitive reserve can protect against brain ageing, pathology, or insult

Cognitive reserve refers to the cognitive process of adapting to ageing, pathology, and insult. The efficiency, capacity, and flexibility of cognitive processes varies between individuals (Stern et al., 2020) creating differences in cognitive reserve and rates of cognitive decline. Cognitive reserve explains the individual differences in the rate of decline and may be impacted by a combination or interaction of life experiences and genetic factors. As age-related or disease related changes occur in the brain, cognitive reserve will decrease.

Higher cognitive reserve is reflective of (and maintained by) intelligence, higher education, engagement in social, physical, and cognitively stimulating activities, higher socio-economic status, and positive early life experiences (Pettigrew and Soldan, 2019). Cognitive reserve is a theoretical construct and is not measured directly, therefore a proxy measure is used. There is strong evidence a higher cognitive reserve is associated with a higher level of cognition and may slow the rate of

cognitive decline and reduce the risk of dementia (Pettigrew and Soldan, 2019, Heilman and Nadeau, 2019).

2.2.2. Metabolic syndrome

2.2.2.1. Metabolic syndrome has several definitions

Metabolic syndrome is characterised by a combination of symptoms which are associated with higher cardiovascular disease outcomes and the development of type 2 diabetes mellitus (Ford et al., 2008, Gami et al., 2007, Mottillo et al., 2010). Several definitions for metabolic syndrome have been proposed by different organisations and the most used definitions and their cut-off points are detailed in Table 2.3. Metabolic syndrome was first defined by the World Health Organization (Alberti and Zimmet, 1998). Insulin resistance is an essential component of this definition but also includes two (or more) criteria relating to obesity, dyslipidaemia, hypertension, and albuminuria. In 2001 (and updated in 2005) another definition was released where insulin resistance was no longer an essential component. The National Cholesterol Education Program Adult Treatment Panel III, more commonly known as NCEP-ATP III, defined metabolic syndrome as three of five components based on blood glucose, obesity, dyslipidaemia, and hypertension (Grundy et al., 2005, National Cholesterol Education Program (NCEP) Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III), 2002). The NCEP-ATP III definition is a common measure of metabolic syndrome (Hao et al., 2011, Rodriguez-Monforte et al., 2017, Atti et al., 2019, Assuncao et al., 2018, Chen et al., 2018). Also, in 2005, the International Diabetes Federation proposed yet another definition (Alberti et al., 2005) where abdominal obesity via waist circumference became an essential component plus two other criteria relating to hyperglycaemia, obesity, dyslipidaemia, and hypertension.

Table 2.3: Common definitions for metabolic syndrome

Clinical Measure	Variable	WHO[a]	NCEP-ATP III[b]	IDF[c]
		Insulin resistance + 2 components.	3+ components.	WC + 2 components.
Insulin resistance / hyperglycaemia	Fasting insulin	IGT, IFG, T2DM OR lower insulin sensitivity[d] OR		
	Fasting blood glucose	≥5.6 mmol/L (≥100 mg/dL).	≥5.6 mmol/L (≥100 mg/dL), OR drug treatment for elevated glucose.	≥5.6 mmol/L (≥100 mg/dL) and diabetes.
Adiposity/obesity	WC or WHR	WHR males: >0.90; females: >0.85; AND/OR	WC males: ≥102 cm; females ≥88 cm.	Population specific WC.
	BMI	>30 kg/m^2.		
Dyslipidaemia	HDL-C	Males <0.9 mmol/L (<35 mg/dL); females: <1.0mmol/L (<39 mg/dL); AND/OR	Males: <1.03 mmol/L (<40 mg/dL); females: <1.3 mmol/L (<50 mg/dL), OR drug treatment for reduced HDL-C	Males: <1.03 mmol/L (<40 mg/dL); females: <1.3 mmol/L (<50 mg/dL), OR drug treatment for reduced HDL-C
	Triglycerides	≥1.7 mmol/L (≥150 mg/dL).	>1.7 mmol/L (>150 mg/dL) OR drug treatment for elevated TG.	>1.7 mmol/L (>150 mg/dL) OR drug treatment for elevated TG.
Hypertension	Blood pressure	Systolic BP ≥160 mmHg OR diastolic BP ≥90 mmHg.	Systolic BP ≥130 mmHg OR diastolic BP ≥85 mmHg OR antihypertensive drug treatment in patient with history of hypertension.	Systolic BP ≥130 mmHg OR diastolic BP ≥85 mmHg.
Other	Albuminuria	Microalbuminuria	n/a	n/a

[a] Alberti and Zimmet (1998).
[b] National Cholesterol Education Program (NCEP) Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) (2002) and (Grundy et al., 2005).
[c] Alberti et al. (2005).
[d] Insulin sensitivity measured under hyperinsulinemia euglycemic conditions, glucose uptake below lowest quartile for background population under investigation.
BMI = body mass index, BP = blood pressure, HDL-C = high density lipoprotein cholesterol, IDF = International Diabetes Federation, IGT = impaired glucose tolerance, IFG = impaired fasting glycaemia, NCEP-ATP III = National Cholesterol Education Program Third Adult Treatment Panel Report, T2DM = type 2 diabetes mellitus, TG = triglycerides, WHO = World Health Organization, WC = waist circumference, WHR = waist to hip ratio.

Waist circumference is commonly used to define adiposity. In 2009, several groups (International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity) recognised that waist circumference was not only sex-specific but ethnic-specific, therefore thresholds were recommended by population groups as outlined in Table 2.4 (Alberti et al., 2009).

Table 2.4: Ethnic and sex-specific waist circumference thresholds for abdominal obesity when determining metabolic syndrome

Population group	Males	Females
European, Caucasian, North American	≥ 102 cm	≥ 88 cm
Asian, Central and South American	≥ 90 cm	≥ 80 cm
Middle Eastern, Mediterranean, Sub-Saharan African	≥ 94 cm	≥ 80 cm
Central and South American	≥ 94 cm	≥ 80 cm

Data adapted from Alberti et al. (2009) and O'Neill and O'Driscoll (2015).

2.2.2.2. It is difficult to determine the true prevalence of metabolic syndrome

While several definitions for metabolic syndrome overlap it remains difficult to estimate the true prevalence of metabolic syndrome (O'Neill and O'Driscoll, 2015). Global estimates range from 5 to 40% in males and 9 to 38% in females with the lower values in Asian countries and higher values in United States (O'Neill and O'Driscoll, 2015). The prevalence of metabolic syndrome parallels the increasing rate of type 2 diabetes mellitus (Ford et al., 2008, Saklayen, 2018), currently at three cases of metabolic syndrome to every one of type 2 diabetes mellitus (Ogurtsova et al., 2017). In the Auckland population, data from The Diabetes, Heart and Health Survey 2002/2003 reported metabolic syndrome (using the NCEP-ATP III definition) occurs in 32% of Māori and 39% of Pacific people, more than double that of European New Zealanders at 16% (Gentles et al., 2007). The Virtual Diabetes Register reports a 40% increase over the last 10 years of type 2 diabetes mellitus (*n* 264 000) in the New Zealand population (Ministry of Health, 2020), so it can be assumed there is also an increase in the prevalence of metabolic syndrome in New Zealand.

2.2.2.3. Ageing and metabolic syndrome

The prevalence of metabolic syndrome increases with age (Park et al., 2003). Ageing per se is related to physiological changes which are on the pathological pathway to metabolic syndrome (Franceschi et al., 2018). This is observed more in females as hormonal changes during menopause influence high-density lipoprotein cholesterol (HDL) levels (by reducing) and fat accumulation (from hip to

abdomen), thereby increasing the prevalence of metabolic syndrome in older females compared to older males and may even drive the prevalence increase in older people (Pucci et al., 2017).

2.2.3. Cognitive function and metabolic syndrome

2.2.3.1. Cognitive function and metabolic syndrome have similar mechanisms

Metabolic syndrome and its components are highly associated with cardiovascular disease (Mottillo et al., 2010). Through this vascular connection and its associated mechanisms, the brain structure and function can undergo abnormal changes (Alfaro et al., 2018) leading to higher cognitive decline and risk of cerebrovascular and neurodegenerative disease (Frisardi et al., 2010, Leritz et al., 2011). The common mechanisms behind metabolic syndrome and cognitive function are complex but centred around vascular health by way of inflammation and oxidative stress.

Inflammation is a natural immune response, however a persistent state of inflammation above baseline is linked to chronic disease and is responsible for tissue and cell damage (Nasef et al., 2017) in multiple organs (Saltiel and Olefsky, 2017). For example, pro-inflammatory reagents enter the brain via a damaged blood-brain barrier leading to increased cognitive decline and Alzheimer's Disease (Aridi et al., 2017). Also, as part of the ageing process, the baseline of inflammation progressively rises eventually leading to a constant inflammatory state described as 'inflammaging' (Franceschi et al., 2018). The level of inflammation can be modulated by genetics and lifestyle behaviours including nutrition (Gu et al., 2018). Evidence suggests the diet is capable of influencing inflammation either through a positive effect of a Mediterranean diet (Schwingshackl and Hoffmann, 2014); a negative effect of a 'Western' dietary pattern (Barbaresko et al., 2013); or a diet with a consistent low or high intake of energy (Franceschi et al., 2018).

Oxidative stress is associated with many chronic diseases including cardiovascular disease, type 2 diabetes mellitus, hypertension, and neurodegenerative disease (Liguori et al., 2018). Reactive oxygen species are a by-product of normal biochemical processes. Normally, antioxidants neutralise reactive oxygen species but when the intake of antioxidants is insufficient oxidative stress occurs. Antioxidants are found in fruits and vegetables and include polyphenols and vitamins (carotenoids, B12, folate, C and E) and play a positive role in brain health by minimising damage to nerve cells, DNA and ultimately cell death which can lead to cognitive impairment (Angeloni et al., 2020, Aridi et al., 2017). This is further confirmed by an inverse association between fruit and vegetables and cognitive disorders e.g., cognitive impairment and dementia (Wu et al., 2017). Improvements have also been observed in type 2 diabetes mellitus and dyslipidaemia when oxidative stress was reduced in adipose tissue. Here, oxidative stress interferes with the regulation of adipocyctokines e.g., leptin

and adiponectin. Lower levels of oxidative stress are associated with reduced plasma glucose, insulin and triglycerides (Furukawa et al., 2004).

Associations have been reported between the gut and neurodegenerative disease and metabolic syndrome (Fava et al., 2019, Zhang et al., 2020). The gut microbiota alters with ageing: the diversity of bacteria in the gut decreases becoming unbalanced (dysbiosis) and with reduced levels of beneficial bacteria e.g., *Bifidobacterium* (Juarez-Fernandez et al., 2021, Ling et al., 2020). This can be caused by medications, long-stay residential care, and lower fibre intake (Ling et al., 2020). The change in the gut microbiota brings poorer health through an innate immune response, 'inflammaging' and increased oxidative stress (Franceschi et al., 2018, Liguori et al., 2018).

2.2.3.2. And similar risk factors

Increasing age and genetic factors are the most significant risk factors for metabolic syndrome, age-related cognitive decline and developing dementia (Park et al., 2003, Franceschi et al., 2018) (Winblad et al., 2016). The main genetic risk factors associated with cognitive health is the apolipoprotein E genotype (Wisdom et al., 2011). Metabolic syndrome also has genetic risk factors. Genome-wide association studies have identified several loci associated with components of metabolic syndrome e.g., ADIPOQ, the adiponectin gene, is associated with type 2 diabetes mellitus and obesity (Zafar et al., 2018). These genetic factors are not commonly included in studies examining the association between dietary patterns and metabolic syndrome.

Other modifiable risk factors common to both age-related cognitive decline and metabolic syndrome (and its components) include education, physical activity, alcohol, smoking, and diet (Norton et al., 2014, Saklayen, 2018, Frisardi et al., 2010, Cooper et al., 2015). These factors are discussed further in the literature reviews.

With regards to cognitive decline, the effect of the risk factors may be dependent on age e.g., as age increases the association between cognition and risk factors decrease. The change is not linear; therefore, it may be pertinent to consider smaller age brackets to minimise the effect of age e.g., 10 years (Legdeur et al., 2018).

2.2.3.3. But evidence for association is weak

With common risk factors and mechanisms, epidemiologic evidence suggests metabolic syndrome may be associated with increased age-related cognitive decline and increased rates of cerebrovascular and neurodegenerative disease (Frisardi et al., 2010, Alfaro et al., 2018). However, systematic reviews and a meta-analysis do not consistently support this idea.

One review exploring whether metabolic syndrome changed the brain structure suggested metabolic syndrome may increase microstructure damage in the brain resulting in slower processing speed and cognitive impairment (Alfaro et al., 2018). The individual components of metabolic syndrome also had specific effects on cognition. For example, obesity and hyperglycaemia increased the rate of cognitive decline; hypertension reduced executive function; and dyslipidaemia had mixed associations with cognition (Alfaro et al., 2018). An earlier systematic review (*n* 19,876, 9 longitudinal studies) reported metabolic syndrome may have a synergistic effect and be associated with cognitive impairment and vascular dementia but not Alzheimer disease (Hao et al., 2011).

On the other hand, a later systematic review (*n* 28,646, 25 cross-sectional and longitudinal studies) concluded there was insufficient evidence to confirm whether metabolic syndrome was associated with cognitive impairment or decline (Assuncao et al., 2018). Though Assuncao et al. (2018) reported hyperglycaemia was consistently associated with cognitive impairment in older adults similar to what Alfaro et al. (2018) observed.

A recent meta-analysis (*n* 18,313, 9 longitudinal studies) reported metabolic syndrome increased the risk of vascular dementia [hazard ratio (HR) = 1.37, (95% confidence interval (CI) 1.01, 1.86), I^2 = 62%[10]] and the progression from mild cognitive impairment to dementia [HR = 2.69, (95% CI 1.16, 6.27), I^2 = 67%] (Atti et al., 2019). However, because the heterogeneity was large (I^2 > 50%), a random effect model was fitted, which attenuated the associations to not significant. In the same meta-analysis, metabolic syndrome was not associated with incident dementia [HR = 1.12, (95% CI 0.94, 1.33), I^2 = 0.28] or Alzheimer disease [HR = 0.84, (95% CI 0.66, 1.08), I^2 = 0] (Atti et al., 2019).

Despite the mixed findings, researchers' have suggested reasons behind no definite conclusions. Firstly, as metabolic syndrome has many possible modifiable risk factors, studies with longer follow-ups and regular assessments of outcomes (both metabolic syndrome and cognitive function) may find conclusive results (Atti et al., 2019). Secondly, outcomes may be underestimated as people with metabolic syndrome may die from cardiovascular disease before the diagnosis of neurodegenerative disease (Kalmijn et al., 2000, Hao et al., 2011). Finally, the association may be indirect and be modulated or mediated by another factor.

2.2.4. To conclude

The prevalence of metabolic syndrome is increasing. It has a larger impact in the older community and may impact brain health. Cognitive decline is also a feature of the older population and part of

[10] I^2 is a measure of heterogeneity where 0-40% is low, 30-60% moderate, 50-90% substantial, 75-100% substantial, depending on magnitude and direction of effect and strength of evidence for heterogeneity (Deeks JJ, Higgins J, Altman DG, 2021)

the natural ageing process. Memory and reasoning (a fluid intelligence) are the most common functions to decline with age, but the decline varies between individuals and is explained by the influence of cognitive reserve. This is the ability of the brain to adapt to changes and cognitive reserve can be maintained by higher levels of education, and engagement in social, physical, and cognitively stimulating activities. Metabolic syndrome and cognitive function are connected through common vascular risk factors and mechanisms, though evidence for a direct association is mixed.

2.2.5. References

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2.3. Reproducibility and relative validity: the suitability of dietary patterns to assess associations between the diet and health outcomes

This section continues the discussion on dietary pattern analysis by reviewing the literature on the reproducibility and/or relative validity of dietary assessment tools for deriving dietary patterns. A chronological perspective of individual studies is followed with particular emphasis on the statistical methods used. Also included are two recent systematic reviews that summarised the reproducibility and validity (both relative and construct) of dietary assessment tools and their derived dietary patterns, emphasised methodological concerns, and suggested improvements to methodology.

2.3.1. Dietary assessment tools and their derived dietary patterns should be valid and reproducible

Dietary assessment tools and dietary patterns have important roles for assessing disease risk which may inform public policy recommendations to promote health. Robust techniques are required to inspire confidence in results particularly as dietary assessment tools and dietary pattern analysis both have limitations.

KEY POINTS

- Dietary assessment tools and their derived dietary patterns require validation due to the subjective decisions involved to derive dietary patterns.
- Valid dietary patterns enhance evidence for relationships between the diet and health outcomes or disease.
- Further research is required to improve methods and encourage the validation of the dietary assessment tools and for deriving their dietary patterns.

Several tools measure dietary intake either retrospectively (24-hour recall, FFQ, diet history questionnaire) or concurrently (food diaries). Researchers commonly assess FFQ for quality by examining the relative validity of their measures using another dietary assessment tool with errors independent of the original FFQ (Gibson, 2005). *A posteriori* dietary pattern methods rely on quality dietary data to create dietary patterns, but the process to derive dietary patterns relies on multiple subjective decisions (e.g., food groupings) and researchers rarely assess the quality of the dietary patterns derived from the valid FFQ (Edefonti et al., 2019, Dietary Guidelines Advisory Committee, 2015).

To have confidence in dietary patterns and associations found with health outcomes, it is important to assess if the chosen dietary assessment tool, usually a FFQ (test), accurately measures the dietary

patterns within the population i.e., are the dietary patterns relatively valid? This is done by deriving dietary patterns from another dietary assessment tool (reference) with measurement errors independent of the test dietary assessment tool, for example, a food record or multiple 24-hour recalls are suitable reference tools to test a FFQ. Additionally, are the dietary patterns reproducible e.g., can the dietary assessment tool duplicate the patterns in the same population at a different time point or by a different interviewer?

This literature review aims to evaluate and summarise the existing evidence on the reproducibility and relative validity of *a posteriori* dietary patterns using two dietary assessment tools (test and reference) at multiple time points. The literature review will draw on studies from two systematic reviews, Edefonti et al. (2019) and Jannasch et al. (2018), and a further search for studies after 1 January 2019 through Web of Science using two search areas: dietary patterns (*a posteriori*) and relative validity or reproducibility (Table 2.5).

Table 2.5: Search strategy for dietary pattern validation and reproducibility studies

	Search term	
	diet	
AND	princip* compon* analys*	OR
	PCA	OR
	factor analysis	OR
	cluster analysis	OR
	rank regression	OR
	posteriori	OR
	empirica* deriv*	OR
	mult*varia* analys*	OR
	dietary pattern*	
AND	valid	OR
	reproduc*	

2.3.2. A timeline of current methods

From the current systematic reviews and the literature search, 19 studies (two published after 1 January 2019) explored the reproducibility and/or relative validity of dietary patterns used to assess associations between dietary patterns and a health outcome. Two tables summarise the 19 studies.

Table 2.6 contains an overview of these studies including their design and dietary patterns while Table 2.7 details their reproducibility and validity results.

Table 2.6: Overview of dietary pattern reproducibility and validation studies including population details, methods overview, and dietary patterns obtained

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Hu et al. (1999), USA, Health Professionals Follow-up study.	*n* 127, 40-75 yrs, 100% M.	1. 131-FFQ over 12 mths (FFQ1), 2. 131-FFQ, 1 yr later (FFQ2), 3. 2 x 1-wk FR 3 wks after FFQ1 and 2-3 mths before FFQ2.	PCA, 40 FGs, g/day, varimax rotation.	2 similar DPs, from 3 DATs, explained 20% of total variance: '**prudent**': ↑veg, fruit, legumes, whole grains, fish/seafood; '**Western**': ↑red/proc'd meat, butter, HF dairy, eggs, refined grains.
Togo et al. (2003), Denmark, MONICA.	*n* >2,000, 30-60 yrs, ~50% M.	1. 26-FFQ, group A, 2. 26-FFQ, group B, 3. 7-day weighed FR within 3 wks of FFQ.	EFA, 21 FGs, g/day, stratified by sex, non-orthogonal rotation CFA, tested in the same participants based on loadings >0·3 on EFA on FFQ and FR	'DP' (variance explained by FFQ/FR): identified DPs were very similar: M '**green**' (12/11%): ↑whole grain bread, veg, fruit, ↓white bread; '**sweet**' (10/8%): ↑cakes/biscuits/baked goods, candy/chocolate, soft drink/ice cream; jam/marmalade/honey; '**traditional**' (8/8%): ↑meat, pate, potatoes, butter, lard/hard margarine. F '**green**' (13/11%): ↑whole grain bread, veg, fruit, fish, cheese, milk/yoghurt, jam/marmalade/honey; '**sweet-traditional**' (11/9%): ↑cakes/biscuits/baked goods, candy/chocolate, soft drink/ice cream, jam/marmalade/honey, pate, white bread, butter, lard/hard margarine.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Khani et al. (2004), Sweden, Swedish Mammography Cohort.	*n* 197 (R) and 111 (V), 40-74 yrs, 0% M.	1. 60-FFQ, 2. 60-FFQ, 1 yr later, 3. 4 x 7-day FR, 3-mths apart to cover variability of food consumption.	FA, 26 FGs, frequency of consumption, varimax rotation.	3 similar DP explained 29–34% of total variance: '**healthy**': ↑veg, fruits, fish, poultry, tomato, cereal, LF dairy; '**Western**': ↑proc'd meat, meat, refined grains, sweets, fried potatoes; '**drinker**': ↑beer, wine/liquor, snacks.
McNaughton et al. (2005), United Kingdom, 1946 British Birth Cohort.	*n* 2265, 43 yrs, 49% M.	1. 48-hr, 2. 24-hr, 3. 5-day FR.	PCA, 56 FGs, g/day, varimax rotation, stratified by sex.	5 DP from 48-hr explained 19% of variation, DP similar between sexes: '**health aware**': ↑wholemeal bread, apples, high-fibre breakfast cereals; '**dinner party**': ↑red/white wine, rice, curries; '**traditional**': ↑potatoes, green leafy veg, carrots, red meat; '**refined**': ↑sweet puddings, sweet biscuits, cakes, citrus fruit; '**sandwich**': ↑tomatoes, lettuce, onions. 5 DP from 24-hr explained 19% of variation, DP similar between sexes: '**health aware misc**': ↑other fruit, citrus, sweet biscuits and cakes; '**dinner party**': ↑rice, curries, meat dishes; '**traditional**': ↑potatoes, carrots, green leafy veg, red meat; '**refined**': ↑HF milk, white bread, butter; '**sandwich misc**': ↑tomatoes, lettuce. 5 DP from 5-day FR explained 22% of variation, DP similar between sexes: '**health aware**': ↑wholemeal bread, other fruit, high-fibre breakfast cereals; '**dinner party**': ↑red/white wine, spirits, rice, coffee; '**traditional**': ↑potatoes, carrots, red meat, green leafy veg; '**refined**': ↑sweet puddings, sweet biscuits, cakes, sugar preserves, chocolate; '**sandwich**': ↑tomatoes, lettuce, onions.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Crozier et al. (2008), United Kingdom.	*n* 585, pregnant, 0% M.	1. 100-FFQ over 3 mths, 2. n/a, 3. 4-day FR.	PCA, 49 FGs, frequency of consumption.	2 DP from FFQ explained 16% of total variation: '**prudent**': ↑fruit/veg, wholemeal bread, yoghurt, cheese, LF milk, rice/pasta, fish; ↓white bread, tinned veg, added sugar, HF milk, crisps; '**Western**': ↑Yorkshire puddings/savoury pancakes, chips, roast potatoes, sweets/chocolate, red/proc'd meat, cakes/biscuits, puddings, boiled potatoes, sugar; ↓LF milk. 2 DP from FR explained 15% of total variation: '**prudent**': ↑fruit/veg, wholemeal bread, yoghurt, cheese, LF milk; ↓white bread, tinned veg, chips/roast potatoes; '**Western**': ↑Yorkshire puddings/savoury pancakes, chips/roast potatoes, sweets/chocolate, HF spread, cooking fats/salad oils, HF milk, white bread, crisps, tea/coffee; ↓LF milk/spread, wholemeal bread, tea/coffee.
Okubo et al. (2010), Japan.	*n* 184, 31-76 yrs, 50% M.	1. 4 x 145-DHQ over 1 mth every 3 mths. 1st DHQ (DHQ1) and mean of DHQ (mDHQ) used in analyses. 2. n/a, 3. 4 x 4-day FR over 12 mths, non-consecutive days, 1 weekend day.	PCA, 33 FGs, g/day (log transformed, EI-adj by residual method), varimax rotation, stratified by sex.	F - 3 DP explained DHQ1 (30%), mDHQ (31%) and FR (31%) of total variation: '**healthy**': ↑veg, fish, fruits, sea products, seaweeds, pickled veg, pulses, ↓beef/pork; '**Western**': ↑veg oil, proc'd meat, butter, eggs; '**Japanese traditional**': ↑miso soup, rice; ↓shellfish, bread. M - 2 DP explained DHQ1 (22%), mDHQ (24%) and FR (26%) variation: '**healthy**': ↑veg, fruits, seaweeds, dairy, sugar, miso soup, pulses; '**Western**': ↑chicken, veg oil, proc'd meat, beef/pork; ↓rice.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Ambrosini et al. (2011), Australia, Raine: Western Australian pregnancy cohort.	*n* 783, 14 yrs, 51% M.	1. 212-item FFQ over past 12 mths (FFQ), 2. n/a, 3. 3-day FR.	EFA, 38 FGs, g/day, loading <|0.10| excl from final factor solution, varimax rotation.	2 DP from FFQ explained 50 and 34% of variation: '**healthy**': ↑veg, fruit, fish, whole grains, LF dairy, mineral water; ↓take-away foods/chips, crisps; '**Western**': ↑take-away foods, confectionery, SSB, crisps, chips, refined grains, red/proc'd meats, potato, HF dairy, sauces/dressings, cakes/biscuits, added sugar, fried fish, poultry. 2 DP from FR explained 25 and 28% of variation: '**healthy**': ↑whole grains, veg, fruit, fish, LF dairy, mineral water; '**Western**': ↑take-away foods, confectionery, SSB, crisps, chips; ↓whole grains, fruit, LF dairy, mineral water.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Bountziouka et al. (2011), Greece.	*n* 432, mean=46 yrs, 40% M.	1. 69-FFQ over 1 mth, 2. n/a, 3. 3-day FR, 1 weekend day.	PCA, 24 FGs, g/day, varimax rotation. CA using k-means algorithm.	4 DP from FFQ explained 35% of total variation, KMO=0.69: '**Western**': ↑HF dairy, refined grains, eggs, potatoes, red meat, HF delicatessen, sweets, sodas, oil/fat; ↓LF dairy, whole grains; '**Mediterranean**': ↑LF dairy, whole grains, poultry, fish/seafood, legumes, veg, fruit, stimulants (coffee/tea), olive oil; '**low-fats**': ↑whole grains, red meat, HF & LF delicatessen, bakery, light sodas; '**drinking**': ↑refined grains, wine, beer, spirits, stimulants. 4 DP from FR explained 29% of total variation, KMO=0.54: '**Western**': ↑refined grains, wine, beer, spirits, stimulants; '**Mediterranean**': ↑LF dairy, whole grains, fish/seafood, veg, fruit, olive oil; ↓HF dairy; '**sweets**': ↑LF dairy, whole grains, sweets; ↓ potato, poultry, fish/seafood, wine '**stimulants**': ↑legumes, stimulants; ↓eggs, LF delicatessen. Using CA: '**unhealthy**' [*n* 335 (FFQ), *n* 205 (FR)]: ↑HF dairy, refined grains, potatoes, red meat; '**healthy**' (*n* 165, 227): ↑LF dairy, whole grains, fish and seafood, veg, fruit.
Asghari et al. (2012), Iran, Tehran Lipid and Glucose Study.	*n* 132, mean=36yrs, mixed.	1. 168-FFQ over 1 mth (V), 2. 168-FFQ, 14 mths later, 3. 12 x mthly 24-hr.	FA, 19 FGs, g/day, varimax rotation.	2 DP from FFQ and mFR explained 27% (FFQ1), 32% (FFQ2) and 32% (mFR) of total variation: '**Iranian traditional**': ↑veg, fruits, potatoes, dairy, legumes/nuts, whole grains, tea/coffee, olive, eggs, red/organ meat; '**Western**': ↑SSB, salty snacks /veg, sugars, sweets, desserts, veg oil, animal fat, fast foods, poultry, fish/seafood, refined grains.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Beck et al. (2012), New Zealand.	*n* 115, 18-44 yrs, 0% M.	1. 144-FeFFQ over 1 mth, 2. 144-FeFFQ, 1 mth later, 3. 4-day FR.	PCA, 30 FGs, frequency of consumption, varimax rotation.	2 DP from FFQ1, FFQ2 and FR explained 20% (FFQ1 and FFQ2), 19% (FR) of total variation, KMO range=0.51-0.55, Bartletts <0.001 (all): '**healthy**': ↑veg, apples, almonds, yogurt, brown bread, crackers, porridge, herbal tea, water; '**sandwich and drinks**': ↑brown bread, butter, cheese, beef, coffee, black tea, milk added to drinks.
Nanri et al. (2012), Japan, Japan Public Health Center-based Prospective Study.	*n* 498, 40-69 yrs, 49% M.	1. 138-FFQ, 2. 138-FFQ, 1 yr before or after test FFQ, 3. 2 (or 4) 7-day FR over 1 yr.	PCA, 48 FGs, g/day (log), varimax rotation, stratified by sex.	3 similar DPs explained 24-29% (M), 23-33% (F) of total variation: '**prudent**': ↑veg, fruit, potatoes, soy products, mushrooms, seaweed, oily fish, green tea; '**Western**': ↑bread, meat, proc'd meat, fruit juice, coffee, black tea, SSB, sauces, mayonnaise, dressing; '**traditional**': ↑rice, miso soup, pickles, salmon, salty fish, seafood (not fish), fruit, sake (M only).
Loy and Mohamed (2013), Malaysia, Universiti Sains Malaysia Birth Cohort study.	*n* 162, 19-40 yrs, 0% M.	1. 82-FFQ, late pregnancy over 6 mths, 2. n/a, 3. 3 x 24-hr, 2 mid, 1 late pregnancy, 1 weekend day.	PCA, 23 FGs, g/day, varimax rotation.	2 similar DPs explained ~21% of total variation, KMO>0.60, Bartlett's p<0.05: '**healthy**': ↑fish/seafood, fruit, dairy, veg, nuts/legumes; '**less healthy**': ↑confectionery, condiments, oils/fats, tea/coffee, cereals, meat/offal.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Appannah et al. (2014), Australia, Raine: Western Australian pregnancy cohort.	*n* 783, 14 yrs, 51% M.	1. 227-FFQ (FFQ1), 2. n/a, 3. 3-day FR (FR).	RRR, predictor = 46 FGs, g/day; response=dietary energy density, %EI from total fat intake and fibre density, separate analysis for M and F gave similar results, therefore total sample used for DPs.	1 DP explained 53% (FFQ1) and 46% (FR) of total variation, remaining 2DPs were not easily interpreted: '**energy dense, high-fat, low-fibre**': ↑proc'd meat, SSB, HF milk, crisps/savoury snacks; ↓veg, fruit, high-fibre bread/cereals, legumes. FFQ1 also contained chocolate/confectionery, low-fibre bread; FR also contained fried/roasted potatoes (chips) and coated/breaded meat/fish.
Liu et al. (2015), China.	*n* 179, 40-70 yrs, 59% M.	1. 76-FFQ, 2. 76-FFQ 12 mths later, 3. 6 x 3-day 24-hr, every 2 months (FR).	PCA, 18 FGs, g/day, varimax rotation.	2 DPs explained 29% (FFQ1), 31% (FFQ2) and 29% (FR) of total variation, KMO >0.53, Bartlett's all p<0.001: '**prudent**': ↑rice, wheat, fruit, veg, bean products, white/red meat, nuts, eggs; '**processed food**': ↑pickled/preserved veg, salted meat/eggs.
Mills et al. (2015), New Zealand, EAT: Eating Assessment in Toddlers.	*n* 160, 12-24 mths, 51% M.	1. 91-FFQ over 4 wks (FFQ1), 2. 91-FFQ, ~5 wks later (FFQ2), 3. 5-day weighed FR, non-consecutive days.	PCA, 16 FGs, frequency of consumption, varimax rotation.	3 DPs explaining 34% (FFQ1), 35% (FFQ2) and 38% (FR): '**sweet food and fries**': ↑sweet foods, fries, roast potato/kumara, butter/margarine, proc'd meat, sweet/fruit/milk drinks; '**vegetables and meat**': ↑veg, meat, eggs/beans, fruit, ↓baby/toddler foods; '**milk and fruit**': ↑milk, fruit; ↓breastmilk, infant/follow-up formula.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Ryman et al. (2015), USA, CANHR - Center for Alaska Native Health Research.	*n* 113,358, median ~37 yrs, ~46% M.	1. 163-FFQ over 12 mths, 2. 163-FFQ over 12 mths, 3. n/a.	CFA, 22 FGs, loading ≥|0.35| and *a priori* knowledge of Alaska native diet on EFA results.	From final CFA solution: '**processed foods**': ↑salty snacks, sweetened cereals, pizza, SSB, hot dogs/lunch meat, fried chicken, canned tuna; '**fruits and vegetables**': ↑citrus, potato salad, juice, veg, market berries (Akutaq) '**subsistence foods**': ↑seal/walrus soup, non-oil fish, wild greens, bird soup.
Hong et al. (2016), China.	*n* 203, 31-80 yrs, 49% M.	1. 87-FFQ, 2. 87-FFQ, 12 mths later, 3. 4 x 3 consecutive days 24-hr over 12 mths.	EFA, 28 FGs, g/day, varimax rotation.	4 similar DPs explained 40% (FFQ1), 45% (FFQ2) and 32% (FR) of total variation, KMO>0.64, Bartlett's all p<0.001: '**animal and plant protein**': ↑poultry/meat, fish/shrimp, legumes; '**nuts and sweets**': ↑nuts, sweets/desserts, snacks; '**Chinese traditional**': ↑grains, potatoes, veg, fried food, HF dairy, wheat, rice, pickled veg; '**beverage and alcohol**': ↑sodas, juice, beer/wine, proc'd meats, liquor.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Korkalo et al. (2019), Finland, DAGIS: Increased health and wellbeing in pre schools.	*n* 705, 3-6 yrs, mixed.	1. 47-FFQ over 1 wk (only foods outside of pre-school) (FFQ1); 2. n/a; 3. 3-day FR 1 wk later, not always consecutive days, 1 weekend day.	PCA, 47 (FFQ1) and 45 (FR) FGs, frequency of consumption (FFQ1), g/day (FR), varimax rotation.	3 DP from FFQ explained 17% of total variation: '**sweets and treats**': ↑biscuits/cereal bars, chocolate, ice cream, sweets, SSB, sweet pastries, crisps/popcorn, sweet breakfast cereals/muesli, sausages/frankfurters/luncheon meats; '**health-conscious**': ↑nuts/almonds/seeds, natural yoghurt/quark, berries, egg, porridge, non-sweet breakfast cereals/muesli, dried fruit/berries, whole grain rice/pasta, legumes, veg, commercial baby foods/smoothies; '**vegetables and processed meats**': ↑berries, veg, cold meat, fruit, flavoured yoghurt/quark, wholemeal bread, HF cheese, juice, sausages/frankfurters/luncheon meats. 5 DP from FR explained 20% of total variation: '**health-conscious**': ↑juice, natural yoghurt, canned fruit, veg, LF milk, potatoes; '**sandwich**': ↑margarine, hard cheese, bread, veg, rye bread; '**sweets and treats**': ↑sweets, cold cuts/sausages, white bread, SSB, flavoured yoghurt; ↓porridge, berries; '**milk, potatoes, and minced meat**': ↑milk, potatoes, mince dishes; ↓LF milk, veg soups/dishes; '**pasta, minced meat, and fruit**': ↑mince dishes, pasta, rice, fruit, ↓rye bread, meat soups/stews.

Study	Population *n*, age, sex	Dietary Assessment Tool 1. test 2. reference for reproducibility 3. reference for validation	Dietary pattern method	Dietary patterns
Niedzwiedzka et al. (2019), Poland.	n >2,000, 30-60 yrs, ~50% M.	1. 26-FFQ, group A, 2. 26-FFQ, group B, 3. 7-day weighed FR within 3 wks of FFQ.	EFA, 21 FGs, g/day, stratified by sex, non-orthogonal rotation CFA, tested in the same participants based on loadings >|0·30| on EFA on FFQ and FR.	'DP' (variance explained by FFQ/FR): identified DPs were very similar: M - '**green**' (12/11%): ↑whole grain bread, veg, fruit; ↓white bread; '**sweet**' (10/8%): ↑cakes/biscuits/baked goods, candy/chocolate, soft drink/ice cream; jam/marmalade/honey; '**traditional**' (8/8%): ↑meat, pate, potatoes, butter, lard/hard margarine. F - '**green**' (13/11%): ↑whole grain bread, veg, fruit, fish, cheese, milk/yoghurt, jam/marmalade/honey; '**sweet-traditional**' (11/9%): ↑cakes/biscuits/baked goods, candy/chocolate, soft drink/ice cream, jam/marmalade/honey, pate, white bread, butter, lard/hard margarine.

24-hr = 24-hour recall, 48-hr = 48-hour recall, %EI = percentage of energy intake, adj = adjusted, alc = alcohol, CA = cluster analysis, CFA = confirmatory factor analysis, DAT = dietary assessment tool, DHQ = diet history questionnaire, DP = dietary pattern, E-adj = energy adjusted, EFA = exploratory factor analysis, excl = exclude, F = female, FA = factor analysis, FeFFQ = iron food frequency questionnaire, FFQ = food frequency questionnaire, FFQ1 = food frequency questionnaire (test), FFQ2 = food frequency questionnaire (reference), FG = food group, FR = food record, HF = high-fat, LF = low-fat, KMO = Kaiser-Meyer-Olkin, M = male, mFR = mean intake from food record, mth = month, NR = not reported, PCA = principal component analysis, PLS = partial least squares, proc'd = processed, R = reproducibility, RRR = reduced rank regression, SSB = sugar sweetened beverage, USA = United States of America, V = validity, veg = vegetables, wk = week, yrs = years.

Table 2.7: Results and statistical methods of dietary pattern reproducibility and validation studies

Study	Results: Correlation coefficient	Results: Bland Altman	Results: cross-classification, weighted κ
Hu et al. (1999), USA, Health Professionals Follow-up study.	R: DP scores: 0.70 'prudent', 0.67 'Western'; V: FFQ1 v FR DP scores: 0.45 'prudent'; 0.58 'Western'; V: FFQ2 v FR DP scores: 0.52 'prudent', 0.74 'Western'; FR corrected for time; sig NR.	n/a.	n/a.
Togo et al. (2003), Denmark, MONICA.	R: EFA FFQ v CFA FFQ DP scores: 0.91** 'traditional (M) to 0.96** 'sweet-traditional' (F); V: EFA FFQ v EFA FR DP scores: 0.34** 'traditional' (M) to 0.61** 'green' (M,F);	n/a.	n/a.
Khani et al. (2004), Sweden, Swedish Mammography Cohort.	R: DP scores: 0.63 'healthy', 0.68 'Western', 0.73 'drinker'; V: DP scores: 0.59 'healthy', 0.50 'Western', 0.85 'drinker' (adjusting for reproducibility of FFQ); all *P*<0.001.	n/a.	n/a.

Study	Results: Correlation coefficient Results: Bland Altman Results: cross-classification, weighted κ
McNaughton et al. (2005), United Kingdom, 1946 British Birth Cohort.	R: DP scores: M - 'health aware' 0.31; 'dinner party' 0.21; 'refined' 0.32; 'sandwich' 0.221 (all ***); 'traditional' 0.07*; F - 'health aware' 0.59; 'dinner party' 0.32; 'refined' 0.44; 'sandwich' 0.32; 'traditional' 0.13 (all ***).. V: DP scores: M: 'health aware' 0.62; 'dinner party' 0.57; 'refined' 0.56; 'sandwich' 0.21; 'traditional' 0.16 (all ***); F: 'health aware' 0.67; 'dinner party' 0.32; 'refined' 0.60; 'sandwich' 0.21; 'traditional' 0.13 (all ***). n/a. n/a.
Crozier et al. (2008), United Kingdom.	V: DP scores: 'prudent' 0.67; 'Western' 0.35 (all ***). V: LoA: 'prudent' ±1.58; 'Western' ±2·22. n/a.
Okubo et al. (2010), Japan.	V: DHQ1 v FR DP scores: F - 'healthy' 0.57, 'Western' 0.36, 'Japanese traditional 0.44; M - 'healthy' 0.62, 'Western' 0.56; all ***. V: mDHQ v FR DP scores: F - 'healthy' 0.63, 'Western' 0.45, 'Japanese traditional 0.69; M - 'healthy' 0.65, 'Western' 0.53; all ***. V: DHQ1 v FR DP scores: mean difference=0. LoA: F - 'healthy' ±1.81, 'Western' ±2.22, 'Japanese traditional' ±2.08; M - 'traditional' ±1.83, 'Western' ±1.71. mDHQ v FR DP scores LoA improved except M 'Western' (NR). n/a.

Study	Results: Correlation coefficient Results: Bland Altman Results: cross-classification, weighted κ
Ambrosini et al. (2011), Australia, Raine: Western Australian pregnancy cohort.	V: DP scores: 'healthy' 0.43, 'Western' 0.27; but improved to 'healthy' 0.45 and 'Western' 0.36 after EI-adj (all ***). V: mean difference (LoA): 'healthy' 0.02 (-1.69, 1.75); 'Western' -0.03 (-1.89, 1.82); mean difference not sig different from zero. n/a.
Bountziouka et al. (2011), Greece.	V: PCA DP scores: 'Western' 0.22, 'Mediterranean' 0.23 (all ***), no details on 3rd and 4th patterns as not similar; V: between clusters 0.81***. V: DP scores: mean difference (not reported); LoA: 'Western' -2.35, 2.30; 'Mediterranean' -2.23, 2.26; no details on 3rd and 4th patterns as not similar; V: 59% of participants were classified in the same cluster.
Asghari et al. (2012), Iran, Tehran Lipid and Glucose Study.	R: DP scores: 'traditional' 0.72; 'Western' 0.80; both ***. V: DP scores: 'traditional' 0.48; 'Western' 0.75. FR corrected for month to month variation, sig NR. V: LoA: 'traditional' ±1.58; 'Western' ±1.33. n/a.

Study	Results: Correlation coefficient	Results: Bland Altman	Results: cross-classification, weighted κ
Beck et al. (2012), New Zealand.	R: DP scores: 'healthy' 0.76; 'sandwich and drinks' 0.76; both ***. V: DP scores: 'healthy' 0.34; 'sandwich and drinks' 0.62; both ***	R & V: plots suggest a slope of bias, as mean difference increased so did average scores.	R: DP scores: >50% classified in same third, <10% misclassified in opposite third; weighted κ, 'healthy' 0.57, 'sandwich and drinks' 0.65. V: DP scores: >50% classified in same third, <10% misclassified in opposite third; weighted κ, 'healthy' 0.37, 'sandwich and drinks' 0.43.
Nanri et al. (2012), Japan, Japan Public Health Center-based Prospective Study.	R: DP scores: M - 'prudent' 0.56; 'Westernized' 0.55; 'traditional 0.77; F - 'prudent' 0.55; 'Westernized' 0.71; 'traditional 0.68; all ***. V: DP scores: M - 'prudent' 0.47; 'Westernized' 0.32; 'traditional 0.49; F - 'prudent' 0.36; 'Westernized' 0562; 'traditional 0.63; all ***	n/a.	n/a.
Loy and Mohamed (2013), Malaysia, Universiti Sains Malaysia Birth Cohort study.	V: DP scores: 'healthy' 0.59, 'unhealthy' 0.63; both ***	V: DP scores: mean difference=0. 'healthy': LoA ±1.87; no slope of bias; 'less healthy': LoA ±1.69, no slope of bias.	V: DP scores, classified in same third | misclassified in opposite third | weighted κ: 'healthy' 49% | 9% | 0.56; 'unhealthy' 54% | 9% | 0.72.

Study	Results: Correlation coefficient Results: Bland Altman Results: cross-classification, weighted κ
Appannah et al. (2014), Australia, Raine: Western Australian pregnancy cohort	V: DP scores: 'energy-dense, high-fat and low-fibre': M - 0.35; F - 0.49; both * after adjusting for misreporting. V: 'energy-dense, high-fat and low-fibre': mean difference (LoA); slope of bias; M - -0.05 (-2.52, 2.41) not sig; 0.49**; F - -0.08 (-2.55, 2.39) not sig; 0.35**. . n/a.
Liu et al. (2015), China.	R: DP scores: 'prudent' 0.52; 'processed food' 0.56; both **. V: FFQ1 v FR DP scores: adjusted for monthly and seasonal variation of food supply: 'prudent' 0.55; 'processed food' 0.55; both **. V: FFQ2 v FR DP scores: adjusted for monthly and seasonal variation of food supply: 'prudent' 0.78; 'processed food' 0.61; both **. R: DP scores: mean difference (LoA): 'prudent' 0.04 (-0.88, 0.96); 'processed food' -0.01 (-1.44, 1.46); V: FFQ1 v FR DP scores: 'prudent' -0.10 (-1.90, 1.70); 'processed food' 0.02 (-1.30, 1.34); V: FFQ2 v FR DP scores: 'prudent' -0.05 (-1.83, 1.73); 'processed food' 0.01 (-1.31, 1.33); visual inspection of plots showed no obvious divergence of plots. R: DP scores: classified in same third | misclassified in opposite third | weighted κ; 'prudent' 56% | 7% | 0.45, 'processed food' 64%, |7% | 0.56; V: FFQ1 v FR DP scores: 'prudent' 55% | 7% | 0.42; 'processed food' 62% | 7% | 0.43; V: FFQ2 v FR DP scores: 'prudent' 57% | 7% | 0.46; 'processed food' 73% | 6% | 0.60; all **.

Study	Results: Correlation coefficient	Results: Bland Altman	Results: cross-classification, weighted κ
Mills et al. (2015), New Zealand, EAT: Eating Assessment in Toddlers.	R: DP scores: Pearson / intraclass: >0.70 / >0.70 for all DPs; V: DP scores: Pearson / intraclass: 'sweet food and fries' 0.68 / 0.69; 'vegetables and meat' 0.56 / 0.56; 'milk and fruit' 0.58 / 0.59; sig NR.	n/a.	V: DP scores: classified in same quartile | misclassified in opposite quartile: 'sweet foods and fries' 51% | 1%; 'vegetables and meat' 45% | 3%; 'milk and fruit' 43% | 3%.
Ryman et al. (2015), USA, CANHR - Center for Alaska Native Health Research.	test-retest reliability: 'processed foods' 0.66; 'fruits and vegetables' 0.54; 'subsistence foods' 0.34; composite DP reliability: 'processed foods' 0.73; 'fruits and vegetables' 0.72; 'subsistence foods' 0.56.	n/a.	n/a.

Study	Results: Correlation coefficient	Results: Bland Altman	Results: cross-classification, weighted κ
Hong et al. (2016), China.	R: DP scores: 'animal and plant protein' 0.87; 'nuts and sweets' 0.65; 'Chinese traditional' 0.73; 'beverage and alcohol' 0.67; V: FFQ1 v m24-hr scores: 'animal and plant protein' 0.84; 'nuts and sweets' 0.44; 'Chinese traditional' 0.39; 'beverage and alcohol' 0.44; V: FFQ2 v m24-hr scores: 'animal and plant protein' 0.75; 'nuts and sweets' 0.45; 'Chinese traditional' 0.49; 'beverage and alcohol' 0.48; all *P*<0.001.	V: mFFQ v m24-hr scores: mean difference (LoA): 'animal and plant protein': 0 (-1.0, 1.0); 'nuts and sweets': 0 (-1.7, 1.6); 'Chinese traditional': -0.1 (-2.0, 1.8); 'beverage and alcohol': -0.2 (-1.9, 1.5); mean difference not sig.	R: DP scores: classified in same tertile | misclassified in opposite tertile | weighted κ: 'animal and plant protein': 0.66|0.01|0.68; 'nuts and sweets': 0.42|0.05|0.34; 'Chinese traditional': 0.52|0.08|0.58; 'beverage and alcohol': 0.50|0.08|0.53. V: FFQ1 v m24-hr DP scores: 'animal and plant protein': 0.47|0.01|0.48; 'nuts and sweets': 0.36|0.04|0.28; 'Chinese traditional': 0.58|0.04|0.28; 'beverage and alcohol': 0.53,0.0 5|0.26. V: FFQ2 v m24-hr scores: 'animal and plant protein': 0.46|0.0 2|0.47; 'nuts and sweets': 0.28|0.02|0.38; 'Chinese traditional':0. 28|0.02|0.36; 'beverage and alcohol': 0.26|0.05|0.30.
Korkalo et al. (2019), Finland, DAGIS: Increased health and wellbeing in Pre schools.	R: DP scores: 'sweets and treats' 0.27; 'health conscious' 0.33; 'vegetable, process meats' / 'sandwich' 0.25; all *P*<0.01.	n/a.	R: DP scores: classified in same quartile | misclassified in opposite quartile: 'sweets and treats' 34%|7%; 'health conscious' 35%|6%; 'vegetable, process meats' / 'sandwich' 35%|9%.

Study	Results: Correlation coefficient	Results: Bland Altman	Results: cross-classification, weighted κ
Niedzwiedzka et al. (2019), Poland.	R: DP scores: 60 FGs - DP1 0.84, DP2 0.68; 25 FGs - DP1 0.76, DP2 0.48; all *.	n/a.	R: DP scores: classified in same tertile | misclassified in opposite tertile: 60 FGs - 'DP1' 59% | 4%; 'DP2' 52% | 7%; 25 FGs - 'DP1' 54% | 8%; 'DP2' 39% | 14%.

κ = kappa statistic, CFA = confirmatory factor analysis, DHQ = diet history questionnaire, DP = dietary pattern, EFA = exploratory factor analysis, EI-adj = energy adjusted, F = female, FFQ = food frequency questionnaire, FFQ1 = test dietary assessment tool, FFQ2 = reference dietary assessment tool for reproducibility, FG = food group, FR = food record used as reference in validation, LoA = Limits of Agreement, M = male, mDHQ = mean intake from diet history questionnaire, mFR = mean intake from food record, NR = not reported, PCA = principal component analysis, R = reproducibility, sig = significance, USA = United States of America, V = validation.
P-value: *P<0.05, **P<0.01, ***P<0.001

Hu et al. (1999) performed the seminal study to validate dietary patterns to assess the relationship between the dietary patterns and health outcomes. The method used a 131-item FFQ to measure food consumed over a 1-year period (FFQ1). The same 131-item FFQ examined reproducibility (FFQ2) 1 year later. Two 1-week food records (FR) examined validity. Principal component analysis identified two similar dietary patterns from all dietary assessment tools (FFQ1, FFQ2 and FR): 'prudent' and 'Western'. Pearson correlation coefficients determined the similarity of dietary pattern scores for reproducibility and relative validity. Hu et al. (1999) also assessed correlations between 1) the dietary assessment tools and the daily intake for each food group, 2) the dietary pattern scores and energy-adjusted nutrient intake (using the residual method) from the FR and 3) the dietary pattern scores and plasma biochemical measures. Hu et al. (1999)'s results showed correlation coefficients between the dietary pattern scores of 0.70 for the 'prudent' pattern and 0.67 for the 'Western' pattern suggested 'reasonable' reproducibility (FFQ1 v FFQ2). Correlation coefficients between the dietary pattern scores of 0.45 for the 'prudent' pattern and 0.58 for the 'Western' pattern suggested 'reasonable' validity (FFQ1 v FR) (significance levels not reported). Other correlations between nutrient intake and blood plasma concentrations were as expected. This study set a benchmark for future studies assessing the reproducibility and relative validity of dietary patterns.

NEW TERMINOLOGY

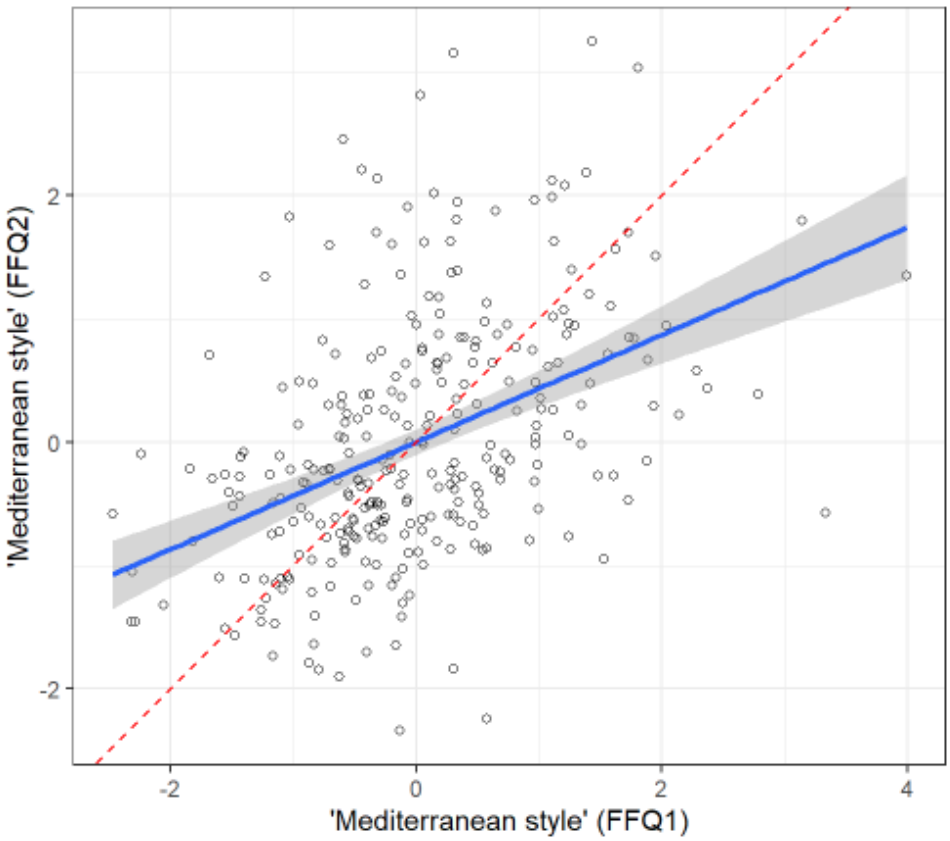
- **Reproducibility** describes how the measures, of the diet, from the dietary assessment tool will change over time.
- **Validity** describes how well a tool measures what it claims to be measuring.
  - **Construct validity** measures the latent constructs of the dietary data to confirm the dietary pattern measures what it claims to measure. Examples include
    - **confirmatory factor analysis** confirms the latent constructs by rebuilding the patterns with specified variables and number of factors.
    - Comparing the nutrient intake (from the food record) with the FFQ dietary pattern scores.
  - **Relative validity** measures the agreement between two dietary assessment tools with independent errors e.g., a FFQ and a food record

Over the next five years, other studies followed Hu et al. (1999)'s example of testing reproducibility and relative validity of dietary patterns (Togo et al., 2003, Khani et al., 2004, McNaughton et al., 2005). The main statistical analysis technique was correlation though Togo et al. (2003) also stratified by age, body mass index (BMI), energy intake, education, physical activity and smoking to

find minimal variation across the sub-groups. McNaughton et al. (2005) compared dietary patterns derived from a 24-hour recall (test) and a 5-day FR (reference), and a 48-hour recall (test) and a 5-day FR (reference) with the aim of evaluating the better test dietary assessment tool for dietary patterns. This study also measured construct validity i.e., dietary pattern scores compared with nutrient intake from the 5-day FR, similar to Hu et al. (1999). As expected, a 48-hour recall characterised the study participant's diet more effectively than a single 24-hour recall.

These early dietary pattern validation studies used a correlation coefficient as their single analytical tool. The coefficients ranged from 0.07 to 0.85 and the results of the studies have been described as 'good' (Hu et al., 1999), 'reasonable' (Hu et al., 1999, Khani et al., 2004), 'acceptable and robust' (Togo et al., 2003) or 'effectively characterising dietary patterns' (McNaughton et al., 2005).

Correlation coefficients can however mislead by measuring a linear relation (direction and magnitude), rather than perfect agreement between two methods (Bland and Altman, 1986). Measuring perfect agreement of two methods relies on identical scales of measurement where a change in one brings an identical change in the other (e.g., line of equality with correlation coefficient of 1.0, red line in top Figure 2) but correlation can have differing scales with correlation occurring along any straight line (e.g., blue line in top Figure 2). Correlation considers rank and relativity – if two sample groups have measurements ranked the same, they are correlated, and it is irrelevant if the unit of measures are the same or not.



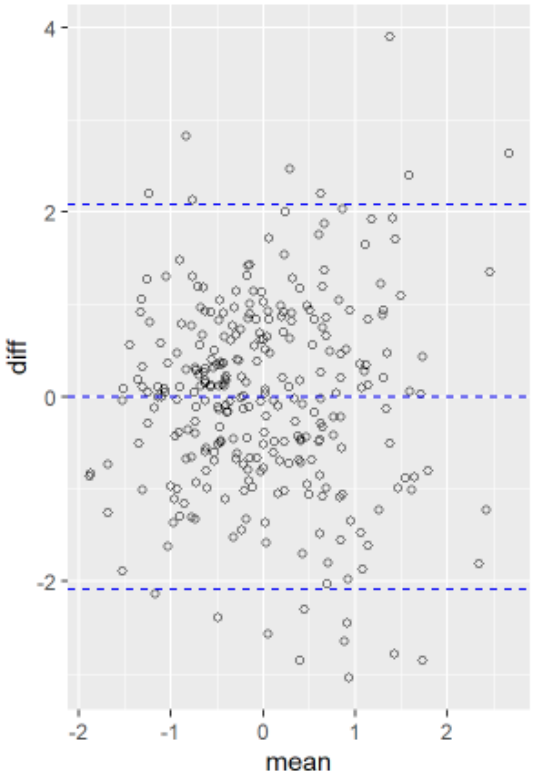


Figure 2: Bland Altman plots showing the dietary pattern scores from a 'Mediterranean style' dietary pattern derived from two FFQs (FFQ1 and FFQ2) administered one month apart.

Top – The red dashed line is the line of equality representing identical whereas the blue solid line represents correlation

Left – a Bland Altman plot where the x-axis represents the mean dietary pattern scores for each participant [(FFQ1 and FFQ2)/2] and the y-axis is the difference between the dietary pattern scores for each participant (FFQ1-FFQ2). The upper and lower blue dotted lines show the Limits of Agreement. The mean difference is the middle blue dotted line and lies at zero as the dietary pattern scores are standardised.

Bland and Altman (1986) suggested extra tools to measure absolute agreement. Firstly, a graphical tool where the score difference between the test and reference dietary assessment tool for each participant (y-axis) is plotted against the average of the two measurements for each participant (x-axis) (left Figure 2). A t-test can assess whether the mean score difference is significantly different to zero. Following this, Limits of Agreement to the graph are added at ± 1.96 standard deviations (SD), where 95% of differences should lie between these two points (left Figure 2). Finally, a slope of bias shows the presence, direction, and size of any bias. The slope of bias can be calculated using a correlation coefficient based on the score difference and mean score for each participant.

Crozier et al. (2008) used Pearson correlation coefficient to validate dietary patterns but also used a Bland Altman plot to find 'reasonable' agreement of dietary pattern scores between a FFQ and 4-day FR. The 'Western' pattern had lesser agreement than the 'prudent' pattern, with wider Limits of Agreement (2.22 v 1.58). The loadings from the 'Western' pattern, derived from a 4-day FR, included only four food groups from the 10 food groups loaded on the 'Western' pattern derived from the FFQ. This study considered these two 'Western' patterns (from the FFQ and the 4-day FR) 'comparable' because the dietary pattern scores were significantly correlated. However, the similarity of the 'two' Western dietary patterns remains unknown without an objective test comparing the loadings (rather than scores) of each of the 'Western' patterns.

Okubo et al. (2010)'s validation study of Japanese dietary patterns used correlation and Bland Altman methods, similar to Crozier et al. (2008). Okubo et al. (2010) pre-defined food groups to minimise the risk of removing food record lines due to a non-match in the FFQ food groups and over-estimating any correlations. Okubo et al. (2010) deemed the correlation coefficients found in Hu et al. (1999) and Khani et al. (2004) may be overstated as some items in the food record were unable to be matched to a FFQ food item. Hu et al. (1999) removed 254/1565 and Khani et al. (2004) 543/1181 food record lines as they remained unmatched to a food group in the 131-item (Hu et al., 1999) and 60-item (Khani et al., 2004) FFQs.

Ambrosini et al. (2011) expanded Bland Altman's validation techniques further by reporting differences of dietary pattern scores (FFQ scores minus food record scores, for each participant) but did not report whether the mean difference was significantly different to zero. Also, Ambrosini et al. (2011) compared dietary pattern scores with nutrient intakes and blood biomarkers (erythrocyte n-3 fatty acids) as done by Hu et al. (1999). The 'healthy' and 'Western' patterns showed similar correlations to the 'prudent' and 'Western' patterns reported in Hu et al. (1999). Likewise, the biochemical measures saw similar correlations as those by Hu et al. (1999) - positive in 'healthy' and negative in 'Western' patterns.

Comparing blood biomarkers with dietary pattern scores adds strength to a validation study by enabling the method of triads to be completed. The method of triads is a triangular comparison between a test method (e.g., FFQ), a reference method (e.g., food record) and a dietary biomarker (Lombard et al., 2015). Using biomarkers for validation has limitations. Measuring biomarkers can be expensive, invasive, and nutrient specific. A biomarker measurement only provides an estimate of the dietary intake and contains errors. For example, measurements are subject to the effects of digestion, absorption, and utilisation of the nutrient and errors associated with the actual measurement of the biomarker (Cade et al., 2002). However, the benefit of including a biomarker is that biomarker errors are independent of associated errors from the FFQ or food record.

Over the period 2010 to 2015 more dietary pattern validation studies were published, yet the number of statistical methods used varied from one (correlation coefficient) (Nanri et al., 2012, Ryman et al., 2015) or two (a correlation coefficient and Bland Altman or cross classification) (Bountziouka et al., 2011, Mills et al., 2015, Appannah et al., 2014, Asghari et al., 2012) to four methods (combinations of correlation coefficient, Bland Altman with t-test and cross classification with a weighted-κ statistic) (Beck et al., 2012, Loy and Mohamed, 2013, Liu et al., 2015). In 2015, Lombard et al. (2015) published a review assessing validation methods for dietary assessment tools. Lombard et al. (2015) was concerned studies were concluding dietary assessment tools as valid, based on limited statistical tests. Lombard et al. (2015) named six statistical tests (and their cut-off points) for validation purposes with differing facets of validity. Using a full set of tests can determine the type of validity – relative (at the individual level and suitable for ranking) or absolute (at the group level) (Gibson, 2005) (Table 2.8). Nevertheless, dietary pattern validation studies continued to use limited statistical methods (Korkalo et al., 2019, Niedzwiedzka et al., 2019).

Table 2.8: Statistical tests used in dietary assessment validation and their facets of validity

Level applied to	Statistical test	Facet of validity
Individual	Correlation coefficient[a]	Strength and direction of association
	Cross classification	Agreement (includes chance)
	Weighted Kappa statistic	Agreement (excludes chance)
Group	Paired t-test	Agreement
	Percent difference[b]	Strength and direction of agreement
	Bland Altman analysis	Presence, direction, and strength of bias

[a] correlation coefficient was the most used statistic
[b] percent difference was the least used statistic
Adapted from (Lombard et al., 2015)

Two recent systematic reviews explored the reproducibility and validity (both relative and construct) of *a posteriori* dietary patterns (Edefonti et al., 2019, Jannasch et al., 2018) based on 16 studies. The main tool for dietary assessment was the FFQ and principal component analysis for dietary patterns. Median time between administrations of the FFQ (for reproducibility) was 12 months. Most studies reported good reproducibility and fair (Edefonti et al., 2019) or modest (Jannasch et al., 2018) relative validity with more convincing results over shorter time frames. Reproducibility studies had better results than relative validity studies. This can be expected as a second administration of an FFQ will cover a similar period as the first, but a food record is likely to cover a shorter time and not capture as many food groups (Jannasch et al., 2018). Dietary patterns with fewer correlated food groups were more likely to have higher reproducibility and relative validity than 'well-characterised' dietary patterns (Edefonti et al., 2019).

Edefonti et al. (2019) expressed three concerns around methodology. Firstly, any dietary patterns not common to all dietary assessment tool data sets were often not discussed. Secondly, the number of dietary patterns to retain were decided separately for test and reference patterns. Thirdly, there were subjective decisions regarding similarities between test and reference dietary patterns relying on loadings, % of variance explained and elementary statistics. The comparison of factor loadings between test and reference dietary patterns are sometimes acknowledged and described as similar or consistent (Beck et al., 2012, Khani et al., 2004, Hu et al., 1999, Hong et al., 2016, Liu et al., 2015) or they shared similar rankings and associations (though, sometimes there were differences in the food group loadings) (Appannah et al., 2014, Okubo et al., 2010) or sometimes not acknowledged at all (Asghari et al., 2012, Mills et al., 2015, Loy and Mohamed, 2013). Similar to above, variation in the loadings of dietary patterns may be due to methodological differences between dietary assessment tools (Willett, 2012), where the food record fails to capture all food groups captured in the FFQ due to different periods, time lengths, and random statistical variation.

Objectively comparing loadings between dietary patterns needs to be addressed: similar or agreeable dietary pattern scores do not necessarily indicate similar dietary pattern loadings. Korkalo et al. (2019) concluded their FFQ could be used to derive consistent dietary patterns based on correlated dietary patterns scores (rho = 0.25, $p < 0.01$), however the loadings in the dietary patterns may not be similar as there were only three of nine loadings in common between the dietary patterns. Without objective statistical analysis, the similarity of dietary pattern loadings remains unknown and a subjective decision. Comparing the sameness of dietary pattern loadings requires a clear method and leaves a gap in the methodology of dietary pattern validation.

2.3.3. Limitation of this review

One limitation from this literature review was the absence of 'reliability' from the search strategy. Sometimes 'reproducibility' can also be considered as 'reliability' but can also refer to the reliability of interviewers (either between interviewers or between different interviews with the same people) (Cade et al., 2002). The measure of reliability does not occur often (Edefonti et al., 2019) therefore its absence from the search strategy is not considered substantial.

2.3.4. Concluding items

Many *a posteriori* dietary patterns are derived from valid dietary assessment tools. Dietary pattern analysis involves subjective decisions and therefore demand validation prior to exploring associations between the dietary pattern and health outcome. Indeed, very few studies perform this necessary validation of their dietary patterns. To strengthen dietary pattern analysis and improve the robustness of dietary patterns through validation and reproducibility:

- dietary pattern loadings derived from the test and reference dietary assessment tool need to be objectively assessed to determine their similarity,
- a full array of recommended statistical tools should be used,
- known biomarkers should be used, when available, to complete a method of triads,
- food groups should be pre-defined and applied to both the FFQ and FR to reduce superfluous food record items.

Applying more research to develop methodology guidelines can encourage the validation of derived dietary patterns, in particular objective methods to determine similarity of dietary pattern loadings.

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2.4. Dietary patterns, socio-demographic and lifestyle factors in older adults: a literature review of observational studies

This section of the literature review chapter discusses the influence socio-demographic and lifestyle factors have on the choice of dietary patterns followed by the older adult. Factors examined are age, sex, ethnicity, education and income, area deprivation, whether a person lives on their own or with someone, and physical activity. Alcohol and smoking are examined separately and as a cluster. Dietary patterns and their associations with socio-demographic and lifestyle factors are reviewed in the New Zealand population across all age groups.

2.4.1. Background information, aim and search methods

KEY POINTS

- Education is a strong and consistent determinant of a dietary pattern with healthy food groups.
- Healthy lifestyle behaviours suggest a dietary pattern with healthy food groups.
- New Zealand studies are primarily based at the younger end of life. A gap exists to explore dietary patterns, socio-demographic and lifestyle factors in older New Zealand adults.

Many factors influence what we eat: the amount of energy we require; our taste preferences (Glanz et al., 1998); cultural influences; a social situation or expectation; food availability and accessibility; our socio-economic situation; where we live; lifestyle choices; health; and many more. The relationships between nutrition, the diet and health outcomes are recognised by science, where a healthy diet, with appropriate energy and nutrients, can support a healthy population and prevent non-communicable disease (World Health Organization, 2019).

Healthy ageing in the older population brings unique challenges compared to other life stages. Movement, sensory, cognitive, and immune functions decline with age (World Health Organization, 2015). These changes affect food choice. Examples include changes in taste and olfactory function may result in a preference for sweet foods or bitter and sour foods (Sergi et al., 2017); reduced appetite will alter dietary intake (Whitelock and Ensaff, 2018); declining physical function can limit access to food (Whitelock and Ensaff, 2018); and changes in oral health may limit intake of some foods (Kiesswetter et al., 2018, Whitelock and Ensaff, 2018). Healthy ageing also depends on demographics, socio-economic, and lifestyle factors.

People with a lower socio-economic status tend to consume lower quality diets. This relationship is consistent with all ages and both sexes (Darmon and Drewnowski, 2008). Socio-economic factors,

diet quality, and non-communicable disease can all follow a similar gradient and socio-economic factors may have a causal influence on diet quality (Darmon and Drewnowski, 2008). Given the relationship between the diet, and demographics, economic, and lifestyle factors (Meader et al., 2016, Darmon and Drewnowski, 2008) it is important to identify determinants of dietary intake. Understanding these determinants can guide the development and targeting of tailored he alth promotion programmes and highlight necessary confounders to consider when exploring the relationship between the diet and disease.

This literature review focuses on *a posteriori* dietary patterns and their associations with socio-demographic and lifestyle factors in community-dwelling, older adults. A search was undertaken using Web of Science and three search areas: socio-demographic factors, dietary patterns (*a posteriori*), and older adults (Table 2.9). The selected peer-reviewed manuscripts included participants older than 40 years and living in the community. Additionally, studies undertaken in the New Zealand population across all age groups are reviewed.

Table 2.9: Search strategy for studies examining associations between *a posteriori* dietary patterns and socio-demographic and lifestyle factors

	Search term	
	sociodemographic	OR
	socio-demographic	OR
	socioeconomic	OR
	socio-economic	OR
AND	diet	
AND	princip* compon* analys*	OR
	PCA	OR
	factor analysis	OR
	cluster analysis	OR
	rank regression	OR
	posteriori	OR
	empirica* deriv*	OR
	mult*varia* analys*	OR
	dietary pattern*	
AND	ageing	OR
	aging	OR
	older adult	OR
	older people	OR
	elderly	

2.4.2. Results from literature search

The search found 14 cross-sectional and three longitudinal studies (Table 2.10 and Table 2.11). Most studies were based in Europe (*n* 5), North America (*n* 4), the United Kingdom (*n* 3), Australia (*n* 2), Asia (*n* 2) or the Middle East (*n* 1). The dietary data were collected by validated FFQ (*n* 11), food records covering 3, 4, or 5 days (*n* 3) or 1, 2, or 3 24-hour recalls (*n* 3). The studies derived dietary patterns [or nutrient patterns (*n* 1)] using principal component analysis (*n* 11) followed by cluster analysis (*n* 4), or other methods (*n* 4). Two studies used both principal component and cluster analysis to derive one set of dietary patterns. Dietary pattern names were based on the main food group components or a character description of the pattern. Common pattern names were 'healthy', 'prudent', 'Western', 'traditional'.

Many studies reviewed were large: 13 studies had sample sizes greater than 1,000, and contained good descriptions of recruitment, study design, subject and setting details. One of the limitations of the studies was the use of ANOVA or Chi-square test for statistical analysis (*n* 4) which does not consider possible influences from other variables e.g., age may influence living alone. Often significant results using a univariate method (ANOVA or Chi-square) are attenuated when added into a multivariate model (Thompson et al., 2010).

Table 2.10: Fourteen cross-sectional studies exploring associations between *a posteriori* dietary patterns and socio-demographic and lifestyle factors

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Pryer et al. (2001), United Kingdom.	British population, *n* 1,097, 65+ yrs, 49% M.	1. 4-DFR (weighed), 2. CA, stratified by sex, 3. 27 FGs, 4. intake by volume.	M - '**mixed**' (*n* 273): ↑HF milk/cream, LF spreads; ↓brown bread, cheese, fruit, sauces/pickles; '**healthy**' (*n* 122): ↑alc, brown bread, LF spreads, fruit; ↓refined cereals, yoghurt/ice cream, butter, margarine, chicken/turkey, juice, SSB, soup/pickles; 't**raditional**' (*n* 97): ↑HF milk/cream, cheese, alc; ↓pasta/rice, LF milk, yoghurt/ice cream, chicken/turkey, fruit juice, SSB, soups/pickles. F - '**sweet, traditional**' (*n* 192): ↑biscuits/cakes/pastries, whole milk/cream, sugar/preserves; ↓butter; '**healthy**' (*n* 185): ↑brown bread, whole grain cereals, LF milk, yoghurt, cheese, LF spread, chicken/turkey, fruit; ↓HF milk/cream; '**mixed**' (*n* 102) ↑white bread, LF milk; ↓HF milk/cream.	1. '**healthy**': ↑income; ↓age, smoking, manual social class, receipt of benefit cf '**mixed**' and '**traditional**' (M&F); '**healthy**': ↑education cf 'mixed' and '**traditional**' (M only). 2. ANOVA, Chi-square as appropriate; no confounders.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Park et al. (2005), USA, Hawaii-Los Angeles Multi-ethnic Cohort.	African American, Hawaiian, Japanese American, Latino, White, *n* 195,298, 45-75 yrs, 45% M.	1. FFQ (V), 2. PCA, 3. 20 FGs, 4. intake by volume.	3 DPs explained 64% of variation in diet '**fat and meat**': ↑discretionary fat, meat, organ/proc'd meat, potatoes, refined grains, eggs, cheese; '**vegetables**': ↑veg, citrus, melons/berries, fruit; '**fruit and milk**': ↑milk/yoghurt, citrus, melons/berries, fruit, cheese.	1. '**fat and meat**': ↑M, Hawaiian and Latino (cf Whites), BMI, smoking, alc, PA (light); ↓age, education, diet suppl; '**vegetables**': ↑age, Hawaiian and Japanese Americans (cf Whites), education, alc, PA, diet suppl; ↓M, smoking; '**fruit and milk**': ↑age, Latinos (cf Whites), educated, PA, alc; ↓African American (cf Whites), smoking. 2. Logistic regression; A, S, E, ethnicity, BMI, smoking, alc, PA, suppl use, cancer, family history of cancer.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Bamia et al. (2005), 9 European countries, EPIC - Elderly.	European, *n* 99,744, 60+ yrs, 34% M.	1. FFQ (V), 2. PCA and CA, 3. 22 FGs, 4. intake by volume, EI-adj using residual method.	2 DPs explained 24% of variation in diet PCA - **'vegetable based**': ↑veg oils, fruit, pasta/rice/other grains/veg/legumes; ↓non-alc beverage, potato, margarine; '**sweet and fat-dominated**': ↑other cereals, cakes, condiments/sauces, margarine, sugar/confectionery, dairy; ↓meat, bread, other alc beverage, wine, eggs. CA - '**cluster A**' (n 18,562): ↑veg, legumes, fruit, pasta, rice, grain, veg oils, wine; ↓potatoes, butter/margarine, dairy, meat, sugar, cakes, alc (except wine); '**cluster B**' (41,912): ↑potatoes, cereals, butter/margarine, sugar, cakes; ↓veg, legumes, pasta, rice, fruit, veg oils; '**cluster C**' (n 39,270): ↑non-alc and alc beverages; ↓veg, legumes, pasta, rice, fruit, veg oils.	1. '**vegetable-based**': ↑F***, education***, BMI***, EI***, manual or sedentary work***, PA***; ↓age***, smoking***; '**sweet and fat-dominated**': ↑F***, age***, secondary school completed**, EI***, PA*; ↓BMI***, manual work***, smoking***. **Cluster A** was overwhelmingly followed by adherers to 'vegetable-based'. 2. Linear regression; A, S, E, BMI, WHR, EI, PA, smoke, study centre.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Cai et al. (2007), China, Shanghai Men's Health Study (SMHS).	Chinese population, *n* 61,582, 40-74 yrs, 100% M.	1. 81-FFQ over 12 mths (V), 2. PCA, 3. 81 FGs, 4. intake by volume.	3 DPs explained 79% of variation in diet '**vegetable**': ↑veg, legumes; '**fruit**': ↑fruit; '**meat**': ↑meat, poultry and animal parts.	1. '**vegetable**': ↑WHR***, education***, tea consumption***, PA; ↓age***, smoking***; '**fruit**': ↑income***, education***, tea consumption***, PA; ↓WHR***, worker or farmer***, smoking***, alc***; '**meat**': ↑WHR**, income***, education***, smoking***, alc***, tea consumption***, PA; ↓age***, worker and farmer***. 2. Logistic regression; A, E, income, smoking, alc, PA, WHR, EI.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Chan et al. (2012), Hong Kong.	Chinese, *n* 3,707, 65+ yrs, 52% M.	1. 280-FFQ over 12 mths (V), 2. PCA, 3. 32 FGs, 4. intake as % contribution to total energy.	3 DPs explained 17% of variation in diet '**vegetables-fruits**': ↑veg, fruits, soy products, legumes; '**snacks-drinks-milk products**': ↑fast food, sweets, desserts, nuts, milk products, whole grains; '**meat-fish**': ↑meat, fish/seafood.	1. M - '**vegetables-fruits**': ↑age, PA, EI, education; ↓alc, smoking; '**snacks-drinks-milk products**': ↑EI, education, Hong Kong ladder, alc, smoking; '**meat-fish**': ↑EI, alc, ↓education. F - '**vegetables-fruits**': ↑EI, community ladder; ↓alc; smoking; '**snacks-drinks-milk products**': ↑EI, education, Hong Kong ladder, alc, smoking; '**meat-fish**': ↑EI, ↓PA. Hong Kong ladder : subjective measure of wealth, education and job status. Community ladder: subjective measure of standing in community. 2. Linear regression, stratified by sex; A, E, EI, PA, Hong Kong ladder, community ladder, smoking, alc.
Hsiao et al. (2013), USA, University of Alabama at Birmingham Study of Aging.	Non-Hispanic Whites and African-Americans, *n* 416, 65+ yrs, 44% M.	1. 3 x 24-hr, 2. LCA, 3. 13 FGs, 4. intake by volume, EI-adj using density method.	'**Western-like**' (*n* 172): ↑fats/oils, refined grain, poultry, fish; ↓dairy; '**low produce, high sweets**' (*n* 168): ↑sweets; ↓fruits, veg; '**more healthful**' (*n* 76): ↑fruit, veg, whole grains, eggs, nuts, legumes, dairy.	1. '**more healthful**': ↑female*, non-Hispanic White***, education*, income*** compared with '**Western-like**' and '**low produce, high sweets**'. 2. Chi-square analysis, ANCOVA; no confounders.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Esmaili et al. (2015), Iran.	Coronary artery disease, *n* 250, 45+ yrs, 52% M.	1. 127-FFQ over 12 mths (V), 2. PCA, 3. 25 FGs, 4. intake by volume.	3 DPs explained 33% of the variation in diet '**traditional**': ↑red/organ meat, poultry, butter, HF dairy, tea, legumes, garlic, refined grains, nuts, olive, hydrogenated oils, pickles, fruit, veg; '**Western**': ↑fast foods, eggs, mayonnaise, sweets and desserts, SSB, French fries, chips; '**healthy**': ↑fish, LF dairy, whole grains, veg oils; ↓hydrogenated oils, HF dairy.	1. '**traditional**': ↑PA, income; ↓education, housewives; variables explained 23% of variation in 'traditional'; '**Western**': ↑smoking; ↓age, farmer, housewives; variables explained 19% of variation in 'Western'; '**healthy**': ↑F, income, urban living; ↓farmers; variables explained 15% of variation in 'healthy'. 2. Multiple linear regression; A, S, E, occupation, income, smoking, place of residence.
Granic et al. (2019), United Kingdom, Newcastle 85+ study.	British population, *n* 791, 85+ yrs, 38% M.	1. 2 x 24-hr, excl Fri, Sat taken by trained research nurses, 2. CA, 3. 33 FGs, 4. dichotomous, consume Y/N.	'**high red meat**' (*n* 277): ↑red meats/meat dishes, gravy, potato/potato dishes, legumes, USF spreads; ↓butter; '**low meat**' (*n* 260): ↑fruit, nuts, whole grains/cereal, seafood, eggs, soup, LF/HF dairy, coffee, alc; ↓meat/meat dishes, gravy, potato/potato dishes; moderate in butter; '**high butter**' (*n* 256): ↑butter; moderate in red meats; ↓spreads.	1. '**low meat**': ↑education; ↓ (cf 'high red meat' and 'high butter'), deprivation index and occupational class ns. 2. Logistic regression; E, BMI, cognitive status, PA, smoking, occupational status, deprivation index.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Kell et al. (2015), USA, REasons for Geographic And Racial Differences in Stroke (REGARDS).	Black (35%), White, *n* 17,062, 45+ yrs, 46% M.	1. 107-Block98 FFQ over 12 mths (V), 2. PCA, 3. 56 FGs, 4. NR.	'**convenience**': ↑mixed dishes with meat, pasta dishes, Mexican dishes, pizza, red meat, soup, chinese dishes, french fries, potato, beans/legumes; '**plant-based**': ↑fruit, veg, fish, breakfast cereal, beans/legumes, soup, tomato; '**sweets/fats**': ↑misc sugar, dessert, bread, chocolate, candy, added fats, sweet breakfast foods, margarine, HF dairy, tea; '**Southern**': ↑fried food, organ/proc'd meat, eggs, added fats, SSB, bread; '**alcohol/salads**': ↑dressings/sauces, green leafy veg, wine, butter, liquor.	1. '**convenience**': ↑education, community-level SES; 'plant-based': ↑income, education, community-level SES; '**sweets/fats**': ↓income, education, community-level SES; '**Southern**': ↓income, education, community-level SES; '**alcohol/salads**': ↑income, education, community-level SES. 2. Logistic regression; A, S, E, race, region, income.
Allès et al. (2016), France / Canada, Three-City &, NuAge.	French and Canadian population, *n* 3,308, 65+ yrs, 37, 49% M.	1. 1 x 24-hr, 2. PCA, 3. 21 nutrients, 4. intake by volume, EI-adj using residual method.	Three-City: 3 DPs explained 50% of variation in diet '**healthy**' ↑CHO, fibre, Mg, K, Fe, carotene, vit B6, C, E, folate; ↓vit D; '**Western**' ↑pro, SFA, MUFA, n-3, n-6 PUFA, Ca, P, Mg, Vit D; '**traditional**' ↑vit A, B12. NuAge: 3 DPs explained 54% of variation in diet '**healthy**' ↑CHO, fibre, Mg, K, Fe, carotene, vit B6, C, E; '**Western**' ↑pro, SFA, MUFA, n-3, n-6 PUFA, Ca, P, Mg, vit D, folate; '**traditional**' ↑vit A, B12, Zn.	1. Three-City - '**healthy**': ↑education (10-13 yrs); '**Western**': ↑F; '**traditional**': ns. Nu-Age - '**healthy**': ↑education, non-physical occupations, living alone, BMI; ↓smoking; '**Western**': ↑smoking; ↓education, BMI; '**traditional**': ns. 2. Linear regression; S, E, BMI, smoking, income, main occupation, living arrangement.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Markussen et al. (2016), Norway.	Norwegian post-menopausal women, *n* 6,298, 50-69 yrs, 0% M.	1. 253-FFQ over 12 mths (V), 2. PCA, 3. 49 FGs, 4. intake by volume.	3 DPs explained 18% of variation in diet '**prudent**': ↑veg, fruit, fish, herbs/spices, berries, nuts/seeds, legumes, meat dishes, soup, tea, salad dressings, poultry; '**Western**': ↑potatoes, sauce, refined grains, red/proc'd meat, cakes/desserts, margarine, sweet spreads; ↓wine, nuts/seeds, herbs/spices; '**Continental**': ↑tomato sauce, pasta, proc'd meat, fat-rich potatoes, pizza, salty snacks, salad dressings, rice, poultry, mustard, wine.	1. '**prudent**': ↑age, education, BMI, PA; ↓smoking (all***); '**Western**': ↑age**, BMI**; ↓education***, PA***, smoking***; '**Continental**': ↑education, BMI, smoking; ↓age, PA (all***). 2. Linear regression; A, E, BMI, PA. smoking, EI.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Thorpe et al. (2016), Australia, Wellbeing eating and exercise for a Long Life (WELL).	Australian population, *n* 3,959, 55-65 yrs, 48% M.	1. 111-FFQ over 6 mths (V), 2. PCA and CA; stratified by sex, 3. 52 FGs, 4. intake by frequency.	M - 4 PCA DPs explained 23% of variation in diet **DP1**: ↑veg dishes, fruit, fish/poultry; ↓potato; **DP2**: ↑spreads, biscuits, cakes and confectionery (similar to cluster 2); **DP3**: ↑red/proc'd meat, white bread, fried fish/hot chips; ↓muesli/porridge, LF milk (similar to cluster 2); **DP4**: ↑veg (similar to cluster 1). **cluster 1** (25%): ↑fruit, veg, whole grain bread, fish/poultry; **cluster 2** (18%): ↑red/proc'd meat, white bread, flavoured drinks, cakes, pastries/confectionery; '**small eaters'** (57%): lower mean frequency for most food items. F - 2 PCA DPs explained 14% of variation in diet **DP1**: ↑veg, fruit, fish (similar to cluster 1); **DP2**: ↑cakes, proc'd meat, hot chips, confectionery (similar to cluster 2); **cluster 1** (25%): ↑fruit, veg, nuts, legumes, fish; **cluster 2** (20%): ↑red/proc'd meat, white bread, flavoured drinks, cakes, pastries, confectionery; '**small eaters**' (55%): lower mean daily intake frequency for the most foods.	1. M - **DP1**: ↑education**, never smoked*, PA**;↓Australian born**; **DP2**: ↑Australian born**, PA*; **DP3**: ↑BMI*, smokers; ↓age*, education**, PA**; **DP4**: ↑Australian born**, married**, PA*;↓education. **cluster 1**: ↑education, non-smoking, PA; ↓BMI; **cluster 2**: ↑Australian born, BMI; ↓age; **cluster 3**: ↑non-smokers, PA. F - **DP1**: ↑education**, non-smokers**, PA**; ↓BMI*; **DP2**: ↑Australian born**, married**, retired*; ↓education**, PA** **cluster 1**: ↑non-smokers, PA; **cluster 2**: ↑BMI, retired; ↓education. 2. Chi-square analysis; no confounders.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Andreeva et al. (2016), France, NutriNet-Sante e-cohort part of ALIMASSENS Collaborative Project.	French population, *n* 6,686, 65+ yrs, 45% M.	1. 3-DFR, non-consecutive over 2 wks incl 1 weekend day, 2. PCA, 3. 22 FGs, 4. intake by volume.	3 DPs explained 25% of the variation in diet '**healthy**': ↑fruit, veg, nuts, whole grains, fish, veg oils; ↓sugar; '**Western**': ↑red/organ meats, appetizers, cheese, alc; '**traditional**': ↑bread, potatoes, milk, veg, butter/margarine, stock.	1. '**healthy**': ↑education**, living alone**; ↓age** (F only), overweight*** (M only), obesity*** (F only), smoking (M only); '**Western**': ↑obesity* (M only), smoking***; ↓age* (F only), living alone*; **traditional**': ↑age***; ↓education** (M only), smoking***. 2. Linear regression, stratified by sex; A, E, BMI, living situation, smoking, BP, residential area.

Study	Population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Bishop et al. (2020), USA, HRS (Health and Retirement Study) / HCNS (Health Care and Nutrition Study).	White, Black, Hispanic, Other Americans, *n* 3,558, 65+ yrs, mixed% M.	1. 164-Harvard FFQ covering 12 mths (V), 2. LPA, 3. 35 FGs, 4. intake by volume.	'**healthy**' (*n* 552): ↑veg, fruit, legumes, LF dairy, nuts, olive oil, tea, whole grains; ↓red meat, proc'd foods, condiments, energy drinks; '**Western**' (*n* 1,495): ↑red meat, proc'd foods, coffee, condiments, HF dairy, energy drinks; ↓veg, fruit, legumes; '**high intake**' (*n* 1,058): ↑veg, fruit, legumes, red meat, proc'd foods; '**low intake**' (*n* 453): ↓veg, fruit, legumes, red meat, proc'd foods.	1. '**healthy**': ↑F, income, white collar, education, normal BMI, PA; ↓White, married/partnered, retired, smoking; '**Western**': ↑high school degree education, blue collar, smoking; ↓F, higher education, white collar, normal BMI, PA; '**high intake**': ↑income, White, married/partnered, education, white collar, normal BMI, alc, PA; ↓Black, Hispanic, Other, food insecurity, smoking; '**low intake**': ↑Hispanic, Other, blue collar, homemaker, other, food insecurity, smoker; ↓income, White, married/partnered, education, white collar, alc, PA, limitation in ADL. 2. ANOVA/Chi square with Bonferroni adj.

25-hr = 24-hour recall, A = age, adj = adjustment, ADL = activities of daily living, alc = alcohol, BMI = body mass index, CC = congruence coefficient, DFR = days food record, CA = cluster analysis, cf = compared with, DP = dietary pattern, E = education, EFA = exploratory factor analysis, EI = energy intake, EI-adj = energy intake adjusted, F = female, FG = food groups, HF = high fat, LF = low fat, LPA = latent profile analysis, M = male, misc = miscellaneous, mths = months, NR = not reported, ns = not significant, PA = physical activity level, PCA = principal component analysis, proc'd = processed, S = sex/gender, SES = socio-economic status, SSB = sugar sweetened beverages, suppl = supplement, USA = United States of America, USF = unsaturated fats, V = validated, veg = vegetables, WHR = waist to hip ratio, wk = week, yrs = years
P-value: *<0.05; **<0.01; ***<0.001, ns≥0.05

Table 2.11: Three longitudinal studies exploring associations between *a posteriori* dietary pattern changes and socio-demographic and lifestyle factors

Study	Follow-up population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method 3. # of food groups 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Mishra et al. (2006), United Kingdom, 1946 British Birth Cohort.	7, 10 yrs, British, *n* 1,265, 53 yrs at last follow-up (1999), mixed	1. 5-DFR (consecutive days), 2. EFA, stratified by sex, 3. 126 FGs, 4. dichotomous, consume Y/N.	M - '**ethnic foods and alcohol**': ↑Indian/Chinese meals, rice/pasta, shellfish, olives, some veg, legumes, alc; ↓meat pies, fried chips, animal fats; '**mixed**': ↑fruit, veg, LF yoghurt, soya milk, cakes, sweet biscuits & pies, puddings, desserts, confectionery, ice cream. F - '**ethnic foods and alcohol**': ↑Indian/Chinese meals, rice/pasta, oily/shell fish, olive oil, some veg, alc; '**meat, potatoes and sweet food**': ↑red/proc'd meat, potato, sweet pies, cakes, puddings/desserts; ↓pasta, LF milk; '**fruit, vegetable and dairy**': ↑LF dairy, fruit, some veg, wholemeal bread; ↓meat products, white bread.	1. F - ↑over time*** in '**ethnic foods and alcohol**', ↑education***, non-manual social class**, ↓BMI*; ↑over time*** **'fruit, vegetables and dairy**', ↑London and SE cf North**, non-manual social class**, education***, U-trend: BMI***; ↓over time*** '**meat, potatoes and sweet foods**': ↓Scotland cf London and SE***. M - ↑over time*** '**ethnic foods and alcohol**': ↑education***, non-manual social class***, London and SE cf other regions***; ↑over time*** '**mixed**': ↑education***, non-manual social class***, ↓BMI***, smoking***. 2. Mixed model; E, BMI, smoking time, social class, region
Harrington et al. (2014), Ireland, Cork and Kerry Diabetes and Heart Disease Study.	10 yrs, Irish, *n* 359, 50-69 yrs baseline, 48% M.	1. 167-FFQ over 12 mths (V), 2. LCA, 3. 23 FGs, 4. intake by volume.	'**Western**': ↑cereal, bread/potato, dairy, red/proc'd meats, foods from top shelf of food pyramid; ↑salt, EI; ↓DASH score; '**healthy**': ↑fruit, veg, LF dairy; ↑DASH score; '**low-energy**': ↓red meat, sweet snacks, EI.	1. Change to '**healthy**': ↑education, CVD risk factors at baseline: smokers, central obese. 2. Univariate analysis.

Study	Follow-up population *n* age sex	1. Dietary assessment tool 2. Dietary pattern method 3. # of food groups 4. Input variable	Dietary patterns identified	1. Dietary patterns and associations with socio-demographic and lifestyle factors 2. Statistical method; confounders
Thorpe et al. (2019), Australia, WELL (Wellbeing eating and exercise for a Long Life).	2 x 2 yrs, Australian, *n* 2,111, 55-65 yrs, 48% M.	1. 111-FFQ over 6 mths (V), 2. PCA, 3. 52 FGs, 4. intake by frequency.	M - 2 DPs explained 11% of variation in diet '**factor 1**': ↑veg dishes, seafood, oil/vinegar dressings, salad veg; '**factor 2**': ↑red/proc'd meat, pizza/hamburger, white bread, fried fish; Tucker's CC 2010/12 0.96, 0.93; 2010/14 0.66, 0.72 but qualitatively similar. F - 2 DPs explained 14% of variation in diet **'factor 1**': ↑veg, fruits, seafood; **'factor 2**': ↑cakes/pastries/other desserts, proc'd meat; Tucker's CC 0.90, 0.97.	1. Reduced consumption in all factors was observed***; predictors of change to healthier pattern were ↑education, not smoking, PA. 2. Linear regression; baseline PCA score, region, A, BMI, smoking and PA.

A= age, adj = adjusted, alc = alcohol, BMI = body mass index, CC = congruence coefficient, CVD = cardiovascular disease, cf = compared with, DASH = Dietary Approaches to Stop Hypertension, DP = dietary pattern, E = education, EFA = exploratory factor analysis, EI = energy intake, F = female, FG = food groups, HF = high fat, LF = low fat, LCA = latent class analysis, M = male, mths = months, NR = not reported, ns = not significant, PA = physical activity level, PCA = principal component analysis, proc'd = processed, veg = vegetables, yrs = years.

P-value: *<0.05; **<0.01; ***<0.001, ns≥0.05

2.4.3. Socio-demographic determinants of the dietary pattern

2.4.3.1. Age

In broad population-based studies relationships between age and dietary patterns are present (Conti et al., 2004, Beck et al., 2018, van Dam et al., 2003, Kang and Sohn, 2016, Okada et al., 2018, Whichelow and Prevost, 1996), though the preferred dietary pattern at a particular life stage is not consistent. Associations with age and dietary patterns across an entire age range may be influenced by generational matters, but associations are also seen in older adult studies where the age span is narrowed to 10–30 years and may be driven by other factors, for example, a loss of functionality, change in living situation, or adopting a diet to support a health condition e.g., diabetes.

The younger segment of the older adults (aged 65 plus years) preferred a mix of healthy and unhealthy food groups e.g., 'healthy' (Pryer et al., 2001, Andreeva et al., 2016); vegetable based (Bamia et al., 2005, Cai et al., 2007); 'meat' (Cai et al., 2007), and Western (Thorpe et al., 2016, Andreeva et al., 2016, Esmaili et al., 2015) patterns. Conversely 'sweet and fat-dominated' (Bamia et al., 2005); 'traditional' (Andreeva et al., 2016); 'prudent', 'Western', 'Continental' (Markussen et al., 2016); and 'vegetables-fruits' (Chan et al., 2012) patterns were preferred by the older of the older age segment. In some instances, no associations between dietary patterns and age were reported.

2.4.3.2. Sex

It is reported women tend to be responsible for preparing food, are more health conscious, have a greater nutrition knowledge, and read food labels (Baker and Wardle, 2003). Whereas older men are (generally) less concerned with eating well, have lower nutrition knowledge, and consume less fruit and vegetables than women (Baker and Wardle, 2003).

Of the 14 cross-sectional studies reviewed, two studies were single sex [male (Cai et al., 2007), female (Markussen et al., 2016)] and two studies derived sex-specific dietary patterns (Thorpe et al., 2016, Pryer et al., 2001). Where studies kept the dietary data set complete for dietary pattern analysis, a preference for one sex to follow a specific pattern type was not observed. 'Fat and meat' (Park et al., 2005) or a 'Western' cluster (Bishop et al., 2020) were preferred by males and a 'more healthful' cluster (Hsiao et al., 2013), vegetables based (Park et al., 2005, Bamia et al., 2005), and 'healthy' (Bishop et al., 2020, Esmaili et al., 2015) patterns were preferred by females. In some cases, females preferred a pattern with unhealthy food groups e.g., 'sweet and fat-dominated' (Bamia et al., 2005) or 'Western' (Allès et al., 2016).

2.4.3.3. Ethnicity

Ethnicity was rarely considered in these dietary pattern studies except for three of four studies based in the United States (Bishop et al., 2020, Hsiao et al., 2013, Park et al., 2005). The three studies reported Japanese Americans (compared with Whites[11]) belonged to a specific 'vegetable' cluster (Park et al., 2005) but other ethnic groups were indifferent. Hawaiians and Latinos (compared with Whites[6]) had mixed preferences for dietary patterns both belonging to a 'fat and meat' cluster and 'vegetable' cluster (Hawaiians only) or a 'fruit and milk' cluster (Latinos only) (Park et al., 2005). Whites[6] preferred 'high intake' and 'more healthful' clusters than 'healthy', 'Western-like' or 'low produce, high sweets' clusters (Hsiao et al., 2013, Park et al., 2005).

2.4.3.4. Education and income

Education is usually attained in the early life stages. Its significance exists in later years where the relationship between education and health is stronger in older cohorts than younger cohorts (Leopold and Engelhardt, 2011, Delaruelle et al., 2015). Education is an important determinant to eating a nutritious diet (Besora-Moreno et al., 2020, Poggiogalle et al., 2021, Granic et al., 2015, Allès et al., 2016): higher education brings better nutrition knowledge, higher income, and an opportunity to purchase healthier foods (Wardle et al., 2000).

Studies in this review (*n* 7) reflect the association dietary patterns have with the combination of education and income. Six dietary patterns containing healthy food groups were positively associated with both education and income in the older adult (Pryer et al., 2001, Hsiao et al., 2013, Bishop et al., 2020, Kell et al., 2015, Cai et al., 2007) with one variation: the positive association for education and income was only reported in males in a 'healthy' cluster (*n* 122) (compared with 'mixed' and 'traditional') in a British cohort (Pryer et al., 2001). In this same British cohort, the female 'healthy' cluster (*n* 185) was positively associated with income but not education (Pryer et al., 2001). In other studies, dietary patterns with unhealthy food groups were inversely associated with both education and income (Kell et al., 2015, Bishop et al., 2020).

There were modest exceptions to this combination: education, but not income, was positively associated with 'healthy' (Allès et al., 2016) or negatively association with 'Western' (Allès et al., 2016). Unexpected exceptions were also reported where income was positively associated with a 'Western' or 'traditional' pattern in coronary artery patients (Esmaili et al., 2015) but education had either no association or a negative association to the respective patterns (Esmaili et al., 2015).

[11] As stated in published manuscript

Income is sensitive information and not always available (Thorpe et al., 2016) or measured. In older adults, income does not necessarily reflect financial status as income may drop after retirement. Wealth, capturing income and accumulated assets over time, may be a more appropriate measure (Wagg et al., 2021). Regardless, income is the common measurement. In studies that did not measure income (*n* 9), higher education was associated with a 'low meat' cluster (*n* 260) (compared with 'high red meat' and 'high butter') in a very old (> 85 years) population (Granic et al., 2015). Other dietary patterns (*n* 8) with healthy food groups were also positively associated with education: plant-based (Park et al., 2005, Chan et al., 2012, Thorpe et al., 2016, Pryer et al., 2001, Cai et al., 2007), 'fruit and milk' (Park et al., 2005), 'healthy' (Andreeva et al., 2016), and 'prudent' (Markussen et al., 2016) patterns. Conversely, 'fat and meat' (Park et al., 2005), 'sweet and fat-dominated' (Bamia et al., 2005) and Western type (Bamia et al., 2005, Markussen et al., 2016, Thorpe et al., 2016) patterns were frequently followed by those with a lower education level. There were some exceptions where dietary patterns with unhealthy food groups (*n* 4) were positively associated with higher education, For example, a 'meat' pattern in a Chinese male population (40-74 years) (Cai et al., 2007), a 'snack-drinks-milk products' pattern in a Hong Kong population (65+ years) (Chan et al., 2012), a 'Continental' pattern in Norwegian women (50-69 years) (Markussen et al., 2016) and a 'convenience' pattern in an American population (45+ years) (Kell et al., 2015). The 'meat' and 'snack-drinks-milk products' pattern (fast foods, desserts, milk products and whole grains) were both in Chinese communities (Cai et al., 2007, Chan et al., 2012). Both patterns also had positive associations to poor lifestyle behaviours - alcohol and smoking. Since both these exceptions were in a Chinese population it may involve a cultural or social concept. Markussen et al. (2016) explained their 'Continental' pattern (considered unhealthy due to higher intakes of alcohol, total and saturated fat) was positively associated with higher socio-economic status, which may influence this finding, whereas Kell et al. (2015) did not offer an explanation about their results and suggested more research to understand the underlying reason.

2.4.3.5. Area deprivation score

It was rare for studies in this literature review to use an area deprivation score as a variable even though other countries have their own deprivation index e.g., United States (Butler et al., 2013), South Africa (Noble et al., 2009). The Newcastle 85+ study (*n* 791, British population) used a current Index of Multiple Deprivation based on residency (Granic et al., 2015). This score was not associated with any dietary pattern when education and occupational class were included in the model. The REasons for Geographic And Racial Differences in Stroke (REGARDS) study (*n* 17,062, 45+ years, USA) (Kell et al., 2015) used a community socio-economic status score based on household income, housing units, education, and occupation class (Roux et al., 2001). This study showed mixed results

with 'sweets/fats' and 'Southern' (fried foods, processed meats) patterns inversely associated, and a 'convenience' (meat, pasta, Mexican dishes) pattern positively associated with the socio-economic status score.

2.4.3.6. Living situation

Living situations can change in older adults. A death of a spouse can dramatically change a lifestyle from living and sharing meals with someone to eating alone. Living alone is associated with a higher nutrition risk through reduced appetite and less motivation to cook resulting in quick and simpler meals (maybe convenience foods) (Whitelock and Ensaff, 2018, Wham and Bowden, 2011). This may be more so for men as their spouse may have previously shopped and prepared meals (Wham and Bowden, 2011). Nevertheless, living alone does not always indicate an absence of nutrition knowledge or a lack of responsibility to eat well (Host et al., 2016).

Only four studies, in this review, investigated the relationship between dietary patterns and the living situation (alone or with someone). Two studies, one in United Kingdom and the other in the United States did not observe any differences between dietary patterns and living situation (Pryer et al., 2001, Hsiao et al., 2013). In the other two studies, 'healthy' patterns were positively associated with living alone (Allès et al., 2016, Andreeva et al., 2016). Both these patterns contained foods that were easy to prepare e.g., salads. In contrast, a 'Western' pattern (red and organ meats, cheese, alcohol) was inversely associated with living alone (Andreeva et al., 2016).

2.4.4. Lifestyle determinants of the dietary pattern

2.4.4.1. Alcohol and smoking

Alcohol is usually included as a food group in the dietary pattern rather than as a response variable. It was common for an alcohol food group to be highly loaded on dietary patterns with both healthy (Pryer et al., 2001, Bishop et al., 2020, Kell et al., 2015, Granic et al., 2015) and unhealthy food groups (Pryer et al., 2001, Markussen et al., 2016, Andreeva et al., 2016, Allès et al., 2016). In some instances, alcohol was negatively loaded to a dietary pattern e.g., 'sweet and fat-dominated' (Bamia et al., 2005) and 'Western' or 'healthy' nutrient patterns (Allès et al., 2016).

In the general population, alcohol and smoking cluster together regardless of the amount of alcohol consumed (Meader et al., 2016). In a British population, Pryer et al. (2001) reported a 'traditional' pattern contained high alcohol consumption but also had a higher proportion of smokers (30% males, 22% females) whereas the 'healthy' pattern' contained the lowest proportion of smokers (14% males, 8% females). Other studies did not always present this information.

Clustering of alcohol and smoking is seen in studies in this literature review. Positive factor loadings for alcohol and positive associations with smoking were reported in two patterns e.g., 'Western' (Andreeva et al., 2016) and 'Continental' (Markussen et al., 2016). Similarly, negative loadings of alcohol and negative associations with smoking were also present in 'sweet and fat-dominated' (Bamia et al., 2005) and 'healthy' (males only) (Andreeva et al., 2016) patterns and a 'healthy' nutrient pattern (Allès et al., 2016). In contrast, a 'Western' pattern had negative loadings of alcohol and positive associations with smoking (Andreeva et al., 2016).

Results were also predictable in the few studies (*n* 3) where alcohol and smoking status were both considered as a lifestyle variable. It was common for alcohol and smoking to be positively associated with dietary patterns with unhealthy food groups e.g., 'fat and meat' (Park et al., 2005), 'meat' (Cai et al., 2007), and 'snacks-drinks-milk products' (Chan et al., 2012). Accordingly, dietary patterns with healthy food groups had negative associations with smoking status e.g., 'vegetable', 'fruit' (Cai et al., 2007), 'vegetables-fruits' (Chan et al., 2012), and 'vegetables' and 'fruit and milk' (Park et al., 2005) with a variety of positive, negative or null associations with alcohol.

In the remaining patterns associations between dietary patterns and smoking were as expected: negative correlations were reported in dietary patterns containing healthy food groups (Pryer et al., 2001, Bishop et al., 2020, Markussen et al., 2016, Bamia et al., 2005) and positive correlations in dietary patterns containing unhealthy food groups (Markussen et al., 2016, Esmaili et al., 2015, Bishop et al., 2020).

2.4.4.2. Physical activity

It was clear, dietary patterns with healthy food groups *(n* 11) were associated with higher physical activity (Park et al., 2005, Thorpe et al., 2016, Bamia et al., 2005, Cai et al., 2007, Markussen et al., 2016, Bishop et al., 2020, Chan et al., 2012) and dietary patterns with unhealthy food groups (*n* 5) were inversely associated with physical activity e.g., 'Western' (Markussen et al., 2016, Thorpe et al., 2016, Bishop et al., 2020, Chan et al., 2012). Sometimes dietary patterns with unhealthy food groups (*n* 4) were also positively associated with physical activity (Bamia et al., 2005, Hsiao et al., 2013, Thorpe et al., 2016, Cai et al., 2007).

The method for collecting physical activity data was by questionnaire and the validity of the questionnaire was not always clear (Bamia et al., 2005, Cai et al., 2007, Bishop et al., 2020, Park et al., 2005). Nevertheless, reliable questionnaires were used to collect physical activity data in two studies. The study in Norwegian post-menopausal women collected both time and activity level to express physical activity in MET minutes (Dallal et al., 2007, Markussen et al., 2016). Similarly, Chan et al. (2012) used the validated Physical Activity Scale for the Elderly (PASE) (Washburn et al., 1993).

2.4.5. A longitudinal view in older adults

The studies discussed above provide a dietary pattern at one time point without consideration of dietary changes over time which may confound results (Cai et al., 2007). To fill this gap and identify determinants of dietary change, a handful of longitudinal studies (Harrington et al., 2014, Mishra et al., 2006, Thorpe et al., 2019) have assessed changes in dietary patterns over time (6-10 years) and how socio-demographic factors were associated with these changes. The 1946 British Birth cohort (*n* 1,265, 53 years old at final follow up) moved towards an 'ethnic foods and alcohol' pattern over a 7–10-year period in both males and females (Mishra et al., 2006). This move was more prominent in educated and those in a non-manual social class. Similarly, educated and non-manual working females moved towards a 'fruit, vegetables and dairy' pattern, and educated, non-smoking males in non-manual working occupations moved towards a 'mixed' (comprised of fruits, vegetables and sweet foods) dietary pattern (Mishra et al., 2006). The Cork and Kerry Diabetes and Heart Disease study [*n* 359, Irish population, 50–69-year-olds (at baseline)] reported 'Western' and 'low-energy' patterns moved towards a 'healthy' pattern over a ten-year period (Harrington et al., 2014). The key determinant to this change was a higher education, which reinforced findings from in the 1946 British Cohort study. In addition, Harrington et al. (2014) noted education was a common characteristic of participants who remained in the 'healthy' pattern over the study period. The most recent longitudinal study published, The Wellbeing Eating and Exercise for a Long Life (WELL) study in Older Australians (*n* 2,111), reported a reduced consumption in all their dietary patterns and the predictors of change to healthier patterns were education, being physically active and not smoking (Thorpe et al., 2019).

2.4.6. In New Zealand, socio-demographic and lifestyle factors are associated with dietary patterns

Four published cross-sectional studies in New Zealand reviewed associations between dietary patterns and socio-demographic and lifestyle factors. Three studies were based around women: pre-conception, pregnancy and their young children (Thompson et al., 2010, Wall et al., 2016, Wall et al., 2013). The fourth study was in the general New Zealand population (Beck et al., 2018).

Using data from the 2008/09 New Zealand Adult Nutrition Survey, Beck et al. (2018) derived the dietary patterns of a representative sample of New Zealanders (*n* 4,657). Two dietary patterns, 'healthy' and 'traditional', observed associations: 'healthy' was positively associated with age, being female and a higher socio-economic status whereas 'traditional' leaned the other way, being associated with males and lower socio-economic status.

The Auckland Birthweight Collaborative study (*n* 1,714, pregnant women) explored socio-demographic factors and their associations with maternal dietary patterns with birthweight as an outcome (Thompson et al., 2010). A later study explored the dietary patterns of the children born in the Auckland Birthweight Collaborative cohort at 3 and 7 years of age (Wall et al., 2013). This study underlined the reducing influence of the maternal socio-demographics on the children's diet as the children aged. The third study used data from the Growing Up in New Zealand study, Wall et al. (2016) derived dietary patterns for pregnant women and explored socio-demographic associations (*n* 5664). There were similarities in maternal dietary patterns derived in the Auckland Birthweight Collaborative study and Growing Up in New Zealand study ('fusion'/'fusion/protein' and 'junk'/'junk') and two similar associations: education was not associated with dietary patterns and Māori, Pacific, Asian and Other ethnic groups were more likely to adhere to the 'fusion/protein' patterns. An unpublished study, NiPPeR study, of New Zealand women (*n* 1,720, pre-conception) found adherence to a dietary pattern with unhealthy food groups was associated with higher incomes (abstract only (Lim et al., 2020)).

2.4.7. How much do socio-demographic and lifestyle factors influence the dietary patterns?

As observed in this literature review, socio-demographic and lifestyle factors do not occur singularly (Noble et al., 2015, Prendergast et al., 2016). For public health interventions to be effective, the multiple factors influencing dietary choice must be identified and the magnitude of these effects measured. The levels of effect for socio-demographic and lifestyle factors on dietary patterns is not commonly reported. However, in an Iranian population (*n* 250, coronary disease patients, 40+ years), socio-demographic and lifestyle factors explained 14-23% of the variation in the dietary patterns (Esmaili et al., 2015) and in a United Kingdom population (*n* 9,003, healthy, 18+ years), socio-demographics explained 5-32% and lifestyle factors explained 1-8% of the variation in the dietary patterns (Whichelow and Prevost, 1996). A study in a Swiss population (*n* 2,057, healthy, 18+ years) reported socio-demographic and lifestyle factors successfully predicted dietary patterns for 37-44% of the study's participants (Krieger et al., 2019).

2.4.8. Limitations of this review

This literature review did not include *a priori* dietary patterns therefore a possibility that some findings are not reported.

2.4.9. Concluding items

This literature review explores *a posteriori* dietary patterns and their associations with socio-demographic and lifestyle factors in the older population. The relationship between dietary patterns and socio-demographic factors is complicated and not fully understood (Thorpe et al., 2016). Nor are socio-demographic and lifestyle factors the sole determinants of dietary pattern choice and may only explain up to 44% of the variation of dietary patterns. However, these factors can be easily measured and play a role in targeting public health interventions.

Education was not only an important determinant for choosing a dietary pattern but also in determining a change in dietary pattern over time. Higher education was consistently associated with a move towards or resistance to change from a dietary pattern with healthy food groups. Likewise, higher income and physical activity were consistently associated to dietary patterns containing healthy food groups. Alcohol was associated with dietary patterns containing both healthy and unhealthy food groups, but smoking status clustered only with alcohol in the dietary patterns with unhealthy food groups. In dietary patterns with healthy food groups, it was common to observe a negative association with smoking regardless of the alcohol association. Living alone was positively associated with dietary patterns containing healthy food groups but evidence was sparse, and more research is required. Age, sex, ethnicity, and index of multiple deprivation did not associate with specific dietary patterns though ethnicity and an index of multiple deprivation was not always measured.

While a large New Zealand study found dietary pattern associations with socio-demographic factors, there is limited information in New Zealand population sub-groups (excluding maternal studies) creating opportunities for these gaps to be filled. Dietary pattern associations with socio-demographics and lifestyle factors (and their magnitudes) have not been explored in the older New Zealand adult.

2.4.10. References

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2.5. *A posteriori* dietary patterns and cognitive function in older adults: a literature review of observational studies

This section reviews associations between dietary patterns and cognitive function by reviewing both individual studies (cross-sectional and longitudinal) and systematic reviews. Large cohorts have published several manuscripts on this topic. This section explores the heterogeneity of the methods, including dietary pattern and cognitive testing methods, choice of outcomes, study populations and confounders.

2.5.1. Background information, aim and search methods

Cognitive function and the diet have been of interest for many decades. Studies examining cognitive function and single nutrients, or foods have reported inconsistent results (Forbes et al., 2015, Solfrizzi et al., 2017). As the diet contains complex relationships between the nutrients and food groups, a dietary pattern approach may be more suitable.

KEY POINTS

- Studies of *a posteriori* dietary patterns exploring cognitive function / decline have increased but mixed results are reported due to heterogeneity of methods.
- Rigorous study methods with common outcomes and essential confounders are required in future studies.

Using *a priori* dietary patterns, studies show better cognitive function in older adults where the dietary intake follows specific features of a diet, for example, the MIND[12] diet (high in green leafy vegetables, nuts, berries, whole grains, beans, poultry, olive oil, and low emphasis on fruit intake) substantially slows cognitive decline with age (Morris et al., 2015). An umbrella review suggests robust evidence for the Mediterranean Diet and its inverse associations with neurodegenerative disease, cardiovascular disease, and type 2 diabetes mellitus (Dinu et al., 2018). *A priori* methods do have limitations: they are not specific to a population, rely on available knowledge, and may not capture all food groups. Results from *a priori* dietary pattern studies have been applied to randomised controlled trials to examine the effects of a Mediterranean diet and cognitive function with mixed results (Knight et al., 2016, Valls-Pedret et al., 2015).

Limitations of *a priori* dietary patterns can be avoided using *a posteriori* dietary pattern methods where studies are finding evidence that dietary patterns are associated with health outcomes though mixed results are also found (Chen et al., 2018, Milte and McNaughton, 2016). This review

[12] Mediterranean-Dietary Approaches to Stop Hypertension (DASH) Intervention for Neurodegenerative Delay

evaluates the literature concerning associations between *a posteriori* dietary patterns and cognitive function in older people. The literature search covered all geographic regions with no time limits and included cross-sectional and longitudinal studies and systematic reviews where the exposure was dietary patterns, and the outcome was cognitive function or decline. As *a posteriori* dietary patterns have many subjective decisions, a spotlight will be on methodologies of the studies.

To approach the above aim, four electronic databases were searched with no time restrictions – PubMed, CINAHL, Web of Science Core Collection and SCOPUS. The key headings used in the search strategy are shown in Table 2.12.

Table 2.12: Search strategy for studies examining associations between *a posteriori* dietary patterns and cognitive function or cognitive decline in older adults.

	Search term	
	diet	
AND	principal component	OR
	(cluster OR factor) analysis	OR
	reduced rank regression	
AND	cognition	
AND	older adults	

The search strategy was tested to find known studies. A second search method reviewed reference lists of selected studies. Selected studies were in English, peer reviewed and had full-text available. Study participants included community-dwelling adults; older than 45 years; from the general population rather than a homogenous study group e.g., people with diabetes; and without any medical condition which may significantly affected cognition or dietary intake. Outcomes were cognitive function or cognitive decline but not a disease state nor diagnosed mild cognitive impairment.

2.5.2. Results from literature search

2.5.2.1. Studies

Thirty-seven studies were found where the exposure was *a posteriori* dietary patterns and the outcome was cognitive function or decline. Of these 37 studies, 24 were published after 2015 and 13 are included in the systematic reviews discussed below. All studies (*n* 37) are outlined in Table 2.13 (cross-sectional) and Table 2.14 (longitudinal) and include the studies design, dietary assessment

methods, identified dietary patterns, cognitive tests used and results. The discussion begins with study cohorts who have more than one publication on this topic.

Eleven manuscripts were published from five cohorts: the Swedish National Study of Aging and Care-Kungsholmen (SNAC-K), Lothian Birth Cohort 1936, Korean Multi-Rural Communities Cohort, Supplémentation en Vitamines et Minéraux Antioxydant Study (SU.VI.MAX 2), and Whitehall II.

The dietary patterns identified, in the longitudinal SNAC-K study (*n* >2,200, 60+ years, Sweden, follow-up of seven to nine years), were based on food groups: 'prudent' and 'Western' (Shakersain et al., 2016) and nutrients: 'plant', 'animal', 'dairy' and 'animal/plant fats' (Prinelli et al., 2019). The authors considered (subjectively) the 'plant' and 'animal' nutrient patterns reflected the 'prudent' dietary pattern and the 'dairy' and 'animal/plant fats' nutrient pattern reflected the 'Western' dietary pattern (Prinelli et al., 2019). Thus, similar results were seen: the 'prudent', 'plant' and 'animal' patterns were protective of and the 'Western' and 'dairy' patterns increased cognitive decline. The association between 'dairy' and cognitive decline was attenuated when the data were stratified by *APOE*-ε4.

The Lothian Birth Cohort 1936 (*n* >863, 68+ years, United Kingdom) derived dietary patterns using principal component analysis in a cross-sectional baseline study, and a longitudinal study testing cognitive decline 10 years later. This cohort consistently found a 'Mediterranean style' pattern was associated with higher verbal ability but also increased the decline in verbal ability (Corley et al., 2020, Corley and Deary, 2020, Corley et al., 2013). This contradictory finding was explained with known ceiling effects, in that, high scoring individuals, at baseline, will have poorer scores in a longitudinal setting.

The cross-sectional Korean Multi-Rural Communities Cohort (*n* >760, 60+ years, Korea) explored associations between cognitive function and dietary patterns using principal component analysis (Kim et al., 2015a) and cluster analysis (Kim et al., 2015b). Between the analytical methods, the patterns and cluster containing healthy food groups were different - 'multigrain rice, fish, dairy products, fruits and fruit juices' (cluster analysis) and 'prudent' and 'bread, egg and dairy' (principal component analysis), whereas the pattern and cluster containing less healthy food groups showed similarities - 'white rice' (cluster) and 'white rice, noodles and coffee' (principal component analysis). In reported results, there were associations between reduced cognitive impairment and the 'bread, egg and dairy' pattern and the 'multigrain rice, fish, dairy products, fruits and fruit juices' cluster compared to the 'white rice' cluster.

The SU.VI.MAX 2 study (*n* >2,900, 45+ years, France) explored associations between dietary patterns and cognitive function using principal component analysis (Kesse-Guyot et al., 2012) and reduced rank regression based on plasma carotenoid concentrations (Kesse-Guyot et al., 2014). Both analytical methods had dietary patterns, with healthy food groups, positively associated with cognitive function. The association reported in the principal component analysis pattern, 'healthy', was only noted in a low energy intake sub-group, highlighting both diet quality and quantity are associated with positive cognition.

Dietary data from the Whitehall II study (n >3,900, mean age ~56 years, United Kingdom) was used in a cross-sectional and longitudinal study at the 10-years follow-up. The principal component derived dietary patterns found a positive association with a 'whole food' pattern and negative association with a 'processed food' pattern in the baseline cross-sectional study (Akbaraly et al., 2009). Whereas, an 'inflammatory' pattern, derived from reduced rank regression based on interleukin-6, was associated with increase cognitive decline over 10 years but not five (Ozawa et al., 2017).

In these five cohorts mixed results were reported (Lothian Birth Cohort 1936) or findings were in subgroups of the main cohort (SU.VI.MAX2 and SNAC-K) or common results were found in dietary patterns with uncommon foods (Korean Multi-Rural Communities Cohort). While other studies have also found inconsistent results, some studies report null findings (Osawa et al., 2017, Sugawara et al., 2015, Allès et al., 2019, Ferrand et al., 2017, Chan et al., 2013). With a variety of results, it has been suggested there is no direct link between diet and cognitive performance in the older population instead the level of intelligence throughout the life or education may be a stronger influencer (Corley et al., 2013) (Akbaraly et al., 2009, Corley and Deary, 2020). Others also suggest the diet preceding the later years is more important (Kesse-Guyot et al., 2014, Kesse-Guyot et al., 2012); or the socio-demographics of study participants (Parrott et al., 2013) all have an impact on the evidence. The SNAC-K study suggested the benefits from a dietary pattern with healthy food groups e.g., 'prudent' may offset the negative effects of a 'Western' pattern (Shakersain et al., 2016). These factors and their complex interactions with cognition, occurring over the life span make the study of cognitive function and decline a difficult task (Sanchez-Izquierdo and Fernandez-Ballesteros, 2021, Chen et al., 2018).

Table 2.13: Twenty-one cross-sectional studies exploring associations between *a posteriori* dietary patterns and cognitive function in older adults

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Samieri et al. (2008), France, Three-City.	European, *n* 1,724, ≥65 yrs, 38% M.	1. 148-FFQ, 2. Hybrid clustering, 3. 20 FGs, 4. intake by frequency.	M - '**small eaters**' (*n* 203); '**biscuits and snacking**' (n 58); '**fish**' (*n* 157); '**charcuterie, meat and alcohol**' (*n* 95); '**pasta**' (*n* 136). F - '**small eaters**' (*n* 334); '**biscuits and snacking**' (*n* 162); '**fruit and vegetable**' (*n* 267); '**charcuterie and starchy foods**' (*n* 66); '**pizza sandwich**' (*n* 48).	1. MMSE, 2. Global, 3. continuous, cog score (√(30-MMSE); low score good).	1. M - '**healthy**': ↑global* (β=-0.11 (-0.22, -0.00)). F - '**healthy**': ↑global** (β=-0.13 (-0.22, -0.04)). 2. A, E, income, marital status.
Akbaraly et al. (2009), United Kingdom, Whitehall II.	European, *n* 4,693, ≥52 yrs, 61% M.	1. 127-FFQ over 12 mths (V), 2. PCA, 3. 37 FGs, 4. intake by volume.	'**whole food**': ↑veg, fruit, dried legume, fish. '**processed food**': ↑desserts, choc, fried food, proc'd meat, pies, refined grains, HF dairy, margarine, condiments.	1. battery of tests, 2. memory, reasoning, vocabulary, phonemic fluency, semantic fluency, 3. dichotomous, where cog deficit=lowest sex specific quintile.	1. '**whole food**': ↓risk of vocabulary deficit* (OR=0.75 (0.60, 0.92); ↓semantic fluency** (OR=0.72, (0.59, 0.88)); '**processed food**': ↑vocabulary** (OR=1.62 (1.25, 2.13)). 2. A, S, E, health behaviour (smoking habits, PA), EI, marital status, health status (diab, BP, CVD, dyslipidemia, BMI and mental health).

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Kesse-Guyot et al. (2012), France, Supplémentation en Vitamines et Minéraux Antioxydants (SU.VI.MAX 2).	Cognitive testing 13 yrs after dietary intake measured, European, *n* 3,054, ≥45 yrs, 54% M.	1. 6 x 1-day FR over 2 years; 10±3 1-day food diaries collected, 2. PCA, 3. 34 FGs, 4. intake by volume, EI-adj using residual method.	2 DPs explained 12% of variation in diet '**healthy**': ↑fruit, whole grains, dairy, veg, breakfast cereal, tea, veg fat, nuts, fish; ↓meat & poultry, refined grains, animal fat, proc'd meat. '**traditional**': ↑veg, veg fat, meat & poultry; ↓confectionary, cakes and pastries, croissants, pizza and dinner pies, desserts, soft drinks, milk, potatoes.	1. battery of tests, 2. global, episodic memory, lexical-semantic memory, working memory, mental flexibility, 3. continuous, cog score.	1. stratified by EI - '**healthy**': ↑global* (low EI only); ↑verbal memory* (low EI only). 2. A, S, E, PA, alc, smoking, EI, BMI, number of 24-hr recalls, follow-up time, memory troubles, diab, menopause, menopausal hormone therapy.
Corley et al. (2013), United Kingdom, Lothian Birth Cohort 1936.	European, *n* 1,091, 68-82 yrs, ~ 50% M.	1. 168-Scottish Collaborative Group FFQ v7 (V), 2. PCA, 3. NR but ~ 50 FGs, 4. intake by volume.	4 DPs explained 12% of variation in diet '**Mediterranean style**': ↑veg, oil & vinegar dressing, tomatoes, smoked oily fish. '**health aware**': ↑fruit; ↓fried eggs, bacon or gammon, sausages (pork, beef or frankfurters). '**traditional**': ↑tinned veg, veg, baked beans, bottled sauces; '**sweet foods**': ↑fruit-based or sponge puddings, pastries, doughnuts/muffins, cake, shortbread, biscuits, sweet spreads & sauces, ice cream.	1. battery of tests, 2. processing speed, exec function, language, working memory, verbal memory, visuo-spatial, 3. continuous, cog score.	1. '**Mediterranean**': ↑verbal ability**; '**traditional**': ↓verbal ability***; '**health aware**', '**sweet foods**': ns. 2. A, S, IQ at age 11, occupation.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Chan et al. (2013), Hong Kong,	Chinese, *n* 3,670, ≥65 yrs, 52% M.	1. 280-FFQ over 12 mths (V), 2. PCA, 3. 32 FGs, 4. intake as % contribution to total energy.	3 DPs explained 17% of variation in diet '**vegetables-fruits**': ↑veg, fruits, soy products, legumes; '**snacks-drinks-milk products**': ↑fast food, sweets, desserts, nuts, milk products, whole grains; '**meat-fish**': ↑meat, fish and seafood.	1. CSI-D, 2. Global, 3. dichotomous, where cog'ly impaired = CSI-D score ≤ 28.4.	1. '**vegetables-fruits**': ↓CogI* (OR=0.73 (0.54, 1.00)) (F only); '**snacks-drinks-milk products**': ↓CogI* (OR=0.65 (0.47, 0.90)) (F only); '**meat-fish**' ns. 2. A, E, PA, EI, alc, smoking, BMI, BP, diab, CVD/stroke, Hong Kong community ladder, #ADLs, GDS category analysis stratified by sex.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Kesse-Guyot et al. (2014), France, Supplémentation en Vitamines et Minéraux Antioxydants (SU.VI.MAX 2).	Cognitive testing 14 yrs after dietary intake measured, European, *n* 2,983, 45-60 yrs, 54% M.	1. mean 10 1-DFR collected over 2 yrs, 2. RRR, 3. 30 FGs, 4. NR.	DP explained 6% variation in FGs, 12% variation in plasma carotenoid concentration (response variable) '**carotenoid-rich**': ↑green and orange fruits and veg, veg oils, soup; ↓wine, beer, cider.	1. battery of tests, 2. global, episodic memory, working memory, mental flexibility, 3. continuous, cog score.	1. '**carotenoid-rich**': ↑global*** (mean diff=0.58 (0.27, 0.90)); RI-48 cued recall task** (mean diff=0.59 (0.25, 0.92)); backward digit task span* (mean diff=0.39 (0.06, 0.72)); ↑trail making test** (mean diff=0.51 (0.19, 0.82)); ↑semantic fluency task** (mean diff=0.59 (0.26,0.91)). 2. A, S, E, PA, smoking, BMI, occupational status, EI, BP, diab, CVD, follow-up time between baseline and cognitive evaluation, supplementation group during trial phase, number of 24-hr dietary records, reported memory problems at baseline, depressive symptoms concomitant with cognitive function assessment.
Kim et al. (2015b), Korea, Korean Multi-Rural Communities Cohort.	Korean, *n* 765, ≥60 yrs, 43% M.	1. 106-FFQ (V), 2. CA, 3. 23 FGs, 4. intake by volume.	'**multigrain rice, fish, dairy products, fruits and fruit juices**' (*n* 589); '**white rice, noodles and coffee**' (*n* 176).	1. MMSE-Korean version, 2. Global, 3. dichotomous, where cog'ly impaired = MMSE score <1.5SD.	1. '**multigrain rice, fish, dairy products, fruits and fruit juices**' had ↓CogI (OR=0.64 (0.44, 0.94)) compared with '**white rice, noodles and coffee**'. 2. A, S, E, PA, alc, diab.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Kim et al. (2015a), Korea, Korean Multi-Rural Communities Cohort.	Korean, *n* 806, ≥60 yrs, 42% M.	1. 106-FFQ (V), 2. PCA, 3. 23 FGs, 4. intake by volume, log transformed.	3 DPs explained 34% of variation in diet '**prudent**': ↑veg, fish, beans, seafood, fruits, juices, green tea, soups, potatoes, nuts, SSB; '**bread, egg, and dairy**': ↑breads, eggs, flour-based foods, dairy, meats, sweet foods, nuts, fruits, juices; '**white rice only**': ↑white rice.	1. MMSE-Korean version, 2. Global, 3. dichotomous, where cog'ly impaired = MMSE score below 1.5 SD of mean.	1. '**bread, egg and dairy**' ↓CogI* (OR=0.57, (0.37, 0.87)); '**white rice only**': ↑CogI** (OR=2.13, (1.38, 3.29)). 2. PA, alc, supplement use Subjects classified by MMSE-KC criteria according to age, sex, and education so not included as confounders.
Sugawara et al. (2015), Japan, Iwaki Health Promotion Project 2011.	Japanese, *n* 388, ≥60 yrs, 37% M.	1. 65-BDHQ over 4 wks (V), 2. PCA, 3. 52 FGs, 4. intake by volume, EI-adj using density method.	3 DPs explained 19% of variation in diet '**healthy**': ↑veg, seaweeds, tofu, fruits, fish; '**noodle**': ↑noodles, soft drinks, proc'd meat, beer; '**alcohol and accompaniment**': ↑alc, tofu/atsuage, natto, and seaweeds.	1. MMSE, 2. Global, 3. dichotomous, where cog'ly impaired = MMSE score below 25.	1. no evident dose-dependent assn between Cogn and DPs. 2. A, S, E, PA, smoking, BMI, marital status, BP, diab, anti-depressants.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Ashby-Mitchell et al. (2015), Australia, Australian Diabetes, Obesity and Lifestyle Study (AusDiab).	NR, *n* 577, 60+ yrs (baseline), 51% M.	1. 121-AusDiab FFQ over 12 mths (V), 2. PCA, 3. 101; 32; 20 FGs, 4. intake by volume.	101 FGs: 7 DPs explained 23% of variation in diet: '**fruit and vegetables**'; '**snack and processed foods**'; '**vegetable**'; '**meat**'; '**fish, legumes & vegetables**'; '**vegetable, pasta and alcohol**'; '**dairy, cereal and eggs**'. 32 FGs: 4 DPs explained 30% of variation in diet: '**Western**'; '**prudent**'; '**vegetable, grains & wine**'; '**high fat**'. 20 FGs: 3 DPS explained 31% of variation in diet: '**variety**'; '**Western**'; '**dairy, grains and alcohol**'.	1. MMSE, California Verbal Learning Test, Symbol-digit modalities test, 2. global, memory, processing speed, 3. both continuous, cog score and dichotomous, where cog'ly impaired = MMSE score below 25.	1. 101 FGs - risk of CogI: '**fruit and vegetable**': ↓CogI* (OR=1.06, (1.01, 1.12)); '**fish, legumes and vegetable**': ↓CogI* (OR=1.03, (1.00, 1.06)); '**dairy, cereal and eggs**' ↓CogI** (OR=1.02, (1.01, 1.03)); '**snack & processed foods**', '**vegetable**', '**meat**', & '**vegetable, pasta & alcohol**' ns. 32 FGs - risk of CogI: ns '**Western**'; '**prudent**'; '**vegetable, grains & wine**'; '**high-fat**'; '**Western**': ↓CVLT** (β=-0.01, SE=0.00); ↓SMDT* (β=-0.02, SE=0.01); '**prudent**': ↓SMDT** (β=-0.04, SE=0.01); '**vegetables, grains and wine**': ↑SMDT* (β=0.02, SE=0.01). 20 FGs - risk of CogI: ns '**variety**'; '**Western**'; '**dairy**'; '**grains & alcohol**'; '**dairy, grains and alcohol**': ↓CVLT** (β=-0.00, SE=0.005); '**variety**': ↓SMDT* (β=-0.03, SE=0.01). 2. A, S, E, PA, smoking, BMI, EI, Spot the Word test.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Ferrand et al. (2017), France, PRAUSE	French, *n* 402, M 72 (9) yrs, F 77 (10) yrs, mean (SD), 38% M.	1. 27-FFQ (V NR), 2. CA, 3. 27 FGs, 4. intake by frequency.	M - '**cluster 1**': ↑cereals, bread, starchy foods, pulses, dairy, veg, meat, poultry, eggs, sweet products; ↓wine (*n* 62); '**cluster 2**': ↑ pulses, ready meals, alcohol; ↓cereals, breads, veg, meat, poultry, eggs (*n* 18); '**cluster 3**': ↑wine; ↓cereals, bread, starchy foods, dairy, veg, fish, seafood (*n* 61); '**cluster 4**': ↑cereals, breads, fish, seafood, wine; ↓fruits, veg, meat, poultry, eggs, ready meals, sweet products (*n* 10). F - '**cluster 1**': ↑pulses, fruits, veg, fish, seafood, ready meals, sweet beverages; ↓cereals, bread, meat, poultry, eggs, sweet products and alcohol (*n* 61); '**cluster 2**': ↑cereals, breads, veg; ↓pulses, fish, seafood, ready meals (*n* 76); '**cluster 3**': ↑ready meals; ↓cereals, breads, starchy foods, pulses, dairy, fruits, veg, meat, poultry, eggs, fish and seafood (*n* 83); '**cluster 4**': ↑cereals, breads, dairy, fruits, veg, meat, poultry, eggs; ↓SSB (*n* 31).	1. MMSE, 2. Global, 3. continuous, cog score.	1. F: '**cluster 3**': ↓global compare with '**cluster 1**'. 2. Unclear.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Okubo et al. (2017), Japan, Septuagenarians, Octogenarians, Nonagenarians Investigation with Centenarians (SONIC).	Japanese, *n* 635, 69-71 yrs, 46% M.	1. 58-DHQ over 4 wks (V but not in older people) 2. PCA, 3. 33 FGs, 4. intake by volume, EI-adj using density method	3 DPs explained 25% of variation in diet '**plant foods and fish**': ↑veg, soy products, seaweeds, fruit, fish, green tea '**Rice and miso soup**': ↑rice, miso soup; ↓bread, fats/oils, ice cream '**animal food**': ↑seasonings, shellfish, chicken, red meats, fish, seafood, and proc'd meats	1. MMSE - Japanese version 2. global 3. continuous, cog score	1. '**plant foods and fish**': ↑global*** (β= 0.41 (0.17, 0.65)) 2. S, E, alc, smoking, residential area, BMI, BP, diab, GDS-5 score (depression), cerebrovascular disease and *APOE*-ε4
Osawa et al. (2017), Japan, Tokyo Oldest Old Survey on Total Health (TOOTH).	Japanese, *n* 512, 85+ yrs, 44% M.	1. DHQ (V) 2. PCA, 3. 48 FGs, 4. intake by volume, EI-adj using density method, log transformed as required	2 DPs explained 20% of variation in diet '**traditional Japanese**': ↑veg, seaweed, legumes, fish; '**noodles and confectionaries**': ↑noodles, confectionery, non-alc beverages	1. MMSE 2. global 3. dichotomous, where cog'ly impaired = MMSE score <24	1. no associations between cognition and dietary patterns 2. A, S, E, PA, drinking habits, smoking, BMI, living arrangement, comorbidity
Yin et al. (2018), China, Nutrition and Chronic Disease Family Cohort (NCDFaC).	Chinese, *n* 1,504, 60-90 yrs, 52% M.	1. 40-FFQ over 12 mths (V), 2. PCA, 3. 24 FGs, 4. intake by volume.	2 DPs explained 95% of variation in diet '**mushroom, vegetables and fruits**': ↑mushrooms, veg, fruits, legumes; moderate consumption of grains, nuts, and soybean milk; '**meat and soybean products**': ↑soybean products, meat, seafood; ↓plant-based foods.	1. MMSE-Chinese version, 2. Global, 3. dichotomous, where cog'ly impaired based on validated education-based cut-off.	1. '**mushroom, vegetable, and fruits**': ↓CogI* (OR=0.60 (0.38, 0.94); '**mushroom and soybean products**': ↓CogI* (OR=0.47 (0.30, 0.74). 2. A, S, E, PA, alc, smoking, marital status, EI, obesity, BP, chol, TG, diab, stroke, obesity, ADL disability.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Shin et al. (2018), Korea,	Korean, *n* 239, 65+ yrs, 37% M.	1. 63-FFQ (V), 2. RRR, 3. 26 FGs, 4. intake by volume.	3 DPs explained 14% variation in FGs, 18% variation in vit B6, C and Fe (response variable) '**seafood and vegetable**': ↑seafood, veg, bread, snacks, soy, beans, chicken, pork, ham, egg, fruits, milk; '**high meat**': ↑whole grains, beef, pork; ↓soy, sweet potatoes, eggs, milk; '**bread, ham, and alcohol**': ↑bread, ham, and alcohol; ↓beans, sweet potatoes, pork, eggs and seaweed.	1. MMSE-Korean version, 2. Global, 3. dichotomous, where cog'ly impaired = MMSE score < 1.5 SD of mean.	1. '**seafood and vegetables**': ↓CogI* (OR=0.06 (0.01, 0.72)). 2. S, E, PA, supplement use, BMI, dementia, sleep duration.
Gu et al. (2018), USA, Washington Heights, Hamilton Heights, and Inwood Columbia Aging Project (WHICAP).	multi-ethnic (US), *n* 330, ≥65 yrs, 36% M.	1. 68-S-QFFQ (version of Willett's, V), 2. RRR, 3. 24 nutrients, 4. intake by volume, EI-adj using residual method.	2 DPs explained 9% variation in IL-6 and CRP (response variable). Only 1st DP used as explained 82% of variation in FGs '**inflammation-related**': ↑chol; ↓Ca, vits A, B1, B2, B3, B5, B6, folate, D and E, omega-3 PUFA.	1. battery of tests, 2. exec function/speed; language; memory; visuo-spatial, 3. continuous, cog score.	1. '**inflammation-related**': visuo-spatial* (β=-0.21). 2. A, S, E, ethnicity, BMI, MRI of brain variables, vascular burden, *APOE* -ε4.
Yu et al. (2018), China.	Chinese, *n* 1676, ≥45 yrs, 53% M.	1. 85-S-FFQ (V), 2. PCA, 3. 29 FGs, 4. intake by frequency.	3 DPs explained 27% of variation in diet **'traditional Chinese**': ↑refined grains, veg, mushrooms, poultry, eggs, soy products, honey, tea, salted meat, fish/eggs; '**Western-style'**: ↑red/ proc'd meat, seafood, dairy, fats, fast foods, nuts, snacks, desserts, wine, SSB, coffee; '**grains, fruits, vegetables**': ↑whole grains, tubers, veg, fruit.	1. MMSE, 2. Global, 3. dichotomous, where cog'ly impaired = MMSE score below 25.	1. '**Western style**': ↑CogI* (OR=1.27 (1.06, 1.81)); '**grains, fruits, vegetables**': ↓CogI* (OR=0,74 (0.54, 1.00). 2. A, S, E, PA, income, EI.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Xu et al. (2018), China, China Health and Nutrition Survey.	Chinese, *n* 4,847, 55+ yrs, 48% M.	1. 24-hr recall over 3 consecutive days, 2. PCA, 3. 35 FGs, 4. intake by volume.	3 DPs explained 16% of variation in diet '**traditional Chinese**': ↑rice, pork, fish; ↓wheat, whole grain; '**protein-rich**': ↑milk, soy milk, eggs; ↓rice, veg; '**starch-rich**': ↑salted veg, legumes, whole grain, tubers.	1. TICS-m, 2. global, verbal memory, 3. continuous, cog score.	1. '**traditional Chinese**': global ns; verbal memory ns; '**protein-rich**': ↑global β = 2.28 (1.80, 2.76)**;↑verbal memory β = 1.36 (1.01, 1.71)**; '**starch-rich**': global ns; ↑verbal memory β = -0.43 (-0.71, -0.15)**. 2. A, S, E, urbanisation index, marital status, work status, alc, smoking, BMI, BP and T2DM.
Chuang et al. (2019), Taiwan.	Taiwanese, *n* 1,245, 65+ yrs, 51% M.	1. 79-FFQ (V) over 12 mths, 2. RRR by sex, 3. 23 FGs, 4. NR.	2 DPs explained 34% variation in MMSE (response variable). '**Male DP**': ↑fruit, nuts/seeds, whole grains, breakfast cereals, coffee, dairy, seafood, fish; '**Female DP**': ↑fruit, nuts/seeds, tea, eggs, whole grains, soybean products, veg, coffee.	1. Chinese-MMSE 2. Global 3. CogI determined as those with MMSE score <18 (for illiterate); <21 (elementary education); <25 (middle or higher education).	1. '**Male DP**': ↓CogI (OR=0.32 (0.14-0.78)*; '**Female DP**': ↓CogI (OR=0.39 (0.20-0.75)** 2. A, E, PA, smoking, alc, DP, diabs, depression, stroke.
Wesselman et al. (2019), The Netherlands, SCIENCe.	NR, *n* 165, ≥45 yrs, 55% M.	1. 34-Dutch Healthy Diet FFQ (V), 2. PCA and CA, 3. 8 FGs, 4. *a priori* Dutch guideline for a Healthy Diet score.	3 DPs explained 67% of variation in diet '**low-fat, low-salt**'; '**high-Veggy**'; '**low alcohol, low fish**'. '**cluster 1**': ↓fish; '**cluster 2**': ↑alcohol; '**cluster 3**': ↑fruit and fibre.	1. MMSE, CCI, CES-D, 2. global; cognitive change, depressive symptoms. 3. continuous, cog score.	1. '**low-fat, low-salt**': ↓depressive symptoms* (β=-0.18 (-2.27–-0.16)); '**high-Veggy**': ↑global** (β= 0.30 (0.21–0.64)). 2. A, S, E.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Corley et al. (2020), UK, Lothian Birth Cohort 1936.	European, *n* 358, mean 79 yrs, 50% M.	1. 130-EPIC-Norfolk FFQ (V), 2. PCA, 3. ~66 FGs, 4. NR.	2 DPs explained 17% of variation in diet '**Mediterranean**': ↑fruits, veg, salad dressing, legumes, fish, wholemeal bread, wine, rice; '**processed food**': ↑meat, sweet foods, fried food, tinned fruit, potatoes.	1. battery of tests, 2. global; processing speed; verbal ability; memory; visuo-spatial, 3. continuous, cog score.	1. '**Mediterranean**': ↑verbal ability (β=0.12)**; ns global, visuospatial, processing speed, memory, brain volumes or white matter microstructure; '**processed food**': ns global, visuospatial, processing speed, memory, verbal ability, brain volumes or white matter microstructure. 2. A, S, IQ at age 11, PA, alc, smoking, BP, chol, diab, stroke, *APOE* -ε4.
Chen et al. (2020), Australia, Sydney Memory and Ageing Study.	Australian population, *n* 819, 70-90 yrs, 44% M.	1. 80-Dietary Questionnaire for Epidemiological Studies v2 by Cancer Council of Victoria (V), 2. PCA, 3. 40 FGs, 4. intake by volume, EI-adj using residual method.	M - '**Western**': ↑HF dairy, cakes, biscuits, tinned fruit, ↓yellow & cruciferous veg, legumes, LF dairy, margarine; F - '**prudent healthy**': ↑veg; ↓fried fish, chips, poultry.	1. battery of tests, 2. global; attention/processing speed; exec function; global memory; language; visuo-spatial. 3. continuous, cog score/	1. '**prudent healthy**': ↑global* (β=0.31; (0.05, 0.56)) in F; '**Western**': ↓global* (β=-0.24; (-0.45,-0.03)); ↓exec function** (β=-0.33; (-0.55,-0.10)) in M. 2. A, S, E, PA, smoking, BMI, MetS, BP, chol, diab, stroke, depression, *APOE* -ε4.

Study	Population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders

[1] for continuous variables, beta coefficient (β) (95% confidence intervals); for dichotomous outcomes, odds ratio (OR) (95% confidence intervals)

24-hr = 24 hour, A= age, ADL = activities of daily living, alc = alcohol, *APOE* = apolipoprotein E, BMI = body mass index, BP = blood pressure or hypertension, CA = cluster analysis, Ca = calcium, CCI = Cognitive Change Index, CES-D = Center for Epidemiologic Studies Depression Scale, chol = cholesterol, cog = cognitive, CogI = cognitive impairment, CS = cross-sectional, CSI-D = Community Screening Instrument for Dementia, CVD = cardiovascular disease, CVLT = California Verbal Learning test, diab = diabetes, diff = difference, E = education, EI = energy intake, EI-adj = energy intake adjusted, exec = executive, F = female, Fe = iron, FG = food groups, FR = food record, GDS = Geriatric depression scale, HF = high-fat, LF = low-fat: M = male, MetS = metabolic syndrome, Mg = magnesium, MMSE = Mini-Mental State Exam, MMSE-KC = Mini-Mental State Examination, Korean version, NR = not reported, PA = physical activity level, PCA = principal component analysis, proc'd = processed, PUFA = polyunsaturated fatty acids, RRR= reduced ranked regression, S = sex/gender, SD = standard deviation, SMDT=symbol digit modalities test, SSB = sugar sweetened beverage, TG = triglycerides, TICS-m = Telephone Interview for Cognitive Status – modified, USA = United States of America, V = validated, veg = vegetables, vit = vitamin, WC = waist circumference, Y/N = yes/no, yrs = years

P-value: *<0.05; **<0.01; ***<0.001; ns≥0.05

Table 2.14: Fourteen longitudinal studies exploring associations between *a posteriori* dietary patterns and cognitive function/decline in older adults

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Parrott et al. (2013), Canada, NuAge.	follow-up: 3 yrs, NR, *n* 1,099, 68-84 yrs, ~ 50% M.	1. 78-FFQ over 12 mths (V), 2. PCA, 3. ~78 FGs, 4. intake by volume.	2 DPs explained 10% of variation in diet '**prudent**': ↑veg, fruit, fatty fish, LF dairy, poultry, legumes. '**Western**': ↑beef, potatoes, white bread, baked goods, proc'd meats, HF dairy, salty snacks.	1. MMSE, 2. Global, 3. continuous, decline in cog score.	1. '**prudent**': ↑global score* (↑education, ↑income, ↑SES only); ↓global decline* (↓SES position only); '**Western**': ↑global decline* (↓education only). 2. A, S, E, PA, smoking, BMI, WC, CVD risk factors, medication and supplement use, social engagement, depression, perceived health status and interactions with time.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Qin et al. (2015), China, China Health and Nutrition Survey.	follow-up: 5 yrs, Chinese, *n* 1,650, ≥55 yrs, 50% M.	1. 24-hr recall over 3 consecutive days by trained interviewer, 2. PCA, 3. 34 FGs, 4. intake by volume.	2 DPs explained 23% of variation in diet '**wheat based diverse**': ↑wheat buns, deep-fried wheat, nuts, fruits, moderate-HF red meat, poultry, game, egg, fish, dairy, sugar, vinegar, soy sauce, plant oil; ↓animal-source fats; '**rice pork**': ↑rice, LF red meats, pork (all fat), organ meats, poultry, game, fish; ↓wheat flour, wheat buns, and coarse grain.	1. battery of tests, 2. global, verbal memory, 3. continuous, decline in cog score.	1. stratified by age (≤65, > 65 yrs) - '**wheat-based diverse**' : ↓global decline* (β=0.42 (0.12, 0.73)) >65 yrs only; verbal memory ns; '**rice, pork**' global and verbal memory decline ns. 2. A, S, E, PA, smoking, BMI, EI, income, urbanisation index, BP and interactions with time.
Gardener et al. (2015), Australia, Australian Imaging, Biomarkers and Lifestyle Study of Ageing (AIBL).	follow-up: 3 yrs, primarily Caucasian, *n* 527, ≥60 yrs, 40% M.	1. 101-Cancer Council of Victoria FFQ over 12 mths (V), 2. PCA, 3. 33 FGs, 4. intake by volume.	2 DPs explained 8% of variation in diet '**prudent**': ↑veg, fruit, nuts; '**Western**': r↑ed & proc'd meat, chips, refined grains, poultry, condiments, potatoes, sweets, breakfast cereals, meat pies, margarine, HF dairy, dark-yellow veg, juice.	1. battery of tests, 2. global; verbal memory; visual memory; exec function; language; attention; visuospatial, 3. continuous, decline in cog score.	1. '**prudent**': ns; '**Western**': more visuospatial decline in *APOE* -ε4 allele non-carriers (β=0.00)**. 2. A, S, E, PA, smoking, BMI, EI, income, country of birth, CVD risk factors and interactions with time.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Granic et al. (2016), United Kingdom, Newcastle 85+.	follow-up: 5 yrs, NR, *n* 791, ≥85 yrs, 38% M.	1. 24-hr on 2 occasions, excl Fri, Sat taken by trained research nurses, 2. CA, 3. 33 FGs, 4. dichotomous (absent or present in diet).	'**high red meat**': ↑red meat/meat dishes, gravy, and potato (*n* 276); '**high butter**': ↑butter; ↓unsaturated fat spreads and oils (*n* 255); '**low meat**': ↑fish, fruits, nuts, dairy, whole grain; ↓red/proc'd meat, gravy, potato (*n* 260)	1. MMSE and 3 attention tests, 2. global, attention, 3. continuous, cog score baseline and decline.	1. '**low meat**' better baseline attention; '**low meat**' better global score (M only). 2. S, E, marital status, social class, PA, smoking, diet change, BMI, multi morbidity and interactions with time.
Pearson et al. (2016), USA, REasons for Geographic And Racial Differences in Stroke (REGARDS).	follow-up: 7yrs, Black (42%) and White Americans, *n* 18,080, ≥45 yrs (baseline), 45% M.	1. 107-Block98 FFQ, 2. PCA, 3. 56 FGs, 4. intake by volume.	5 DPs explained 24% of variation in diet '**convenience**': ↑mixed dishes with meat, pizza, Chinese food, Mexican dishes; '**plant-based**': ↑veg, fruits, fish, beans; '**sweets/fats**': ↑miscellaneous sugars, desserts, candy, sweet breakfast foods, added fats; '**southern**': ↑added fats, fried food, egg dishes, organ meats, proc'd meats, SSB; '**alcohol/salads**': ↑green-leafy veg, tomatoes, salad dressing, wine, liquor.	1. 6-item screener and 3-item battery, 2. memory, learning and exec function, 3. dichotomous, where cog'ly impaired = 6-item screener score <5.	1. '**convenience**', '**plant-based**', '**sweets/fats**', '**Southern**' ns; '**alcohol/ salads**' ↓CogI [OR=0.68 (0.56, 0.84)]***. 2. A, S, E, race, region, EI, income, PA, smoking, BMI, CVD risk factors and depression and interactions with time.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Shakersain et al. (2016), Sweden, Swedish National study on Aging and Care-Kungsholmen (SNAC-K).	follow-up: ~ 7 yrs, NR, *n* 2,223, 2 cohorts (60-77 yrs and ≥78 yrs), 39% M.	1. 98-FFQ (V), 2. PCA, 3. 35 FGs, 4. intake by frequency.	'**prudent**': ↑veg, fruit, fish, rice/pasta, whole grains, LF dairy, water, poultry, oil, legumes; '**Western**': ↑red/proc'd meat, refined grains, potatoes, sugar/sweets, pastry, juice, HF spreads, medium & HF dairy, soda, beer.	1. MMSE, 2. Global, 3. continuous, mean change in MMSE score.	1. '**prudent**': reduced cognitive decline [β=0.04 (0.02, 0.07)]; '**Western**': increased cognitive decline [β=-0.05 (-0.07, -0.02]; ↑adherence to '**prudent**' may counteract effects of ↑adherence to '**Western**' on cognitive decline. 2. A, S, E, PA, smoking, *APOE* -ε4, civil status, BMI, supplement intake, depression, CVD risk factors and interactions with time.
Mazza et al. (2017), Italy.	follow-up: 1 yr, European, *n* 214, ≥65 yrs, NR% M.	1. 24-hr and 7-DFR, 2. PCA, 3. 8 FGs and 10 nutrients, 4. intake by volume.	food patterns: **'cereals, meat, fish, olive oil**'; '**cakes, fruit**'; '**animal fats, margarines**'; '**legumes**'. nutrient patterns: '**animal protein**'; '**vegetal oils**'; '**fats**'; '**plant proteins, polyunsaturated fats**'.	1. MMSE, 2. Global, 3. continuous, cog score.	1. '**legumes**': improved MMSE scores after 1 year (β=0.22, (0.04, 0.42))*. 2. A, S, E, BMI, WC, glucose, HDL, LDL, triglycerides, BP (some removed through stepwise).

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Chen et al. (2017), Taiwan.	follow-up: 2 yrs, Taiwanese, *n* 475, ≥65 yrs, 52% M.	1. 44-FFQ (V), 2. PCA, 3. 24 FGs, 4. intake by volume.	3 DPs explained 26% of variation in diet '**vegetables**': ↑veg; '**meat**': ↑meat, poultry; '**traditional**': ↑pickled veg and fermented foods.	1. MoCA, battery of tests, 2. global; memory and attention; exec function, 3. continuous, decline in cog score and dichotomous, where cog decline = change in cognition tertile.	1. '**vegetable**' ↓decline logical memory; ↑decline in exec function; '**meat**' ↓decline attention; ↑decline verbal fluency; '**traditional**' ↓decline logical memory. 2. A, S, E, *APOE*-ε4, PA, EI, supplement use, depression, CVD risk factors.
Ozawa et al. (2017), UK, Whitehall II.	follow-up: ~ 5 & 10 yrs, White, South-Asian, Black, Other, *n* 5,083 (L) and 3,917 (CS), mean ~56 yrs, 71% M.	1. 127-FFQ (V), 2. RRR, 3. 37 FGs, 4. intake by volume, EI-adj using density method.	2 DPs explained 4% variation in IL-6 at 2 time points (response variable). Only 1st DP used as explained 95% of variation in FGs '**inflammatory**': ↑red/proc'd meat, peas/legumes, fried foods; ↓whole grains.	1. MMSE, battery of tests, 2. global, reasoning, memory, verbal fluency, 3. continuous, cog score and dichotomous, where cog decline = reduction of 3 points or more on MMSE score.	1. '**inflammatory**': reasoning ↑decline* (β=-0.37 (-0.40, -0.33)); global ↑decline* (β=-0.35 (-0.38, -0.32)); ns memory and verbal fluency. ns result in OR for global decline (5yrs). 2. A, S, E, ethnicity, occupational position, EI, PA, smoking, BMI, T2DM, BP (at baseline).

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Richard et al. (2018), USA, Rancho Bernardo Study.	follow-up: 9 (8) mean (SD) yrs, primarily White (99%), *n* 1,499, ≥50 yrs (baseline), 42% M.	1. 153-Willett FFQ over 12 mths (V), 2. PCA, 3. 23 nutrients, 4. intake by volume, EI-adj using residual method, log transformed.	5 DPs explained 76% of variation in diet **'fortified cereals'**: ↑iron, zinc, vit B6, B12 folate, thiamin, and E; **'fruits and vegetables'**: ↑crude fibre, β-carotene, vit C, fructose, ↓SF; '**animal fat/vit B12**': ↑cholesterol, arachidonic acid, vit B12, SF, protein, zinc; '**dairy**':↑lactose, Ca, vit D; '**plant PUFA/vitamin E**': ↑LA, ALA, vit E, SF; '**sugar/low protein**': ↑sucrose, fructose, ↓protein.	1. MMSE, battery of tests, 2. global; exec function/psychomotor processing speed; verbal semantic fluency; verbal episodic memory, 3. continuous, cog score.	1. '**plant PUFA/vitamin E**': ↑executive function (β=-7.85 (-13.2, -2.47))* (score is based on time), ns CogD; '**sugar/low protein**': ↓verbal fluency (β=-0,57 (-1.03, -0.11); ↓global (β=-0.29 (-0.49, -0.09)), ns CogD; **'fortified cereals'**; '**fruits and vegetables**'; '**animal fat/vit B12**'; '**dairy**' ns at baseline or CogD. 2. A, S, E, EI, smoking, alc, PA and time effects.
Allès et al. (2019), France / Canada, Three-City, NuAge.	follow-up: 5 yrs, NR, *n* 2,827, ≥65 yrs, 43% M.	1. 3 Cities: 1 x 24hr NuAge: 3 x 24hr (but only 1 used in this study), 2. PCA, 3. 21 nutrients, 4. intake by volume, EI-adj using residual method.	Three-City: 3 DPs explained ~50% of variation in diet '**healthy**' ↑K, fibre, Mg, folate, vit B6, CHO, vit C, Fe, vit E, carotene; '**Western**' ↑MUFA, SFA, P, pro, n-3 PUFA, Ca, n-6 PUFA, vit D, vit E; '**traditional**' ↑vit B12, vit A. NuAge: 3 DPs explained ~50% of variation in diet '**healthy**' ↑K, Mg, fibre, vit B6, vit C, P, Fe, CHO, vit E, carotene; '**Western**' ↑MUFA, SFA, n-3 PUFA, pro, folate, Ca, n-6 PUFA, vit D; '**traditional**' ↑vit B12, vit A, Zn.	1. MMSE, 2. Global, 3. continuous, cog score.	1. Three-City: '**healthy**': ↑global**, no CogD; '**Western**': ↓global*, no CogD; '**traditional**': ns. Nu-Age: '**healthy**', '**Western**', '**traditional**': ns. 2. A, S, E, EI, T2DM, BP, stroke and time effects.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Dearborn-Tomazos et al. (2019), USA, Atherosclerosis Risk in Communities (ARIC) study.	follow-up: ~18 yrs, Black and white, *n* 13,588, mean 55 yrs at baseline, 44% M.	1. 66-FFQ (V unclear), 2. PCA, 3. 20 FGs, 4. NR.	2 DPs explained 22% of the variation in the diet '**Western**': ↑meat, refined grains, processed and fired foods; '**prudent**': ↑fruits, veg, fish, chicken, whole grains, dairy, nuts, alcohol.	1. Delayed Word Recall; Digit Symbol Substitution; and Word Fluency, 2. Global, 3. Continuous, decline in cog score.	1. '**Western**': ns with CogF nor CogD; '**prudent**': ns with CogF nor CogD. 2. A, S, E, race, PA, alc, smoking, EI, BMI, chronic disease, *APOE*-ε4 .
Prinelli et al. (2019), Sweden, Swedish National study on Aging and Care-Kungsholmen (SNAC-K).	follow-up: ~9 yrs, NR, *n* 2,250, 60+ yrs, 39% M.	1. 98-FFQ (V), 2. PCA, 3. 30 nutrient FGs, 4. nutrient variable log transformed and EI-adj using residual method.	4 DPs explained 79% of the variation in the diet **'plant-derived nutrients**': ↑fibre, monosaccharide, K, Mg, vits C, B1, B6, E, folic acid, β-carotene; ↓MUFA and SFA. 'a**nimal-derived nutrients**': ↑protein, cholesterol, phosphate, Na, Se, vit B3, B12, D, Zn; ↓disaccharides. 'd**airy-derived nutrient**': ↑protein, disaccharides, phosphate, Ca, Se, vit B2, B12. 'a**nimal/plant fats**': ↑cholesterol, SFA, MUFA, PUFA, vit K, E.	1. MMSE, 2. Global, 3. continuous, decline in cog score.	1. stratified by *APOE*-ε4 allele: without *APOE*-ε4: '**plant**', '**animal**', '**dairy**', '**animal/plant fats**': ns. with *APOE*-ε4: '**plant**': reduced CogD*** (β=0.17 (0.08, 0.27)); '**animal**': reduced CogD** (β=0.16 (0.07, 0.26)); '**dairy**', '**animal/plant fats**': ns. 2. A, S, E, marital status, PA, smoking, alc, EI and 4 NP scores.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders
Corley and Deary (2020), UK, Lothian Birth Cohort 1936.	follow-up: every 3 yrs between 70-82 yrs, European, *n* 863, 70 yrs (baseline), 50% M.	1. 168-Scottish Collaborative Group FFQ v7 (V), 2. PCA, 3. 168 FGs, 4. intake by volume, DP scores were EI-adj using the residual method.	2 DPs explained 12% of variation in diet '**Mediterranean style**': ↑veg, fish, legumes, olive oil, salad dressing, poultry, pasta, rice, water, tomato-based sauces; '**traditional**': ↑meat, proc'd meats, mashed potatoes, tinned veg, peas or beans, carrots, baked beans, bottled sauces, sweet sauces, milk-based puddings; ↓coffee.	1. battery of tests, 2. global, visuospatial ability, processing speed, memory and verbal ability, 3. continuous, cog score.	1. '**Mediterranean style**': ↑verbal ability β=0.06 (SE=0.02)**, ↑verbal ability decline β=-0.00 (SE=0.00)**; ns global, visuospatial, processing speed, memory; '**traditional**': ↓global β=-0.09 (SE=(0.02)***, ↓verbal ability β=-0.09 (SE=0.02)***; ns global decline, visuospatial, processing speed, memory, verbal ability decline. 2. A, S, age 11 IQ, *APOE* -ε4, smoking, PA, marital status, SES.
Muñoz-García et al. (2021), Spain, Seguimiento Universidad de Navarra (SUN).	follow-up: 6 yrs, Spanish, *n* 806, 55+ yrs (baseline), 70% M.	1. 136-FFQ (V), 2. PCA, 3. 31 FGs, 4. intake by volume.	2 DPs explained 14% of variation in diet '**Western**': ↑refined cereals, HF dairy, eggs, sweets, SSB, commercial bakery, sauces, precooked meals, fast food, proc'd and non-proc'd red meat, potatoes (baked or fried); '**Mediterranean**': ↑veg, dried fruits, nuts, fish, juices, olive oil.	1. TICS-m, 2. Global, 3. continuous, change in cog score.	1. '**Western**': CogD, β=-0.80 (-1.51, -0.08)*; '**Mediterranean**': improved CogF, β=0.71 (0.15, 1.26)*. 2. A, S, E, BMI, PA, EI, smoking, alc, follow-up time, CVD risk factors and disease at recruitment.

Author, location, study name	Study Design, population, *n*, age, sex	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable	Dietary patterns identified	1. Cognitive tests used 2. Domains tested 3. Outcome used	1. Results[1] 2. model confounders

[1] for continuous variables, beta coefficient (95% confidence intervals); for dichotomous outcomes, odds ratio (OR) (95% confide nce intervals)

24-hr = 24 hour; A= age; ADL = activities of daily living; alc = alcohol; *APOE* = apolipoprotein E; BMI = body mass index; BP = blood pressure or hypertension; CA = cluster analysis; Ca = calcium; chol = cholesterol; cog = cognitive; CogD = cognitive decline; CogI = cognitive impairment; CS = cross-sectional; CSI-D = Community Screening Instrument for Dementia; CVD = cardiovascular disease; CVLT = California Verbal Learning test; diab = diabetes; diff = difference; E = education; EI = energy intake; EI-adj = energy intake adjusted; exec = executive; F = female; Fe = iron; FG = food groups; GDS = Geriatric depression scal e; HF = high-fat; LF = low-fat: M = male; MetS = metabolic syndrome; Mg = magnesium; MMSE = Mini-Mental State Exam; NP = nutrient pattern, NR = not reported; OR = odds ratio; PA = physical activity level; PCA = principal component analysis; proc'd = processsed; PUFA = polyunsaturated fatty acids; RRR= reduced ranked regression; S = sex/gender; SD = standard deviation; SMDT=symbol digit modalities test; SSB = sugar sweetened beverage; TG = triglycerides; TICS-m = Telephone Interview for Cognitive Status – modified; USA = United States of America, V = validated; veg = vegetables; vit = vitamin; WC = waist circumference; Y/N = yes/no; yrs = years

P-value: *<0.05; **<0.01; ***<0.001; ns≥0.05

2.5.2.2. Systematic reviews

Four reviews explored studies in older adults regarding associations between dietary patterns (both *a priori* and a *posteriori*) and cognitive function or decline, and/or dementia as outcomes (Table 2.15). Although the systematic reviews found evidence supportive of a beneficial relationship between cognitive health and adherence to a *a priori* Mediterranean Diet, Dietary Approaches to Stop Hypertension (DASH), MIND and adherence to a *a posteriori* dietary patterns (with healthy food groups) there remained inconsistencies amongst the methods and results (Milte and McNaughton, 2016, Chen et al., 2018, Solfrizzi et al., 2017, van de Rest et al., 2015).

The most recent systematic review evaluated evidence of dietary patterns and associations with cognitive function and/or dementia (Chen et al., 2018). This review focussed on studies with higher levels of evidence e.g., randomised controlled trials and longitudinal studies, rather than the cross-sectional studies seen in Milte and McNaughton (2016) and Solfrizzi et al. (2017). With the *a posteriori* studies, the review found mixed results on the 'prudent' or 'healthy' diet (longitudinal, *n* 3) which may be due to the nature of the differing methods, but the 'Western' pattern (longitudinal, *n* 1) was associated with a poorer cognitive outcome (Chen et al., 2018).

The other systematic reviews (Milte and McNaughton, 2016, Solfrizzi et al., 2017, van de Rest et al., 2015) covered both cross-sectional and longitudinal dietary pattern (both *a priori* and *a posteriori*) studies. The outcomes explored included cognitive function, cognitive decline, health ageing, and dementia risk. The results broadly supported adherence to a 'healthy' dietary pattern (in particular, the Mediterranean Diet) was beneficial to cognitive health though some inconsistencies were present and further higher quality research is required for conclusive evidence.

Methodology was a limitation in many studies creating heterogeneity (van de Rest et al., 2015). Chen et al. (2018) outlined several limitations. These include failing to adjust for long-term medications, *APOE*-ε4, and other known risk factors such as physical activity levels, obesity, diabetes, smoking, and alcohol; short follow up times (in longitudinal studies) which may reflect reverse causality; specific cut-off points for *a priori* adherence scores; and randomised controlled trials were limited by single blinding. In addition, a risk of bias assessment undertaken in the systematic review of Milte and McNaughton (2016) identified another two common methodological failings. Firstly, selection bias, referring to whether the study population re presented the target population and secondly, high withdrawals and drop-outs which may come from the dietary pattern study being secondary to the initial study aim.

Table 2.15: Four systematic reviews exploring the associations between dietary patterns and cognitive function in older adults

Author, year	Scope	Results	Conclusion and recommendations
van de Rest et al. (2015)	Aim: to summarise and critically evaluate studies with assns between MeDi and other DPs and cognitive performance and/or dementia. Search period: 1980 to Dec 14 Include: older adults, full articles Exclusion: NR RoB: NR	MeDi: 26 studies; other DPs: 15 studies, of which CA (*n* 3), RRR (*n* 3), PCA (*n* 2) and *a priori* patterns (*n* 7) Better adherence to a MeDi is associated with ↓CogD, dementia, or AD, as shown by 4/6 CS studies, 6/12 L studies, 1 trial, and 3 Meta-A. Other healthy DPs, derived both *a priori* (e.g., HDI, HEI, Program National Nutrition Santé guideline score) and *a posteriori* (e.g., FA, CA, RRR), were associated with ↓CogD and/or ↓risk of dementia (6 CS and 6/8 L studies).	Overall, all DP approaches suggest healthy DP (including MeDi) is associated with ↓CogD and/or ↓risk of dementia. Most studies CS, only 2 interventions. Several different methodologic factors between the studies. Heterogeneity hinders comparison between studies. More conclusive evidence is needed.
Milte and McNaughton (2016)	Aim: to review studies examining dietary DPs and quality of life, physical function, CogF and mental health in older adults Search period: 1980 to Dec 14 Include: *a priori* and *a posteriori* DPs; community-dwelling adults, 45+ yrs; CS or L Exclusion: single 24-hr recall, evaluation of single food or nutrients, intervention studies RoB: Effective Public Health Practice Project's Quality Assessment Tool for Quantitative Studies	*a priori* (*n* 12), *a posteriori* (*n* 7) studies explored assns between DPs and CogF. The *a posteriori* studies had a low (*n* 1), moderate (*n* 4) and high (*n* 2) RoB. Better CogF was associated with 'healthy/prudent' (*n* 3), 'Mediterranean style' (*n* 1),'traditional' (*n* 1), 'vegetable–fruits' (*n* 1), 'snacks–drinks–milk products' (*n* 1) or 'whole food' (*n* 1) DP, despite varying CogF measures. Poor CogF was associated with 'processed food/Western' (*n* 2) DP	Evidence broadly supports r'ship between 'healthy' diet and better CogF or ↓CogD, though inconsistencies among results, particularly MeDi indices. Need for further high-quality research.

Author, year	Scope	Results	Conclusion and recommendations
Solfrizzi et al. (2017)	Aim: to explore r'ships among DP, foods, FGs, micro- macronutrients and late-life Cog disorders Search period: 2014-16 Include: *a priori* and *a posteriori* DPs, foods, food groups, micro and macronutrients; 45+ yrs; CS or L; assessing CogF using diagnostic criteria for MCI, AD, vascular dementia, unspecified dementia or neuropsychological tools to define CogI or CogD; also in non-demented participants Exclusion: NR RoB: NR	Reviewed *a priori* (*n* 13) and *a posteriori* (*n* 4) DPs. Evidence suggests r'ship between DPs and changes in brain structure and activity. MeDi associated with ↓CogD. DASH, MIND diets associated with slower rates of CogD and ↓AD rate.	Patterns provide stronger health benefits than individual diet components. MeDi, DASH and MIND diets were associated with ↓CogD. Larger studies with longer follow-up periods required, addressing potential bias and confounding sources.
Chen et al. (2018)	Aim: update and evaluate RCTs and prospective cohorts conducted DPs and CogF and/or dementia Search period: Jan 1997 to Sep 17. Include: RCT and L studies; measured CogF or brain morphology, followed up to test CogF or incidence of MCI or dementia; 50+ yrs; *a priori* and *a posteriori* DPs Exclusion: CS studies R0B: Cochrane Risk of Bias tool	MeDi, DASH, MIND and anti-inflammatory *a priori* DPs (*n* 37) associated with better Cog outcomes except MeDi in non-Mediterranean studies had mixed results. Mixed results also reported with *a posteriori* (*n* 7) DPs	Overall, findings support positive assns between plant-based DPs with ↓consumption of processed foods and Cog health in older adults. More research to understand mechanisms to protect against CogD and dementia

AD = Alzheimer disease, assns = associations, CA = cluster analysis, CogD = cognitive decline, CogF = cognitive function, CogI = cognitive impairment, CS = cross-sectional, DASH = Dietary Approaches to Stop Hypertension, Dec = December, DP = dietary pattern, HDI = Healthy DIet Index, HEI = Healthy Eating Indes, hr = hour, L = longitudinal, MCI = mild cognitive impairment, MeDi = Mediterranean diet, Meta-A = meta-analysis, MIND = Mediterranean-DASH diet Intervention for Neurodegenerative Delay, NR = not reported, PCA = principal component analysis, r'ship = relationship, RCT = randomised controlled trials, RoB = Risk of Bias, RRR = reduced rank regression, yrs = years

2.5.3. Critique

2.5.3.1. Dietary assessment tools

A FFQ or diet history was the preferred method to collect dietary data for the dietary patterns (*n* 30) with the remaining studies using 24-hour recalls or food diaries. A valid FFQ or diet history questionnaire was used to collect dietary data (*n* 26). Three studies (Ashby-Mitchell et al., 2015, Dearborn-Tomazos et al., 2019, Ferrand et al., 2017) did not clearly state the validity of the dietary assessment tool. Other studies used a 24-hour recall or food record (*n* 7) covering at least three days though Allès et al. (2019), using NuAge and Three-City dietary data (*n* 2,827, 65+ years, France/Canada), based their dietary patterns on one 24-hour recall which may not demonstrate sufficient day to day variability (Willett, 2012a) for dietary patterns.

2.5.3.2. Dietary pattern methods

Several methods were employed to derive dietary patterns, with some studies applying more than one dietary pattern analysis method. Principal component analysis was the most popular method to derive dietary patterns (*n* 27), followed by cluster analysis (*n* 4), reduced rank regression (*n* 5) or a mix of principal component and cluster analysis (*n* 1).

Principal component analysis was commonly accompanied by varimax rotation to improve the interpretability of the patterns. Factors were often retained based on scree plots, eigenvalues (> 1 or more cut-off point) and interpretability. The average number of food groupings was 44, 29, 26 used in principal component analysis, reduced rank regression and cluster analysis, respectively. Principal component analysis requires the dietary data to have adequate variation and correlation to obtain suitable dietary patterns. Often adequacy measures of dietary data go unmeasured. Where principal component analysis was the chosen method of dietary pattern analysis, only four of 27 dietary pattern analyses reported the Kaiser-Meyer-Olkin measure of sample adequacy and/or the result from the Bartlett's test of sphericity (Richard et al., 2018, Osawa et al., 2017, Shakersain et al., 2016, Yu et al., 2018).

Clustering was used in four studies (Ferrand et al., 2017, Granic et al., 2016, Kim et al., 2015b, Samieri et al., 2008) and one study clustered principal component dietary pattern scores in a mixed method design (Wesselman et al., 2019). Methods employed were the *k*-means cluster (Kim et al., 2015b, Wesselman et al., 2019) or a hierarchical approach (Ferrand et al., 2017, Samieri et al., 2008, Granic et al., 2016). Reduced rank regression was used in five studies and based on MMSE scores (Chuang et al., 2019), plasma carotenoids (Kesse-Guyot et al., 2014); interleukin-6 (Ozawa et al., 2017); interleukin-6 and CRP (Gu et al., 2018); and vitamins B6, C and iron (Shin et al., 2018).

Accounting for energy intake

In dietary pattern studies, it is important to consider energy intake (Willett, 2012b). An adjustment for energy intake is not necessary prior to dietary pattern analysis (Granic et al., 2016, Edefonti et al., 2019, Shakersain et al., 2018) though an adjustment is, at least, required in the statistical analysis. Thirteen studies in this literature review failed to make any energy intake adjustment prior to or after analyses though eight studies did use a proxy measure as a confounder, such as, BMI or physical activity level as suggested by Willett (2012b). This leaves five studies with no consideration for energy intake (Samieri et al., 2008, Wesselman et al., 2019, Ferrand et al., 2017, Mazza et al., 2017, Corley et al., 2013). It then remains unclear whether the associations reported in these five studies is due to the dietary pattern or the energy intake of the participants.

Validation of patterns

As discussed previously, the validation of derived dietary patterns is not common, though it would improve confidence in results and add value to the evidence base (Allès et al., 2012). No studies reported validated dietary patterns though seven studies did undertake further steps to test the robustness of their patterns (Akbaraly et al., 2009, Pearson et al., 2016, Okubo et al., 2017, Kim et al., 2015b, Kesse-Guyot et al., 2014, Granic et al., 2016, Gu et al., 2018). These extra tests included running the dietary pattern analysis again: in a random 50% of the sample (Kim et al., 2015b, Okubo et al., 2017); by randomly reordering the data set in cluster analysis (Granic et al., 2016); using confirmatory factor analysis (Pearson et al., 2016); with more food groups (Akbaraly et al., 2009); by varying the response variables (Gu et al., 2018) or using bootstrap analysis (Kesse-Guyot et al., 2014).

By sex (or gender)

As associations between outcomes and dietary patterns sometimes differ between the sexes (or genders), consideration of these differences is encouraged (Milte and McNaughton, 2016). Though most studies constructed dietary patterns based on the full data set, four studies stratified by sex (Ferrand et al., 2017, Chen et al., 2020, Samieri et al., 2008, Chuang et al., 2019). The Three-City study (*n* 1,724, 65+ years, 38% male, France) reported increased global scores in both the 'fish' (male) and 'fruit and vegetable' (female) patterns (Samieri et al., 2008) whereas the PRAUSE[13] study (*n* 402, 38% male, France) reported only female clusters were associated with better cognitive function (cluster 1: fish, fruit and vegetables) and reduced cognitive decline (cluster 3: ready meals) (Ferrand et al., 2017). A study in Taiwan (*n* 1,245, 65+ years, 51% male) found associations between reduced cognitive impairment and dietary patterns, similar in both males and females (Chuang et al.,

[13] Seniors' autonomy preservation in Poitou-Charentes

2019). Finally, sex-specific dietary patterns were created in the Sydney Memory and Ageing Study (*n* 819, 70+ years, 44% male, Australia) as there were significant sex differences in food group consumption and cognitive performance (Chen et al., 2020). The Sydney Memory and Ageing Study found a 'prudent healthy' female pattern was positively associated with the global cognition domain and 'Western' male pattern was negatively associated with both the global cognition and executive function domain.

2.5.3.3. Areas of heterogeneity

There are several areas of heterogeneity in the design of the studies in this literature review, in particular the variety of cognitive tests used and choosing the outcome variable. Also, the selection of study participants ranged from high scores on the MMSE to participants with neurodegenerative disease.

Cognitive testing methods

The depth and breadth of validated cognitive tests is vast and while the outcome is cognitive function/performance or decline, the methods used to reach these outcomes are heterogenous (National Academies of Sciences, Engineering, and Medicine, 2017). The various outcomes from the studies in this literature review varied between a single global cognitive score (primarily MMSE); specific cognitive domains; incidences of cognitive impairment (with varying cut off points); and cognitive decline both with continuous and categorical variables. This adds complexity in interpretation and comparisons which is further complicated by a diversity of dietary patterns derived with slightly different methods. Furthermore, the lack of a standardised measurement tool to evaluate cognitive outcomes is not limited to *a posteriori* dietary pattern studies (Fessel et al., 2017, Plassman et al., 2010).

One of the few tests consistently used to test the global cognitive domain is the MMSE. Despite being frequently used (Alavi-Naeini et al., 2019, Shin et al., 2018, Yu et al., 2018, Ferrand et al., 2017, Kim et al., 2015a, Kim et al., 2015b, Parrott et al., 2013, Samieri et al., 2008, Osawa et al., 2017, Shakersain et al., 2016, Sugawara et al., 2015, Wesselman et al., 2019, Yin et al., 2018, Mazza et al., 2017), the MMSE is designed to diagnose and assess the progression of dementia (Folstein et al., 1975) and as such may not be a sensitive tool for cognitive assessment in those with age-related cognitive decline or mild cognitive impairment (Sugawara et al., 2015, Osawa et al., 2017). Another tool used to test the global cognitive domain, but designed to assess neuropsychological status, is the MoCA (Smith et al., 2007). Both these tools are quick to administer and often the only test of cognitive function in the dietary pattern studies.

A battery of tests assessing multi-cognitive domains adds breadth to a study as domains will be unique in mechanisms and dietary effects. Associations between dietary patterns and several domains have been reported. Positive associations with dietary patterns containing healthy food groups have been seen in global cognition (Kesse-Guyot et al., 2014, Kesse-Guyot et al., 2012), executive function (Kesse-Guyot et al., 2014), language (Kesse-Guyot et al., 2014, Corley and Deary, 2020), attention (Granic et al., 2015, Chen et al., 2020), visuospatial (Corley et al., 2020), episodic (Corley et al., 2020, Chen et al., 2017) but there are also reports of negative associations with dietary patterns (containing healthy food groups) and processing speed (Ashby-Mitchell et al., 2015), executive function (Richard et al., 2018), and episodic memory (Chen et al., 2017). Negative associations have been reported between dietary patterns containing unhealthy food groups, e.g., 'Western' / 'processed food', and episodic memory (Ashby-Mitchell et al., 2015), visuospatial (Gu et al., 2018), language (Richard et al., 2018, Pearson et al., 2016, Corley and Deary, 2020), executive function (Chen et al., 2020), and episodic memory (Xu et al., 2018, Pearson et al., 2016). There have also been domains without associations and also associations between cognitive domains and dietary patterns containing a mix of healthy and unhealthy food groups such as a 'traditional Chinese' pattern, characterised by rice, pork, fish and low intakes of wheat and whole grains (Xu et al., 2018). Here, this 'traditional Chinese' pattern was positively associated with verbal memory.

Outcomes

In studies where a quick tool such as the MMSE measured the global cognition domain, approximately half dichotomised the outcome to good or poor cognitive function. The decision to use a dichotomised variable, over a continuous variable, means determining a cut-off point for healthy cognitive function. This cut-off point is not always consistent. The MMSE has a recommended cut off point of 24 i.e., 24 and above is cognitively healthy (Tombaugh and McIntyre, 1992, Folstein et al., 1975) but this cut off score is without consideration to the participants age or educational background and may lead to classification errors (Lezak et al., 2012). Furthermore, studies used other cut-off points, such as, 25 (compared with 24) (Ashby-Mitchell et al., 2015, Yu et al., 2018, Sugawara et al., 2015); below 1.5 SD of the mean score (Kim et al., 2015a, Shin et al., 2018, Kim et al., 2015b) which alters the sensitivity and specificity of the test (Tombaugh and McIntyre, 1992); or based on a percentile or other score (Yin et al., 2018, Chuang et al., 2019).

Study populations

The inclusion and exclusion criteria of the study populations in this literature review are heterogenous. Some studies included dementia or stroke as a confounder (Chuang et al., 2019) which suggested some participants, while living independently, may be clinically impaired. The Lothian Birth 1936 cohort studies excluded participants with a MMSE score <24 (Corley et al., 2020,

Corley et al., 2013). The Swedish cohort, SNAC-K, excluded participants with a MMSE score below 27 (Shakersain et al., 2016) or below 24 (Prinelli et al., 2019). This reduced variation in cognitive abilities is likely to affect outcomes, though the SNAC-K study had enough variation to report modest associations (Shakersain et al., 2016). Of concern, was the lack of report for the differences between the study group and excluded participants (Prinelli et al., 2019, Shakersain et al., 2018)).

2.5.3.4. Confounders

Cognitive status is complex and influenced by many variables (Akbaraly et al., 2009, Chen et al., 2018, Norton et al., 2014, Parrott et al., 2013) including age, sex, socio-demographics, health, and lifestyle factors (Allès et al., 2012, Chen et al., 2018, World Health Organization, 2019, Parrott et al., 2013, Akbaraly et al., 2009, Kesse-Guyot et al., 2012). To avoid residual confounding, it is important known risk factors are considered as confounders (Chen et al., 2018). These are discussed below.

Apolipoprotein E ε4

Apolipoprotein is a lipid transporting protein with three common isoforms, -ε2, -ε3 and -ε4, of which -ε4 is the least abundant. The -ε4 isoform is one known genetic factor likely to increase the risk for developing Alzheimer Disease (Mahoney-Sanchez et al., 2016), vascular dementia (Sun et al., 2015) and puts healthy individuals at risk of increased age-related cognitive decline (Wisdom et al., 2011). It remains unknown exactly how *APOE*-ε4 impacts cognitive health (Mahoney-Sanchez et al., 2016).

This genetic risk factor is not commonly recognised in studies exploring associations between dietary pattern and cognition (Chen et al., 2018), though carriers of at least one *APOE*-ε4 allele have lower scores in episodic memory, executive function and overall global ability as reported in a meta-analysis of 77 studies exploring the *APOE*-ε4 genotype and measures of cognitive performance (Wisdom et al., 2011). Wisdom et al. (2011) suggested *APOE*-ε4 and age interact thus, as people age, the gap between cognitive scores (particularly global and episodic memory) will increase between participants with and without *APOE*-ε4 i.e., older participants with *APOE*-ε4 will have poorer scores. Another interaction examined by Wisdom et al. (2011) was zygosity, where homozygous *APOE*-ε4 alleles resulted in lower cognitive scores than heterozygous alleles. The studies with an *APOE*-ε4 component included age as a covariate but not zygosity as this reduces statistical power and an analysis may not be viable.

The literature, reviewed in this section, had 12 of the 36 studies with *APOE*-ε4 data where 15 to 29% of the populations carried at least one *APOE*-ε4 allele (Shakersain et al., 2016, Muñoz-García et al., 2021, Gardener et al., 2015, Prinelli et al., 2019, Corley and Deary, 2020, Chen et al., 2017, Dearborn-Tomazos et al., 2019, Granic et al., 2016, Chen et al., 2020, Corley et al., 2020, Gu et al., 2018, Okubo et al., 2017). Of interest, one (Muñoz-García et al., 2021) and two studies (Gardener et

al., 2015, Granic et al., 2016) reported participants with or without an *APOE*-ε4 allele, respectively, were more likely to consume a dietary pattern containing healthy food groups.

The primary method for introducing the *APOE*-ε4 data into the analysis was as a confounder (participants having one or more *APOE*-ε4 allele). Studies controlling for *APOE*-ε4 (amongst other things) reported more consistent results with positive associations between global cognition and a 'prudent' (Shakersain et al., 2016), 'plant food and fish' (Okubo et al., 2017), 'plant-nutrient' (Prinelli et al., 2019), 'prudent healthy' (Chen et al., 2020), and 'Mediterranean' (Corley et al., 2020, Muñoz-García et al., 2021) patterns. Negative associations between global cognition and a 'Western' pattern were also reported (Chen et al., 2020, Shakersain et al., 2016, Muñoz-García et al., 2021). Results in the SNAC-K cohort may be influenced by the exclusion of ~12% (*n* 306) of participants with a MMSE score below 27 (Shakersain et al., 2016). Participants with *APOE*-ε4 alleles may have lower cognitive function scores (Wisdom et al., 2011) and the SNAC-K study did not report differences between excluded and included participants (Shakersain et al., 2016). Granic et al. (2016) introduced the *APOE*-ε4 allele independently into the final model of the Newcastle 85+ study (*n* 791, 85+ years, 38% male, United Kingdom). Here, the global cognition score became insignificant in a 'high red meat' and the 'high butter' cluster, compared to a 'low meat' reference cluster when the *APOE*-ε4 allele was added to the model suggesting the *APOE*-ε4 allele was responsible for some variation in the MMSE scores by attenuating cognition associations.

There were mixed results when data was stratified by the *APOE*-ε4 allele. Stratification creates smaller sample groups with reduced statistical power. As expected, a 'vegetable' pattern protected people, without an *APOE*-ε4 allele, against episodic memory decline and increased executive function decline in people with an *APOE*-ε4 allele (Chen et al., 2017). Inversely and unexpectedly, the Australian Imaging, Biomarkers and Lifestyle Study of Ageing (*n* 527, 60+ years, 50% male, Australia) found adherence to the 'Western' dietary pattern was associated with greater cognitive decline in the visuospatial function of participants without an *APOE*-ε4 allele (Gardener et al., 2015). This detrimental effect was small and only explained 3% of the model whereas age, education, and BMI explained 15%, 10% and 2% respectively. In a separate analysis of the SNAC-K study, where the cohort was stratified by the *APOE*-ε4 allele, a more marked association of reduced cognitive decline in people with *APOE*-ε4 allele was observed in the 'plant-' (β increased from 0.08 to 0.18) and 'animal-' (β increased from 0.10 to 0.16) nutrient patterns. These mixed results need to be clarified as it has been suggested people with *APOE*-ε4 alleles may be more sensitive to environmental risk factors affecting the brain e.g., diet. Perhaps, the brain structure may be compromised by a less efficient cholesterol transport system and a greater effect may be seen between those with and without the *APOE*-ε4 allele (Prinelli et al., 2019, Gardener et al., 2015).

Both the Whitehall II and Lothian Birth Cohort 1936 cohorts collected *APOE*-ε4 data (Marmot and Brunner, 2005, Luciano et al., 2009), and reported associations between the dietary patterns and cognitive function while excluding this confounding variable (Ozawa et al., 2017, Akbaraly et al., 2009, Corley et al., 2013). The focus from their studies was education (Akbaraly et al., 2009) or childhood IQ (Corley et al., 2013). A later published cross-sectional study from the Lothian Birth Cohort 1936 reported *APOE*-ε4 data. Here, the positive association between a 'Mediterranean' pattern and verbal ability remained with *APOE*-ε4 as a confounder (Corley et al., 2020).

Education

A higher childhood IQ suggests better education (Ritchie and Tucker-Drob, 2018) and evidence indicates higher education is associated with better cognitive performance (Opdebeeck et al., 2016). Mechanisms behind this association include improved socio-economic status influencing lifestyle in a positive way with greater nutrition knowledge and access to healthier food (Akbaraly et al., 2009, Corley et al., 2013). Also, with higher intelligence (Ritchie and Tucker-Drob, 2018) a larger cognitive reserve can be maintained in later years (Seblova et al., 2020). The Whitehall II study demonstrated the influence of education, where, as a confounder five of eight significant associations between cognition and a 'whole food' pattern (positive associations) and a 'processed food' pattern (negative association) were attenuated after education was added into the statistical model (Akbaraly et al., 2009). It was unlikely that education mediated the association between the dietary pattern and cognitive function as the dietary pattern is unlikely to influence education (Akbaraly et al., 2009). The Lothian Birth Cohort 1936 suggests the link between dietary pattern and cognition is not causal, that is, the dietary pattern does not sway cognition performance instead they suggest childhood IQ and adult socio-economic status have a greater effect on cognition than the diet (Corley et al., 2013).

Lifestyle factors

Regular physical activity supports healthy cognition by improving the vascular system (Klimova et al., 2017) and possibly, lowering amyloid beta concentrations[14] in the blood (Brown et al., 2013). Two thirds of the reviewed literature collected physical activity data. Unfortunately, few studies collected the data using valid tools. In some instances, the collected data was not used in the statistical analysis and no reason given for its absence (Corley et al., 2013, Xu et al., 2018, Samieri et al., 2008). There is low evidence that smoking, or alcohol consumption affects cognitive decline (World Health Organization, 2019, Plassman et al., 2010) though they are recommended to be included as confounders in the analysis of the data (Chen et al., 2018). Data on alcohol intake was not always

[14] Pathogenic factor on path to Alzheimer's disease

collected but was often included as a food group in the dietary pattern. Smoking data was collected and used as a confounder in 24 studies.

2.5.4. Mid-life exposures

Mid-life exposure to obesity and vascular events e.g., hypertension, type 2 diabetes mellitus and smoking may increase risk of cardiovascular disease and dementia in later life (Debette et al., 2011, Luchsinger and Gustafsone, 2009, Xu et al., 2011). Moreover, mid-life exposure to a dietary pattern containing healthy foods was protective against Alzheimer disease and dementia (Eskelinen et al., 2011, Hu et al., 2020). Three studies in this literature review had dietary data collected at mid-life and cognitive data collected over the following 13 – 20 years (Dearborn-Tomazos et al., 2019, Kesse-Guyot et al., 2014, Kesse-Guyot et al., 2012).

The Atherosclerosis Risk in Communities study (ARIC) (*n* 13,588, Black and White Americans) found no cognitive associations to their 'Western' or 'prudent' patterns (Dearborn-Tomazos et al., 2019). In contrast, the Supplémentation en Vitamines et Minéraux Antioxydants (SU.VI.MAX 2) study (*n* ~3,000, French population) reported a 'healthy' dietary pattern was beneficial to global and verbal memory but only in participants below the gender specific mean for energy intake being <10,458 kJ (2490 kcal) for males and <7,602 kJ (1810 kcal) for females (Kesse-Guyot et al., 2012). In the same study, a 'carotenoid-rich' pattern was also beneficial to cognitive function at all levels of energy intake (Kesse-Guyot et al., 2014).

2.5.5. Statistical methods

Some studies identified several dietary patterns and performed several cognitive tests without considering an adjustment for multiple testing. For example, in 475 older Taiwanese people, aged 65+ yrs, Chen et al. (2017) identified three dietary patterns and tested for 11 cognitive domains and continued to test by stratifying by age, sex, *APOE*-ε4 status, and supplement use with a p-value <0.05 considered significant. Similarly, Ashby-Mitchell et al. (2015) undertook many tests using both a dichotomous and a continuous outcome with dietary patterns derived from 20, 32, and 101 food groups with not multiple testing adjustment. Multiple testing can potentially increase Type I errors and the risk of false-positives results (George et al., 2016). In more recent studies multiple testing adjustments have been applied to statistical results (Corley et al., 2020, Corley and Deary, 2020, Richard et al., 2018).

2.5.6. Other strengths and limitations

The strengths of these studies come from the large sample sizes where 19 studies (51%) had a study population greater than 1,000. Many limitations of the studies in this literature review are discussed

above e.g., minimal cognitive testing. Several studies were of cross-sectional design (60 %), so reverse causality would be a main limitation, that is, dietary choices may be prompted by cognitive status. In addition, the diet is measured at one time point which may not be representative of the longer-term diet. The study populations may not be representative of and may be healthier than the general population based on many of study populations being self-selecting. With an older population, recall bias may be present.

2.5.7. To improve the level of evidence

As discussed above there are challenges relating to the methods for examining dietary patterns and their associations with cognitive function. The Committee on Preventing Dementia and Cognitive Impairment also found challenges with methodology of randomised controlled trials seeking to prevent cognitive decline and dementia (National Academies of Sciences, Engineering, and Medicine, 2017). The Committee made specific recommendations which may be useful when undertaking cross-sectional studies. These include using consistent cognitive outcome measures, identifying higher risk individuals, and exploring under-represented populations. Chen et al.'s (2018) systematic review suggests including common confounders such as gender, physical activity, diabetes, smoking, alcohol, long term medications and *APOE* -ε4 and stratifying by age groups (from >50 years, >85 years). Moreover, the use of a broad cognitive battery and neuroimaging could be included in the outcome assessment. Finally, longitudinal studies should account for dietary changes over the time of the study with dietary intake being assessed, with a validated tool, at baseline (at least).

2.5.8. Concluding items

There has been an increase of studies examining associations between *a posteriori* dietary patterns and cognitive function. While several dietary patterns, containing healthy food groups, are beneficial for cognitive health, there are still inconsistencies in the results and comparison between studies is difficult due to the heterogeneity of the methods.

Many of the inconsistencies arise through the dietary pattern methodology. None of the reviewed studies reported assessing their dietary assessment tool for suitability to derive reproducible and relatively valid dietary patterns. Important confounding variables, such as *APOE* -ε4 and physical activity levels, were not always included in the statistical analysis. While future research should cover all geographic regions and populations (including under-represented groups and high-risk individuals), further rigorous research into developing consistent methods outcomes is required.

2.5.9. References

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2.6. *A posteriori* dietary pattens and metabolic syndrome: a literature review of observational studies

This section of the literature review explores a posteriori dietary patterns and their associations with metabolic syndrome. The results from meta-analyses and recent observational studies are summarised with emphasis placed on studies in the context of the older population and in the Australasian region.

2.6.1. Background information, aim and search methods

Key points

- The prevalence of metabolic syndrome increases with age. Diet is one strategy to reduce risk of metabolic syndrome.
- Studies report dietary patterns with unhealthy food groups increase the risk and dietary patterns with healthy food groups decrease the risk of metabolic syndrome.
- Studies in Australasia and in older adults are sparse.

Dietary intake is a modifiable risk factor of metabolic syndrome (O'Neill and O'Driscoll, 2015, Fabiani et al., 2019). The *a posteriori* dietary pattern can summarise the whole diet of a population, including synergistic interactions, enabling exploration of relationships between dietary patterns and metabolic syndrome. Studies have explored this relationship and this review evaluates the literature concerning associations between *a posteriori* dietary patterns and metabolic syndrome in the general adult population. The literature search covered all geographic regions and included cross-sectional and longitudinal studies, and meta-analyses where the exposure was dietary patterns, and the outcome was metabolic syndrome. As recent meta-analyses have satisfactorily covered this area, individual studies were only searched from 1 January 2019.

To approach the above aim, Web of Science was explored for meta-analyses using the key headings in the search strategy shown in Table 2.16.

Table 2.16: Search strategy for studies examining associations between *a posteriori* dietary patterns and metabolic syndrome in adults

	Search term	
	princip* compon* analys*	OR
	PCA	OR
	factor analysis	OR
	cluster analysis	OR
	rank regression	OR
	posteriori	OR
	empirica* deriv*	OR
	mult*varia* analys*	OR
	dietary pattern*	
AND	metabolic syndrome	

2.6.2. Results from literature search

2.6.2.1. Recent studies

Fourteen observational studies have been published since 1 January 2019. These studies are further detailed in Table 2.17 (cross-sectional studies) and Table 2.18 (longitudinal studies). The studies were conducted in Asia (*n* 6), the Middle East (*n* 5), Europe (*n* 2) and North America (*n* 1); spread over all adult life-stages; and included mixed sex analyses. Five studies had sample sizes greater than 1,000 participants. Studies used a mix of methods to define metabolic syndrome: National Cholesterol Education Program Third Adult Treatment Panel Report (and variations of) (*n* 6), International Diabetes Federation (*n* 6), Chinese Diabetes Society definition (*n* 1) (Hailili et al., 2020) and a metabolically unhealthy definition (*n* 1) (Osadnik et al., 2020). The last two definitions were based on variations of cut-off parameters of the metabolic components. Principal component analysis was the primary dietary pattern analysis method (*n* 12) followed by reduced rank regression (*n* 4). Most studies derived the dietary patterns from food group intake or frequency though four studies used nutrient intake.

Fifty-three dietary patterns were identified, of which 13 were based on nutrients rather than food groups. Fourteen patterns had no associations with metabolic syndrome. Three nutrient patterns, from the large Japan Multi-institutional Collaborative Cohort study (*n* 30,108, mean age ~55 years) had associations with metabolic syndrome: 'fiber, potassium and vitamins' [odds ratio (OR) = 0.69, (0.63, 0.77), *P*<0.001], 'saturated fatty acids, calcium and vitamin B12' [OR = 0.87, (0.79, 0.95), *P*<0.001] and 'fats and fat-soluble vitamins' [OR = 1.27, (1.17, 1.39), *P*<0.001] (Iwasaki et al., 2019).

However, in a secondary analysis stratified by BMI the associations with 'saturated fatty acids, calcium and vitamin B12' and 'fats and fat-soluble vitamins' only remained in participants with a BMI higher (or equal to) 25kg/m^2. The 'fiber, potassium and vitamin' pattern still reported inverse associations at all levels of BMI, but more so in the <25kg/m^2 group than ≥25kg/m^2 group. The analysis shows the association between the diet and metabolic syndrome may only be relevant in overweight or obese participants (Iwasaki et al., 2019). Of interest, the 'fats and fat-soluble vitamins' pattern was highly loaded in healthy fats, (loadings for mono-unsaturated fatty acid = 0.92 and poly-unsaturated fatty acid >0.80) but not saturated fats (loading = 0.17) though many Western food groups correlated with this pattern, such as, deep fried foods, and red and processed meat. Even though energy intake was considered as a confounder in the analysis, the authors suggested it was the high energy intake of this pattern which influenced the positive association.

Two longitudinal studies have been published recently. First, the Tehran Lipid and Glucose Study (*n* 1,915, 19-74 years, follow-up 9 years) found an interaction between the valid dietary patterns (Asghari et al., 2012) and weight change during follow-up (*P*=0.001). This meant associations between metabolic syndrome and all dietary patterns were significant only where the weight gain (during follow-up) was less than 7%; 'fresh fruit', 'vegetable' and 'dried fruits and cruciferous' patterns had reduced risk for metabolic syndrome and 'potatoes and fruit juice' increased the risk (Mirmiran et al., 2020). The second longitudinal study, Atherosclerosis Risk in Communities (ARIC) study of 10,681 Americans (79% White, 21% African American, aged 45-64 years), derived dietary patterns stratified by ethnic group (Hardy et al., 2021). The ARIC study also investigated whether a genetic risk score interacted with the dietary pattern and its association with metabolic syndrome. The genetic risk score was based on alleles associated with metabolic syndrome, its components and cardiovascular disease. Longitudinally, the 'Western' dietary pattern increased the risk of metabolic syndrome in Whites regardless of the genetic risk score. However, a 'high-fat dairy' pattern had a protective effect against metabolic syndrome, but the protective benefit decreased in the 'high-fat dairy' as the genetic risk score increased in Whites (*P*=0.008) and lesser so in African Americans (*P*=0.04).

With the remaining studies, the trend continued where dietary patterns containing unhealthy food groups were associated with metabolic syndrome, for example, 'fried-processed' (Kurniawan et al., 2020), 'fast food' (Al-Lahou et al., 2020), 'sugar sweetened beverages' (Balasubramanian et al., 2020), 'Western' (Osadnik et al., 2020), 'dysregulated iron metabolism'[15] (Cempaka et al., 2019), and 'unhealthy' (Arif and Khan, 2021) patterns. In contrast, dietary patterns with healthy food groups

[15] A reduced rank regression dietary pattern

continued to be inversely associated with metabolic syndrome, for example, a SELENOP[16] dietary pattern characterised by fruit, vegetables, and antioxidant beverages (*n* 853, mean age = 61 years) (di Giuseppe et al., 2019) and a pattern characterised by dried fruit and vegetables, nuts, and grains from a Chinese (Urumqi) population (*n* 4,265, mean age = 60 years) (Hailili et al., 2020). Of interest, these last two patterns, with healthy food groups, were reported in studies with a sizeable proportion of older adults.

Incidentally, many of the studies examined associations between dietary patterns and metabolic syndrome components though evidence suggests metabolic syndrome may be a graded condition where increasing the number of components substantially increases the risk for cardiovascular disease and type 2 diabetes mellitus. For this reason, the metabolic syndrome must be targeted as one (O'Neill and O'Driscoll, 2015).

[16] Seloenoprotein P

Table 2.17: Twelve cross-sectional studies from 1 January 2019 exploring associations between *a posteriori* dietary patterns and metabolic syndrome in adults

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Cempaka et al. (2019), Taiwan.	Taiwanese adults, *n* 208, 20-65 yrs, mean=41 yrs, 50% M, 25% MetS.	1. 55-FFQ, 2. RRR, 3. 31 FGs, 4. intake by volume, 5. NCEP-ATP III for the Asia Pacific.	1 DP explained 65% of variation in FGs and 37% variation in response variables (serum hepcidin, ferritin, ALT and HDL-C) '**DIM**' DP: ↑deep fried foods, proc'd meats, chicken, pork, eating out, coffee, animal fat/skin, ↓steamed/boiled raw food, dairy	'**DIM**': ↑MetS OR=1.89 (1.07, 3.35)*. model confounders: A, S, BMI, hepcidin, ferritin, ALT, TG, HbA1c, HDL-C
di Giuseppe et al. (2019), Germany.	German, *n* 853, mean=61 yrs, 55% M, 42% MetS.	1. 112-FFQ over 12 mths (V), 2. RRR, 3. 39 FGs, 4. intake by volume, EI-adj by residual method, 5. NCEP-ATP III.	1 DP explained 4% of the variation in FGs and 13% variation in response variables (plasma concentrations of selenoprotein) **'SELONOP'** ↑pattern: veg, fruit, nuts, tea, wine, condiments, yeasts; ↓red/proc'd meat, game, poultry, coffee, spirits	**'SELONOP'**: ↓MetS OR=0.54 (0.40, 0.73) model confounders: A, S, E, PA, EI, smoking, CRP, selenium supplementation, prevalent diabetes

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Iwasaki et al. (2019), Japan, Japan Multi-Institutional Collaborative Cohort (J-MICC).	Japanese, *n* 30,108, 35-69 yrs, mean = ~55 yrs, 50% M, MetS 23% (M), 11% (F)%.	1. 46-FFQ over 12 mths (V) 2. PCA, 3. 21 nutrients, 4. intake by volume, EI-adj by residual method, log transformed, 5. IDF.	3 DPs explained 61% of variation in diet '**fiber, potassium, vitamins**': ↑fibre, K and vitamins; '**fats and fat-soluble vitamins**': ↑fats and fat-soluble vitamins; '**saturated fatty acids, calcium and vitamin B2**': ↑SFA, Ca, vit B2.	'**fiber, potassium and vitamin**': ↓MetS OR=0.69 (0.63, 0.77)***; '**fats and fat-soluble vitamins**': ↑MetS OR=1.27 (1.18, 1.38)***; '**saturated fatty acids, calcium and vitamin B2**': ↓MetS OR=0.87 (0.79, 0.95)***. stratify by BMI: <25kg/m^2: '**fiber, potassium and vitamin**': ↓MetS OR=0.70 (0.58, 0.84)***; '**fats and fat-soluble vitamins**': ns; '**saturated fatty acids, calcium and vitamin B2**' ns. ≥25kg/m^2: '**fiber, potassium and vitamin**': ↓MetS OR=0.81 (0.70, 0.94)**; '**fats and fat-soluble vitamins**': ↑MetS OR=1.19 (1.04, 1.37)*; '**saturated fatty acids, calcium and vitamin B2**': ↓MetS OR=0.81 (0.71, 0.93)***. model confounders: A, S, E, PA, EI, BMI, study site, smoking and drinking habits.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Kurniawan et al. (2020), Taiwan.	Taiwanese adults, *n* 25,569, >40 yrs, mean=51 yrs, 56% M, 27% MetS	1. 85-FFQ over 1 mth (V), 2. PCA and RRR, 3. 22 FGs, 4. intake by frequency, 5. NCEP-ATP III.	1 DP explained 16% of variation in diet PCA: '**fried-processed**': ↑fried foods, proc'd foods, dipping sauce, meat, SSB, organ meats, jam/honey, fried rice, flour products, instant noodles eggs; **RRR**: ↑proc'd foods, organ meats, dipping sauce, meat, fried rice, rice, flour products, eggs, instant noodles, fried foods; ↓fruits, bread.	PCA '**fried-processed**': ↑MetS 1.37 (1.26, 1.49)***; **RRR DP**: ↑MetS 1.70 (1.56, 1.85)***. model confounders: A, S, E, PA, income, marital status, smoking, alc, sleep quality and CVD status.
Akbarzade et al. (2020), Iran.	Iranian, *n* 850, 20-59 yrs, mean=42 yrs, mixed, NR.	1. 3 x 24-hr, 2. PCA, 3. 37 nutrients, 4. intake by volume, EI-adj by residual method, 5. IDF.	3 DPs explained 42% of variation in diet '**pattern 1**': vit B1, B2, B3, B5, B6, B12, Zn, Fe, SFA, Pro; '**pattern 2**': Sn, SFA, vit E, α-tocopherol, oleic acid, PUFA, β-carotene, linolenic acid, MUFA; '**pattern 3**': K, Mg, P, Ca, Pro, CHO, vit C, folate.	No associations with MetS by sex with any pattern reported. model confounders: A, E, PA, EI, smoking, job status analysis stratified by gender.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Al-Lahou et al. (2020), Kuwait.	Kuwaiti adults, *n* 555, 20+ yrs, mean=35 yrs, 49% M, NR.	1. 24-hr, 2. PCA, 3. 32 FGs, 4. intake by volume, EI-adj by density method, 5. IDF.	3 DPs explained 7% of variation in diet '**vegetable-rich**': ↑veg except white potato; '**fast-food**': ↑burgers/sandwiches, french fries, SSB; '**refined-grains/poultry**': ↑refined grains, poultry; ↓whole grains.	'**vegetable rich**': ns MetS; '**fast food**': ↑MetS**; '**refined grains/poultry**': ns MetS. model confounders: A, S, E, PA, EI, BMI, geography, income, smoking, suppl use, other DPs, family history dyslipidemia/BP.
Balasubramanian et al. (2020), Malaysia, Malaysia Lipid Study.	Malays (40%), Chinese (36%), Indians (25%), *n* 562, mean=38 yrs, 37% M, NR.	1. 3 x 24-hr, 2. PCA, 3. 23 FGs, 4. intake by volume, 5. IDF.	4 DPs explained 76% of variation in diet '**Home meal**': ↑white rice, SSB, non-starchy veg; '**Chinese traditional**': ↑noodle dishes, unsweetened plain coffee and tea; '**plant foods**': ↑fruit and non-starchy veg; '**Sugar-sweetened beverages**': ↑SSB.	'**Home meal**', '**Chinese traditional**', '**plant based**': ns MetS; '**sugar sweetened beverages**': ↑MetS**. model confounders: A, S, E, PA, income.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Hailili et al. (2020), China, Xinjiang multi-ethnic cohort.	Chinese population, *n* 14,982, 35-74 yrs. Urumqi mean=60 yrs; Huo Cheng 50 yrs, Mo Yu 52 yrs; 41% M, NR .	1. 127-FFQ over 12 mths (no V at time of publication), 2. PCA, RRR, 3. 30 FGs, 4. intake by volume, 5. Chinese Diabetes Society: presence of ≥3 of the following metabolic risk factors: M WC≥90 cm, F WC≥ 85 cm; SBP/DBP≥130/85 mmHg; TG≥ 1·70 mmol/L; fasting HDL<1·04 mmol/L; FBG≥6·1 mmol/L.	**Urumqi**: **RRR**: ↑milk tea, ↓yogurt; **PC1**: ↑raisins, gouji berries, dates, dried apricots, nuts, dried veg, grains; **PC2**: ↑milk, yoghurt, eggs, soyabean milk, beans. **HuoCheng**: **RRR**: ↑lamb, dairy, milk tea;, ↓beef; **PC1**: ↑beef, beans, dried veg;, ↓lamb, milk tea; **PC2**: ↑pasta, fruit, veg, potatoes, dairy milk tea; ↓grains. **Mo Yu**: **RRR**: ↓beans, gouji berries; **PC1**: ↑gouji berries, dried apricots, soyabean, juice; **PC2**: ↑eggs, dried veg, nuts, nuts, dates, raisins.	**Urumqi - RRR** DP: ↑MetS OR=1.17 (1.08, 1.27); **PC1**: ↓MetS OR=0.80 (0.65, 0.97); **PC2** ns. **Huo Cheng - RRR** DP, **PC1**, **PC2** MetS ns. **Mo Yu - RRR** DP: ↑MetS OR=1.11 (1.04, 1.19); **PC1** and **PC2** MetS ns. model confounders: A, S, PA, SES, race, smoking, alc, living area.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Osadnik et al. (2020), Poland, Metabolic and Genetic Profiling of Young Adults with and without a Family History of Premature Coronary Heart Disease cohort (MAGNETIC).	healthy, young adults, *n* 797, 18-35 yrs, mean=28 yrs, 58% M, 29% MetS.	1. 62-FFQ (V). 2. PCA, 3. 46 FGs, 4. intake by frequency. 5. metabolically unhealthy being 2 or more: SBP/DBP≥130/85 mmHg, TG≥1.70 mmol/L, TC>5.2 mmol/L, glucose>5.55 mmol/L or HDL-C<1.0 mmol/L (M), <1.2 mmol/L (F) OR drug treatment for any of the criteria.	3 DPs explained 30% of variation in diet '**Western**': ↑white/red/proc'd meat, potatoes, refined grain products, animal fats, other edible fats, SSB, energy drinks, sugar, alc, cheese, sweets/snacks; '**Prudent**': ↑whole grain products, veg, fish, eggs/egg dishes, nuts/seeds, fruit, milk, fermented milk, curd cheese, veg oils, white meat, legumes; '**Dairy breakfast cereals & treats**': ↑sweetened/fermented milk products, curd cheese, breakfast cereals, sweets/snacks, fruit.	'**Western**': ↑MetS OR=1.74 (1.07, 2.84); '**prudent**', '**dairy breakfast cereals & treats**': ns MetS. model confounders: A, S, BMI, WHR, diet quality scores.
Shahinfar et al. (2020), Iran.	Iranian, *n* 522, mean=53 yrs, 42% M, NR.	1. 147-SQ-FFQ over 12 mths (V), 2. PCA, 3. 26 nutrients FGs, 4. intake by volume, 5. NCEP-ATP III.	3 DPs explained 35% of variation in diet '**mono- and di-saccharides**': ↑glucose, sucrose, fructose, lactose, galactose; '**macronutrient**': ↑pro, CHO, fat and SFA; '**antioxidant**': ↑omega3, Na, K, lycopene.	'**mono and disaccharides**', '**macronutrients**', '**antioxidant**': ns MetS. model confounders: A, S, E, PA, EI, BMI, smoking, marital status.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Vajdi et al. (2020), Iran, Lifestyle Promotion Project.	Iranian, *n* 588, 18-64 yrs, 46% M, 39% MetS.	1. 80-FFQ over 12 mths (V), 2. PCA, 3. 40 nutrients, 4. intake by volume, 5. NCEP-ATP III.	3 DPs explained 54% of variation in diet '**animal-sourced**': ↑SFA, fat, Pro, sugar, vit B5, B12, B2, A, K, biotin, P, chol, Se, Na, PUFA, Ca, Zn; '**plant-sourced**': ↑fibre, CHO, vit B6, B3, C, B1, E, D, Mg, K, LA, DHA; '**mixed-source**': ↑Fl, Mn, caffeine, folate.	'**animal sourced**', '**plant sourced**' ns MetS; '**mixed source**': ↑MetS*. model confounders: A, S, E, PA, EI, smoking.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Arif and Khan (2021), Pakistan.	Pakistani, *n* 288, mean ~36 yrs, 50% M, 39% MetS.	1. FFQ, 2. PCA, 3. 20 FGs, 4. intake by volume, 5. IDF.	3 DPs explained 40% of variation in diet '**healthy**': ↑fermented milk, raw veg, fish, fruit, veg oils, nuts; ↓ghee, eggs, potatoes; '**mixed**': ↑non-fermented milk, legumes, cooked veg, potatoes, grains; '**unhealthy**': ↑red meat, eggs, kabuli polao/rice/ biryani, sugar, sweets.	'**healthy**': ↓MetS OR=0.74 (0.41-0.92); '**mixed**': MetS ns; '**unhealthy**': ↑MetS OR=1.81 (1.01-2.71). model confounders: A, S, E, income, PA, smoking, region.

A = age, alc = alcohol, ALT = alanine aminotransferase, BMI = body mass index, BP = blood pressure, Ca = calcium, cf = compared with, CHO = carbohydrate, chol = cholesterol, CVD = cardiovascular disease, DBP = diastolic blood pressure, DHA = decosahexaenoic acid, DP = dietary pattern, E = education, EI = energy intake, EI-adj = energy intake adjusted, F = female, Fe= iron, FBG = fasting blood glucose, FFQ = food frequency questionnaire, FG = food group, Fl = fluoride, HDL-C = high-density lipoprotein cholesterol, HF = high fat, hr = hour, HR = hazard ratio, IDF = International Diabetes Federation, K = potassium, L = longitudinal, LA = linoleic acid, LF = low-fat, M = male, MetS = metabolic syndrome, Mg = magnesium, Mn = manganese, mth = months, MUFA = monounsaturated fatty acids, Na = sodium, NCEP-ATP III = National Cholesterol Education Program Third Adult Treatment Panel Report, NR = not reported, ns = not significant, OR = odds ratio, P = phosphorous, PA = physical activity, PCA = principal component analysis, Pro = protein, proc'd = processed, PUFA = polyunsaturated fatty acid, RRR = reduced rank regression, S = sex, SBP = systolic blood pressure, SD = standard deviation, Se = selenium, SFA = saturated fatty acid, SSB = sugar sweetened beverage, suppl = supplement use, TG = triglycerides, V = validated, veg = vegetables, vit = vitamin, WC = waist circumference, WHR = waist to hip ratio, yrs = years, Zn = zinc

P-value: *<0.05; **<0.01; ***<0.001; ns≥0.05

Table 2.18: Two longitudinal studies from 1 January 2019 exploring associations between *a posteriori* dietary patterns and metabolic syndrome in adults

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Hardy et al. (2021), USA, Atherosclerosis Risk in Communities study (ARIC).	follow-up 11 yrs, Whites (79%), African American (21%), *n* 10,681, 45-64 yrs (at baseline), 45% M, MetS: Whites: 43-51% (baseline-follow-up); African American 49-56%. Statistically different at baseline***.	1. 66-FFQ (V), 2. PCA, by ethnic group, 3. 39 FGs, 4. NR, 5. NCEP-ATP III but BP based on American Heart Association/American College of Cardiology guidelines: ≥120 mmHg systolic or ≥80 mmHg diastolic cf ≥130 mmHg systolic or ≥85 mmHg diastolic).	3 DPs explained 15% of variation in Whites diet. '**Western**': ↑fried foods, red/proc'd meat, chicken with skin, eggs, condiments; '**healthy**': ↑pasta, veg, mashed potato, chicken (no skin), legumes; '**high-fat dairy**': ↑butter, HF milk, eggs. 3 DPS explained 16% of variation in African Americans diet '**Western**': ↑eggs, proc'd meat, biscuits/cornbread, cooked breakfast cereal, fried foods, white bread, margarine/butter; '**healthy**': ↑chicken (no skin), veg, legumes, fruit, cooked and cold breakfast cereal, fish, mashed potato, shellfish; '**high-fat dairy**': ↑margarine/butter, HF milk, cheese.	**White -** 'Western': ↑MetS RR=1.21 (1.12-1.31)***; 'healthy': ns MetS; 'high-fat dairy': ↓MetS RR=0.72 (0.66-0.79)***. **African American -** 'Western': ns MetS except low genetic risk score ↑MetS RR=1.46 (1.04-2.04)*; 'healthy': ns MetS; 'high-fat dairy': ↓MetS RR=0.81 (CI 0.69-0.96). all Bonferroni adjusted for multiple testing model confounders: A, S, E, time, PA, smoking, alc.

Study	Population, *n*, age, sex, % with MetS	1. Dietary assessment tool 2. Dietary pattern method, 3. # of food groups, 4. input variable 5. Criteria for defining MetS	Dietary patterns identified	1. Results[1] 2. model confounders
Mirmiran et al. (2020), Iran, Tehran Lipid and Glucose Study.	follow-up 9 yrs, Iranian population, *n* 1,915, 19-74 yrs, mixed, 31% MetS, 591 new cases of MetS during follow-up	1. 4 x 168 (or 147)-FFQ over 12 mths (V), 2. PCA, 3. 17 FGs, 4. intake by volume, EI-adj by residual method, 5. IDF.	'**fresh fruit**': ↑fruits, berries; '**vegetable**': ↑tomatoes, alliums, veg; '**dried fruit and cruciferous**': ↑cruciferous veg, veg, dried fruit; '**potatoes and fruit juice**': ↑potatoes, mushrooms, bananas, fruit juice.	'**fresh fruit**': ↓MetS HR=0.37 (0.27, 0.49) (with <7% weight gain). '**vegetable**': ↓MetS HR=0.74 (0.60, 0.91)* (full cohort); HR=0.47 (0.36, 0.60) (with <7% weight gain); ↑MetS HR=0.63 (0.48, 0.82) (with ≥7% weight gain). '**dried fruit and cruciferous**': ↓MetS HR=0.36 (0.26, 0.48) (with <7% weight gain). '**potatoes and fruit juice**': ↑MetS HR=1.25 (1.01, 1.54)*; ↓MetS HR=0.61 (0.46, 0.81) (with <7% weight gain). model confounders: A, S, E, PA, EI, BMI, smoking, occupation status, family history of diabetes or CVD.

A = age, alc = alcohol, BMI = body mass index, BP = blood pressure, cf = compared with, CVD = cardiovascular disease, DP = dietary pattern, E = education, EI = energy intake, EI-adj = energy intake adjusted, FFQ = food frequency questionnaire, FG = food groups, HF = high-fat, HR = hazard ratio, IDF = International Diabetes Federation, L = longitudinal, LF = low-fat, M = male, MetS = metabolic syndrome, NCEP-ATP III = National Cholesterol Education Program Third Adult Treatment Panel Report, NR = not reported, ns = not significant, PA = physical activity, PCA = principal component analysis, proc'd = processed, RR = relative risk, S = sex, USA = United States of America, V = validated, veg = vegetables, yrs = years

P-value: *<0.05; **<0.01; ***<0.001; ns≥0.05

2.6.2.2. Meta-analyses

Three meta-analyses reviewed dietary patterns and their association with metabolic syndrome and one umbrella review covered meta-analyses exploring *a posteriori* dietary patterns and the risk of chronic disease, which included metabolic syndrome (Fabiani et al., 2019, Jayedi et al., 2020, Rodriguez-Monforte et al., 2017, Shab-Bidar et al., 2018). All studies included in the meta-analyses were published prior to 1 January 2019. These studies are further detailed in Table 2.19. Although slightly different briefs among the meta-analyses (study design, dietary pattern methods), the outcomes were similar – observational studies showed dietary patterns containing healthy food groups had lower odds (pooled odds ratios (OR) between 0.83 and 0.86) for metabolic syndrome, and dietary patterns containing unhealthy food groups reported higher odds (pooled OR between 1.18 and 1.28) for metabolic syndrome.

The results contained large heterogeneity (I^2)[17] due to wide variability in dietary data collection, methods to identify dietary patterns, and confounding factors used in analysis (Fabiani et al., 2019). However, in sub-groups there were clear results with low or no heterogeneity. For example, a dietary pattern containing healthy food groups had lower pooled odds ratio for metabolic syndrome in males (*n* 5 studies) [OR = 0.85 (95% CI 0.73, 0.99), I^2 = 0.00] (Fabiani et al., 2019); females (*n* 4) [OR = 0.55 (95% CI 0.46, 0.66) , I^2 = 0.00] (Rodriguez-Monforte et al., 2017); adults aged 36 – 70 years (*n* 5) [OR = 0.71 (95% CI 0.59, 0.85) , I^2 = 0.00] (Rodriguez-Monforte et al., 2017); and those already with a metabolic disease and/or cardiovascular disease (*n* 3) [OR = 0.53 (95% CI 0.36, 0.79) , I^2 = 0.00] (Rodriguez-Monforte et al., 2017). No significant associations in studies with low heterogeneity were seen in dietary patterns containing unhealthy food groups in sub-groups (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017).

The meta-analyses had limitations where dietary patterns were characterised to either a 'healthy' or 'unhealthy' dietary pattern based on food group loadings. In some instances, patterns with high loadings of fruit and vegetables were considered 'healthy' though they may have contained food groups considered 'unhealthy' e.g., cheese or wine (Rodriguez-Monforte et al., 2017). Furthermore, some dietary patterns may have been excluded because they did not fall clearly into a 'healthy' or 'unhealthy' pattern.

A recent umbrella review by Jayedi et al. (2020) examined longitudinal studies exploring associations between *a posteriori* dietary patterns and the risk of non-communicable diseases including

[17] I^2 is a measure of heterogeneity where 0-40% is low, 30-60% moderate, 50-90% substantial, 75-100% substantial, depending on magnitude and direction of effect and strength of evidence for heterogeneity (Deeks JJ, Higgins J, Altman DG, 2021)

metabolic syndrome. This review included the four cohort studies found in Fabiani et al. (2019)'s meta-analysis. With these four studies, the results showed moderate evidence[18] that a dietary pattern containing unhealthy food groups is associated with metabolic syndrome [summary relative risk (RR) = 1.29 (95% CI 1.09, 1.52), I^2 = 0.49]. Heterogeneity was fair and without publication bias. Also, there was low evidence[19] a dietary pattern containing healthy food groups is inversely associated with metabolic syndrome [RR = 0.76 (95% CI 0.50, 1.15), I^2 = 0.91]. In this case, heterogeneity was extreme and Egger's test suggested evidence of publication bias.

[18] Based on a NutriGrade score where moderate evidence means moderate confidence in the effect estimate, further research could add evidence on the confidence and may change the effect estimate (Jayedi et al., 2020).

[19] Based on a NutriGrade score where low evidence means low confidence in the effect estimate, further research will provide important evidence and likely change the effect estimate (Jayedi et al., 2020).

Table 2.19: Four meta-analyses exploring the associations between *a posteriori* dietary patterns and metabolic syndrome in adults

Author, year	Scope	Results	Conclusion and recommendations
Rodriguez-Monforte et al. (2017)	**Aim**: to clarify assns between *a posteriori* DPs and MetS. **Search period**: to May 16. **Include**: original, observational studies using PCA, FA or CA; all MetS definitions; reports HR, OR or RR. **Exclude**: NR. **RoB**: quality assessed on study design and method; attrition; measurement of DPs and MetS; and statistical analysis.	28 CS, 3 L studies containing 85,137 participants. DPs with healthy FGs were inversely associated with MetS in CS studies (*n* 24) [OR=0.83 (0.76, 0.90), I^2=72%]. No assns in L studies (*n* 3). DPs with unhealthy FGs were positively associated with MetS in CS studies (*n* 27) [OR=1.28 (1.17, 1.40), I^2=72%]. No assns in cohort studies (*n* 2). Quality scores ranged from 9.5 to 14 (out of 16) with no obvious differences between studies. No publication bias detected.	Meta-A showed prudent/healthy DP is protective factor for MetS. An unhealthy DP could be associated with ↑risk of developing MetS. Additional prospective studies required to confirm assns.
Shab-Bidar et al. (2018)	**Aim**: to assess assns between *a posteriori* DPs and risk of MetS. **Search period**: to July 15. **Include**: CS studies, aged 18-60 yrs, report OR or RR. **Exclude**: subgroups with different needs to general population; CA or RRR. **RoB**: NR.	19 CS studies with 22 'healthy' and 27 'unhealthy' patterns from Europe (*n* 4), America (*n* 6), Asia (*n* 6), Middle East (*n* 3). DPs with healthy FGs were inversely associated with MetS (*n* 22) [OR=0.89 (0.84, 0.94), I^2=68% (51, 80)]. DPs with unhealthy FGs were positively associated with MetS (*n* 27) [OR=1.16 (1.11, 1.22), I^2=68% (50, 78)]. No publication bias detected.	Findings indicate inverse assn between 'healthy/ prudent' and risk of MetS and positive assn between 'unhealthy/Western' and risk of MetS.

Author, year	Scope	Results	Conclusion and recommendations
Fabiani et al. (2019)	**Aim**: to investigate and provide an estimate of the assn between *a posteriori* DPs and MetS risk in adults. **Search period**: to March 19. **Include**: case control, L and CS studies with OR, RR or HR; consider only patterns sharing food with similar factor loadings to obtain 'healthy' and 'meat/Western' patterns. **Exclude**: NR. **RoB**: Quality assessment performed but method and outcome not reported.	39 studies with 42 'healthy' and 40 'meat/Western' style patterns from Asia (*n* 14), Europe (*n* 8), Middle East (*n* 8), USA (*n* 4), Central, South America (*n* 3), and Australia/Samoa (*n* 3) using PCA (*n* 38), RRR (*n* 1), or partial least squares (*n* 1). DPs containing healthy FGs were inversely associated with MetS (*n* 42) [OR=0.85 (0.79–0.91), I^2=0.69] with lower risk in Eastern cf Western countries. DPs with unhealthy FGs were positively associated with MetS (n 40) [OR=1.19 (1.09–1.29), I^2=0.75]. Publication bias detected in DPs with healthy FGs (*P*<0.01) but not unhealthy FGs (*P*=0.12).	Findings indicate a protective effect on MetS attributable to DPs with healthy FGs. DPs with meat and unhealthy FGs were positively associated with MetS. Additional prospective studies needed to investigate assn further in gender and geographical regions.

Author, year	Scope	Results	Conclusion and recommendations
Jayedi et al. (2020)	**Aim**: to perform an umbrella review of Meta-A of prospective observational studies on assn between *a posteriori* DPs and MetS (and others). **Search period**: to Sept 19. **Include**: established DATs used. **Exclude**: primary studies, no summary risk estimate, meta-A with only one cohort study. **RoB**: modified version of the NutriGrade score -study quality/limitations; precision of estimate; heterogeneity; directness; publication bias; funding bias; effect size and dose–response assn.	One meta-A included (Fabiani 2019) for MetS. DP with healthy FGs inversely associated with MetS, [OR=0.76 (0.50, 1.15), I^2=0.91 (76, 96)], evidence of publication bias, low NutriGrade score. DP with unhealthy FGs positively associated with MetS [OR=1.29 (1.09, 1.52), I^2=0.49 (0, 85)], no publication bias, moderate NutriGrade score.	DPs with unhealthy FGs were positively associated with MetS and DPs with healthy FGs were inversely associated with MetS. More research required in DPs with healthy FGs as evidence was low with extreme heterogeneity.

assns = associations, CA = cluster analysis, cf = compared with, CS = cross-sectional, DAT = dietary assessment tool, DP = dietary pattern, FA = factor analysis, FG = food groups, HR = hazards ratio, L = longitudinal, Meta-A = meta-analysis, MetS = metabolic syndrome, NR = not reported, OR = odds ratio, PCA = principal component analysis, RCT = randomised controlled trials, RoB = Risk of Bias, RR = relative risk, RRR = reduced rank regression, USA = United States of America, yrs = years.

2.6.3. In older adults …

Age is a risk factor of metabolic syndrome (Iwasaki et al., 2019, Gentles et al., 2007, Kurniawan et al., 2020, Barbaresko et al., 2014, di Giuseppe et al., 2019). However, few studies have examined associations between dietary patterns and metabolic syndrome in older adults. Two recent studies, as discussed in the preceding paragraphs, reported dietary patterns with healthy food groups had lower risk for metabolic syndrome in older adults (OR between 0.80 and 0.54) (di Giuseppe et al., 2019, Hailili et al., 2020). In contrast, two earlier studies (mean age > 60 years) reported dietary patterns, with unhealthy food groups, increased the risk of metabolic syndrome. Here, a pattern characterised by legumes, beef, processed meat, and bouillon, OR = 1.71 (95% CI 1.04, 2.79), in a German population (*n* 905) (Barbaresko et al., 2014) and participants in the 'Western' cluster (*n* 343) were more likely to have metabolic syndrome than participants in the 'healthy' cluster (*n* 343), relative risk = 1.60 (95% CI 1.09, 2.68) in a Chinese population (Sun et al., 2014).

2.6.4. Confounding factors

Residual confounding is a limitation of observational studies even with adjustment of known or suspected confounders. The influence of age and sex on metabolic syndrome have been discussed earlier. Lifestyle factors can also affect the prevalence of metabolic syndrome. Physical activity is associated with a decreased risk towards metabolic syndrome. Indeed, the meta-analysis of He et al. (2014) showed the inverse association between metabolic syndrome was stronger with high levels of physical activity. There was no heterogeneity between the studies and publication bias was not detected.

Most of the studies examining associations between dietary patterns and metabolic syndrome adjusted for age, sex, and physical activity, though BMI and energy intake were commonly left out (Rodriguez-Monforte et al., 2017). In the recent studies, seven of the fourteen studies omitted energy intake as a confounder in the statistical analysis nor made an energy adjustment to the dietary input variables prior to dietary pattern analysis. Therefore, any observed effect of the diet would be based on the quality and quantity of the dietary pattern. There is further risk of residual confounding when BMI is excluded as a confounder, as done in four of the seven studies omitting energy intake. The large Japan Multi-institutional Collaborative Cohort study (Iwasaki et al., 2019) demonstrated the importance of BMI in their analysis. However, the longitudinal Atherosclerosis Risk in Communities study purposely excluded BMI as a covariate because BMI is on the causal pathway of the dietary patterns and metabolic syndrome outcome (Hardy et al., 2021).

Even though sex was considered as a confounder in all the studies the mechanism influencing metabolic syndrome in older adults is different and may alter the level of risk (Pucci et al., 2017). For

this reason, and where possible, it may be worthwhile exploring dietary patterns and their associations with metabolic syndrome stratified by sex.

2.6.5. In Australasia …

The associations between the dietary pattern and metabolic syndrome have been assessed in studies based in Asia, the Middle East or Europe though few investigations have occurred in Australasian populations (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017, Shab-Bidar et al., 2018). This literature review found three studies that examined associations between dietary patterns and metabolic syndrome in Australia (*n* 1) and Samoa (*n* 2).

In 2002 and 2010, two cross-sectional studies collected dietary data in Samoan and American Samoan populations and a Samoan only population (DiBello et al., 2009, Wang et al., 2017). During those eight years, changing dietary patterns showed a trend away from the traditional Samoan diet to a Western diet. Consequently, the prevalence of metabolic syndrome increased from 31% to 40% in Samoa. Risk factors for metabolic syndrome included being female (Wang et al., 2017), being older (DiBello et al., 2009, Wang et al., 2017), having lower physical activity levels (DiBello et al., 2009, Wang et al., 2017) and a 'modern' dietary pattern (Samoa only) (DiBello et al., 2009). The 'modern' dietary pattern (ripe coconut and soup with vegetables), though reported as significant had a weak association, prevalence ratio (PR) = 1.21 (95% CI: 0.93, 1.57), *P*-trend = 0.05 (DiBello et al., 2009). In contrast, the later study in Samoa found a 'mixed-modern' pattern was protective of metabolic syndrome, PR = 0.79 (95% CI: 0.69, 0.91), *P*-trend <0.01 (Wang et al., 2017). The association between the 'mixed modern' pattern (seafood, red meat, coconut, grains and low in fish (fresh, fried, or canned)) and metabolic syndrome may be mediated through blood lipids and obesity. While the 'mixed modern' pattern contained red meat, the authors suggested the absolute intake of red meat was low compared with countries where red meat is associated with cardiometabolic risks.

Data from the 2011-13 Australian Health Survey (aged 45+ years) was used to determine whether dietary patterns were associated with a metabolic phenotype in participants classed as obese and non-obese (BMI <30 kg/m^2) (Bell et al., 2015). Forty-one percent of the representative sample of adults were metabolically unhealthy, of which 50% were obese and 50% were non-obese. Metabolically unhealthy was based on three or more abnormal criteria from: total cholesterol, high-density lipoprotein cholesterol, fasting low-density lipoprotein cholesterol, fasting triglycerides, fasting plasma glucose status, waist circumference and high systolic or diastolic blood pressure. Of the three dietary patterns identified, a 'healthy' pattern (whole grains, fresh fruit, low-fat dairy,

dried fruit and low in fried potatoes, alcohol, and soft drinks), was positively associated with a healthy metabolic and BMI profile, OR = 1.16 (95% CI 1.04, 1.29) *P*<0.01.

2.6.6. Concluding items

Meta-analyses suggest inverse associations between dietary patterns with unhealthy food groups and metabolic syndrome, however the evidence quality is low with dietary patterns with healthy food groups. There is large heterogeneity amongst the studies and promising results have come from meta-analyses by sub-group: males, females, and those with chronic disease. More studies are required, both observational and longitudinal in the Australasian region, in older age groups, by BMI status and stratified by sex (where statistical power allows).

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Chapter Three: Study protocol: Associations between dietary patterns, cognitive function, and metabolic syndrome in older adults – a cross-sectional study

Following the review of the literature of dietary patterns, cognitive function and metabolic syndrome, this chapter presents the methods to collect the data used in the REACH study. The chapter is presented in manuscript format and was published in BMC Public Health (May 2019). Copyright to this open access article has been retained by the authors.

Mumme, K., von Hurst, P. R., Conlon, C. A., Jones, B., Haskell-Ramsay, C. F., Stonehouse, W., Heath, A.-L. M., Coad, J. & Beck, K. L. 2019. Study protocol: Associations between dietary patterns, cognitive function and metabolic syndrome in older adults – a cross-sectional study. *BMC Public Health*, 19, 535. DOI: 10.1186/s12889-019-6900-4

This published protocol includes the full methodology for the REACH Study. To align with this thesis, there are slight changes to formatting, layout, and referencing style. The manuscript was written before data collection and is in future tense.

3.1. Abstract

Background: Loss of cognitive function is a significant issue as the world's population ages. Preserving cognitive function maintains independence in older adults bringing major societal and financial benefits. Lifestyle factors such as diet are modifiable risk factors, which may help preserve cognitive function.

Most nutrition research aimed at preserving cognitive function and metabolic health has focussed on individual nutrients and foods, not allowing for food combinations and interactions. A dietary pattern approach considers the entire diet including its complexity. Previous research investigating dietary patterns and cognitive function has not always considered relevant covariates such as physical activity and the Apolipoprotein E genotype, which are known to have associations with cognitive function.

The aim of the REACH study is to investigate associations between dietary patterns, cognitive function and metabolic syndrome, accounting for a range of covariates.

Methods: This cross-sectional study design will recruit older, community-living adults (65–74 years) from Auckland, New Zealand. Dietary data will be collected via a 109-item food frequency questionnaire validated using a 4-day food record. Cognitive function will be assessed using the Montreal Cognitive Assessment (paper based) and the Computerised Mental Performance Assessment System (COMPASS) - a testing suite covering six domains. Additional data will include genetic (Apolipoprotein E ε4) and biochemical markers (fasting glucose, HbA1c, lipids profile), anthropometric measurements (weight, height, waist and hip circumference, body composition using dual X-ray absorptiometry), blood pressure, physical activity (International Physical Activity Questionnaire – short form) and health and demographics (questionnaire).

Dietary patterns will be derived by principal component analysis. Associations between cognitive function and dietary patterns will be examined using multiple regression analysis. Covariates and interaction factors will include age, education, socio-economic status, physical activity, Apolipoprotein E ε4 genotype, family history of dementia or cognitive impairment, and lifestyle factors. Differences between participants with and without metabolic syndrome will also be examined.

Discussion: This study will bring new knowledge regarding associations between dietary patterns and cognitive function and metabolic health in older adults living in New Zealand. This is important for developing nutrition related recommendations to help older adults maintain cognitive function.

3.2. Background

The global population aged over 60 years has doubled in the last 30 years and is expected to double again by 2050 (United Nations et al., 2017). Independence and quality of life are valued by older adults (Blazer et al., 2015) but these attributes are threatened by poor health in later years (Associate Minister of Health, 2016). Delaying entry of older adults into aged care residential facilities brings substantial financial benefits to individuals and governments (Deloitte, 2017). A key predictor for admission into residential care is impaired cognitive function or dementia (Luppa et al., 2010). Loss of cognitive function takes away independence, a healthy fulfilling life in final years and can significantly affect family members (Winblad et al., 2016). Hence, there is a case for preserving cognitive function for as long as possible.

Age-related cognitive decline, mild cognitive impairment and dementia are progressive with limited pharmacological and non-pharmacological treatments available (Horr et al., 2015). Without a cure, researchers should strive to discover ways to prevent or slow cognitive decline and the onset of dementia through lifestyle and dietary changes (Winblad et al., 2016).

Age and genetic factors are the most significant risk factors for developing dementia (Winblad et al., 2016). One specific genetic factor, Apolipoprotein E ε4 (*APOE*-ε4) not only increases the risk for developing Alzheimer's Disease (Mahoney-Sanchez et al., 2016) and vascular dementia (Sun et al., 2015) but also puts healthy individuals at risk of a faster cognitive decline as they age (Wisdom et al., 2011). Age and genotype cannot be altered but there are some modifiable risk factors (Norton et al., 2014) which may slow cognitive decline.

Modifiable risk factors include physical inactivity, smoking, hypertension, obesity, type 2 diabetes mellitus and low educational attainment (Norton et al., 2014). Three of these risk factors (hypertension, obesity, and diabetes) are components of metabolic syndrome, which further suggests the presence of a "metabolic-cognitive syndrome" via their similar underlying mechanisms through vascular changes (Frisardi et al., 2010). The relevance of lifestyle and diet in cognitive decline and metabolic syndrome is well-recognised (Cooper et al., 2015) and lifestyle and diet are a starting point in the prevention, delay, or reduction of the impact of cognitive decline.

Foods and nutrients that may protect against the loss of cognitive function have been identified. These include fruits and vegetables (Wu et al., 2017, Solfrizzi et al., 2017, Loughrey et al., 2017), fish (Solfrizzi et al., 2017, Loughrey et al., 2017), mono- and poly-unsaturated fats (Solfrizzi et al., 2017, Loughrey et al., 2017) and antioxidants (Crichton et al., 2013, Cao et al., 2016). In contrast, nutrients

such as refined carbohydrates and saturated fat may impair cognitive function (Francis and Stevenson, 2013, Solfrizzi et al., 2017).

Studies of food groups and macro- and micro-nutrients make a valued contribution to nutritional science. However, people consume a diet consisting of many foods, and single nutrient or food group studies may have outcomes confounded by the overall complexity of the diet. The food combinations within a diet can act synergistically, for example altering the bioavailability of nutrients within the body (Hu, 2002). These changes are not considered in studies of individual food groups or nutrients alone (Hu, 2002). The study of the combinations and complexities of dietary intake is a more recent development and dietary pattern analysis acknowledges the complexities of food combinations and their associated biochemical interactions as important (Milte and McNaughton, 2016).

Dietary patterns are derived through two processes using dietary data. The first process uses theoretically derived (*a priori*) dietary patterns based on current nutritional knowledge. A dietary index is created, ranking study participants' adherence to dietary guidelines (e.g., US dietary guidelines) or a dietary pattern (e.g., the Mediterranean diet index) (Hu, 2002). Several studies show better cognitive function in older adults if their normal dietary intake follow specific features of a diet, for example the Mediterranean diet with its high intake of vegetables, fruits, fish, nuts, cereals, and olive oil (Loughrey et al., 2017, Blazer et al., 2015) or the Dietary Approaches to Stop Hypertension (DASH) diet, high in vegetables and dairy with a low consumption of saturated fats and sodium (Solfrizzi et al., 2017). Additionally, the Mediterranean diet, DASH, and a Nordic diet, based on Nordic nutrition recommendations, may also have benefits with regards to metabolic syndrome (Robberecht et al., 2017).

The second process is an empirically derived (*a posteriori*) dietary pattern. The statistical method of principal component analysis allows measurements of many dietary components to be reduced to measures on a few different dietary patterns (Hu, 2002). This method enables a better understanding of eating behaviours and a unique view of dietary intake (Newby and Tucker, 2004) within a population setting. With regards to the older adult, positive associations between empirically derived dietary patterns and cognitive function have been recognised in 'healthy/prudent' (Samieri et al., 2008, Parrott et al., 2013, Kesse-Guyot et al., 2012) or 'carotenoid-rich' (Kesse-Guyot et al., 2014) dietary patterns in primarily European or North American populations and 'plant food and fish' (Okubo et al., 2017) , 'vegetables-fruits' (Chan et al., 2013) and 'snack-drinks-milk products' (Chan et al., 2013) dietary patterns in Asian populations. Conversely, negative associations have been noted in cognitive function where a 'Western' (Parrott et al., 2013)

dietary pattern was consumed. In some instances, no associations were found between cognitive function and 'traditional' (Kesse-Guyot et al., 2012), 'meat-fish (Chan et al., 2013), 'health aware' (Corley et al., 2013) or 'sweet foods' (Corley et al., 2013) dietary patterns.

Associations can be attenuated when important covariates are included in the statistical analysis suggesting that the covariate has an effect on the outcome. For example, negative associations between cognitive function and 'high red meat' (Granic et al., 2016), 'high butter' (Granic et al., 2016), 'processed food' (Akbaraly et al., 2009) and 'traditional' (Corley et al., 2013) dietary patterns were weakened when the *APOE*-ε4 genotype (Granic et al., 2016), education (Akbaraly et al., 2009) or childhood IQ (Corley et al., 2013) were considered in the analysis. Likewise, a positive association was weakened in a 'whole food' and 'Mediterranean style' (Corley et al., 2013) dietary pattern with education (Akbaraly et al., 2009) or childhood IQ (Corley et al., 2013) as covariates. Consideration of covariates is critical; without it some studies may not be as robust and lead to misinformed conclusions. One of these covariates is the *APOE*-ε4 genotype. This genotype has been considered in recent research. Analyses show associations are still apparent between dietary patterns and cognitive function when *APOE*-ε4 is adjusted for (Gardener et al., 2015, Gu et al., 2010, Berendsen et al., 2018), though in older studies this covariate was disregarded (Samieri et al., 2008, Akbaraly et al., 2009, Chan et al., 2013, Kesse-Guyot et al., 2012, Torres et al., 2012, Parrott et al., 2013).

A 'dietary pattern' is population specific and dietary patterns have been studied in the New Zealand context (Thompson et al., 2010, Wall et al., 2016, Beck et al., 2013, Schrijvers et al., 2016, Beck et al., 2018b, Saeedi et al., 2018). However, no studies have investigated dietary patterns exclusively in an older New Zealand population. Therefore, the objectives of the REACH study are to investigate associations between dietary patterns and cognitive function in older adults within the New Zealand population. A secondary objective is to investigate associations between dietary patterns and metabolic syndrome.

3.3. Methods

3.3.1. Study design and participants

The participants in this cross-sectional study will be men and women aged 65-74 years, living independently in Auckland, New Zealand and proficient in English. Participants will be excluded if they are colour blind (due to the computerised cognitive testing requiring colour recognition); have a diagnosis of dementia or any of the following conditions which may impair cognitive function: stroke, traumatic head, or brain injury, a neurological or psychiatric condition; or if they are taking medication which may influence their cognitive function. Another exclusion criterion is any event in

the last two years which had a substantial impact on dietary intake and cognitive function, for example, death or illness of a family member.

A sample size of 350 participants is required to see a medium size effect (Pearson correlation 0.3) with 80% power for the main outcome of a linear association between the cognitive scales and dietary patterns. This sample size is similar to other studies investigating cognitive function and dietary patterns (Torres et al., 2012). Data will be collected from 360 participants to allow for missing or incomplete data.

Recruitment and data collection will commence in 2018 and is expected to take 12 months. Participants will be required to attend the Human Nutrition Research Unit, Massey University, Auckland, New Zealand on one occasion. Informed consent forms will be completed at the research facility prior to data collection (Appendix 9.2.4). The research day involves collecting health and demographic data, blood pressure, anthropometric and physical activity data as per Table 3.1. A fasted blood sample will be taken prior to a standardised breakfast. Two cognitive assessments will be completed after breakfast. An online food frequency questionnaire (FFQ) and a food diary information video complete the session.

Funding is provided by the Health Research Council of New Zealand, Grant 17/566. Ethical approval has been granted by Massey University Human Ethics Committee: Southern A, Application 17/69).

Table 3.1: Outcome measures and testing methods for REACH data collection

Variables	Methods
Questionnaires	
Health and demographics	Written questionnaire developed by the researchers – questions regarding socio-demographic, health, lifestyle, and dietary factors (Appendix 9.4.1.1).
Physical Activity	International Physical Activity Questionnaire - short form (Craig et al., 2003)
Anthropometry	
Height, weight, and waist and hip circumference	ISAK anthropometry methods (Marfell-Jones et al., 2012) – stadiometer, Tanita Electronic Scales, Lufkin W600PM flexible steel tape
Muscle mass and fat mass	Dual-emission X-ray absorptiometry, Hologic, Discovery QDR series
Blood Analysis	
Fasting blood glucose	HemoCue Glucose 201RT
HbA1c	Cobas b 101 system (La Roche Ltd, 2018)
Lipid Profile (total cholesterol, triglycerides, HDL-C, LDL-C[a])	Cobas b 101 system (La Roche Ltd, 2018)
Apolipoprotein E ε4	Polymerase chain reaction amplification and direct nucleotide sequence analysis
Clinical	
Blood pressure	Digital Automatic Blood Pressure Monitor, Omron HEM-907
Dietary intake	
Food Frequency Questionnaire	Via Survey Monkey – adapted from Beck et al (Beck et al., 2011) (Appendix 9.4.1.2)
Estimated 4-day food diary	Paper form (Appendix 9.4.1.2)
Cognitive tests	
Global cognitive function	Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005)
Multiple cognitive domains	Computerised Mental Performance Assessment System (COMPASS-Northumbria University, Newcastle upon Tyne, UK) refer Table 3.2.

[a] calculated,
HDL-C = high-density lipoprotein cholesterol, ISAK = International Society for the Advancement of Kinanthropometry, LDL-C = low-density lipoprotein cholesterol.

3.3.2. Recruitment and screening

Participants will be recruited throughout the wider Auckland region via several channels including: the Human Nutrition Research Unit, Massey University participant database; media, including radio interviews and press releases from Massey University; posters (Appendix 9.2.1) and flyers at local libraries, community centres, recreation centres, sports and hobby clubs, Citizens Advice Bureaus, retirement villages and second hand shops; inclusion in relevant newsletters, e.g., Age Concern New Zealand; and online promotion on appropriate social media pages e.g., GrownUps, Office for Seniors Facebook page. The REACH study will have a website where potential participants will be directed for further information and to register interest (Massey University, 2018). Only one person per household will be eligible to participate in the study. Participants expressing an interest in the study will be provided with an information sheet (Appendix 9.2.3) and undergo a screening interview (Massey University, 2018) (Appendix 9.2.2), via telephone, to ensure inclusion criteria are met.

3.3.3. Health, demographic, and physical activity data

Health, demographics, lifestyle, and physical activity information will be collected through written questionnaires in person (Table 3.1). Data quality will be ensured by checking questionnaires for completeness and sensibility. If further clarification is required, it will be done immediately or within a few days by phone or email. Socio-demographic information includes age, gender, ethnicity, marital status, education, household income, work history, living situation and food security. Health information will include past and current disease (acute and chronic), medication, family history of dementia or cognitive impairment, vision, hearing, dental health, and mobility issues. Lifestyle information will include smoking history, alcohol intake, substance abuse, supplement use, and changes in physical activity. Dietary information will include changes in diet over past 10 years and possible factors behind these changes e.g., dentition, health concerns, disposable income, appetite. An Index of Multiple Deprivation will be calculated from the residential address of participants (Exeter et al., 2017).

3.3.4. Anthropometric data and blood pressure

Anthropometry, including body fat percentage, BMI, hip and waist circumference, and blood pressure will be measured as in Table 3.1.

Blood pressure will be measured twice. Participants will rest quietly (seated) for 5 minutes before the first measurement is taken. There will be a one-minute rest period between measurements. The mean blood pressure measurement will be used unless either systolic or diastolic measurements

differ by more than 5 mmHg from the first measurement. In this instance, a third measurement will be taken, and the median value used.

3.3.5. Blood sampling, processing, analysis, and genotyping

For consistency, all participants will be fasted (except water) from 2200 hours the night prior to their visit. Between 0700 and 0900 at the research facility, a qualified phlebotomist will draw fasted blood samples in the following order: 10ml BD Vacutainer® Plus (cat 367895), 10ml BD Vacutainer® K2EDTA (cat 367525) and 6ml BD Vacutainer® K2EDTA (cat 367873). The 10ml BD Vacutainer® Plus will be maintained at an ambient temperature for 30 minutes to allow clotting, then will be centrifuged with the 10ml BD Vacutainer® K2EDTA (Heraeus Labofuge 400R) for 15 minutes at 1,547 g-force (3500 rpm) at 4°C. The resulting serum, from the 10ml BD Vacutainer® Plus, will be aliquoted into four Eppendorf tubes which will be stored for further measures. The resulting plasma, from the 10ml BD Vacutainer K2EDTA, will be aliquoted into six Eppendorf tubes and stored for further research. The 6ml EDTA vacutainer will be placed on ice and tested for blood glucose, HbA1c and a lipid profile using point-of-care equipment (Table 3.1). The remaining blood (~5 ml) will be stored for *APOE*-ε4 analysis (Table 3.1) by an accredited laboratory, and two Eppendorf tubes (500 µl) will be kept for backup. All samples will be stored at -80° C.

3.3.6. Assessment of dietary intake

The study spans a 10-month period from autumn to summer. Dietary data will be collected using two methods. First, a self-administered 109-item FFQ will collect data, covering the previous month, via an online survey on two occasions: at the research facility (FFQ1) and one month later (at home) (FFQ2) to assess reproducibility. The FFQ is adapted from a validated New Zealand FFQ aimed at assessing iron related dietary patterns in young women (Beck et al., 2012). Changes included the addition of serving sizes; combining some food groups to shorten the questionnaire; the addition of foods not included in the initial nutrient specific FFQ e.g., confectionary; as well as extra questions for added clarification e.g., type of milk or oils used. The FFQ was further cross-checked with the New Zealand Women's Food Frequency Questionnaire (Beck et al., Houston, 2014) to ensure all relevant food groups were included. Ten individuals in the study age range pre-tested the FFQ for understanding and readability. The completed FFQ will be entered into Foodworks 9 (Xyris Software, 2017), which uses the New Zealand FOODfiles(TM) 2016 (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2016) food composition database. After data entry and

inspection, any necessary adjustments will be made e.g., Goldberg Cut-off for energy intake (Goldberg et al., 1991)[20].

Second, an estimated 4-day food diary will be collected from a subset of participants to validate the modified FFQ for food and dietary patterns. Participants will complete the 4-day food diary within one month of the study visit. The 4-day food diary covers four consecutive days including at least one weekend day. Prior to completing the 4-day food diary, participants will view an instructional video which explains the need to record all foods and beverages consumed including type, brands, and cooking methods. Participants will be taught how to estimate quantities using pictures (Nelson et al., 1997), household measures, and measuring scales. The 4-day food diary will be processed by four trained nutritionists using Foodworks 9 (Xyris Software, 2017). A register of common food items will be kept ensuring consistency in data entry among the four nutritionists. Additionally, every tenth food record entered will be audited for accuracy and consistency.

3.3.7. Cognitive assessment

Cognitive testing will be carried out after a standardised breakfast to minimise any effects food may have on cognition. The cognitive testing will be undertaken in two parts. First, a trained examiner will administer the Montreal Cognitive Assessment (MoCA) on a one-to-one basis. MoCA is a clinically available and validated (Nasreddine et al., 2005) tool. It takes ten minutes, assesses global cognitive function, short-term memory, visuospatial and executive function, attention, language and orientation, concentration and working memory (Nasreddine et al., 2005). MoCA will be used to provide comparisons with other studies, and as a descriptor.

The second part will be the Computerised Mental Performance Assessment System (COMPASS - Northumbria University, Newcastle upon Tyne, UK). This software platform presents tasks on desktop computers using a variety of methods to collect responses: mouse and cursor, a four-button coloured response pad, and pen and paper for word recall. This broad battery of tests assesses all cognitive domains (Table 3.2) and is sensitive to normal age-related effects and dietary factors (Stonehouse et al., 2013, Kennedy et al., 2017).

[20] The Goldberg method methods was not used as a cut-off for energy intake. Instead, the average daily energy intake was considered implausible if < 2,100 kJ or > 14,700 kJ for women and < 3,360 kJ or > 16,800 kJ for men (Chapter 4.3.2).

Table 3.2: The COMPASS battery of cognitive assessments

Cognitive Domain	Definition	Test
Mood	Measurement of subjective feelings	Bond and Lader Mood Scales
Attention and vigilance	Attention - ability to concentrate on selected aspects of the environment while ignoring other stimuli Vigilance - ability to maintain attention and alertness over time	Simple reaction time Choice reaction time Digit vigilance task
Executive function	Co-ordination of cognitive responses – sub-serves planning, initiating and inhibiting actions, cognitive flexibility, abstract thinking, and rule acquisition	Stroop test
Episodic memory	Ability to retain memories that can be consciously recorded e.g., facts, items, events, faces	Immediate and delayed word recall Delayed word recognition Delayed picture recognition
Working memory	Ability to hold information in mind while carrying out more complex cognitive processes	Corsi blocks
Location learning	Assesses visuo-spatial memory	Computerised location learning Computerised location recall

COMPASS = Computerised Mental Performance Assessment System (COMPASS-Northumbria University, Newcastle upon Tyne, UK)

The reaction time for correct responses will be assessed and participants will be assigned a composite score for global cognitive function and for each cognitive domain. Z-scores will be used for analysis.

Cognitive testing will be undertaken in a cognitive suite controlled for environmental factors e.g., noise and temperature. The tests will be taken at a similar time of day and participants will be instructed to avoid undue stress, alcohol, recreational drugs, and physical activity that is not routine prior to their appointment. Testing will take approximately one hour. The first 15 minutes will be training. The investigator will verbally describe the tasks, the format of the testing, and use of the

response pad, and will answer any questions. The practice tests will be shorter and easier versions of the actual test. Participants will have a five-minute break before actual assessment is undertaken. The investigator will ensure any new computer users are comfortable with using a mouse before testing starts.

3.3.8. Metabolic syndrome

To determine the incidence of metabolic syndrome the criteria recommended by the American Heart Association/National Health, Lung and Blood Institute Scientific Statement will be followed (Grundy et al., 2005). Metabolic syndrome will be considered to exist where three of the following five criteria are met or medication is used to treat: waist circumference ≥ 88 cm for women and ≥102 cm for men; a triglyceride level of ≥ 1.7 mmol/L; HDL cholesterol level of < 1.03 mmol/L in men or < 1.3 mmol/L in women; blood pressure ≥ 130/85 mmHg; fasting blood glucose ≥ 5.6 mmol/L.

3.3.9. Provision of results to participants

Feedback to participants after assessment will include anthropometric measurements (height, weight, BMI, waist and hip circumference, body fat %), blood pressure and blood results (HbA1c, fasting blood glucose, lipid profile). A registered (NZ Medical Council) general practitioner will review all biochemical results prior to communicating them to participants. On completion of the study, participants will receive a report summarising the main findings of the REACH study.

3.3.10. Statistical analysis

Statistical analysis will be performed using R (R Core Team, 2019). Participant data will be described using mean (95% confidence intervals) for normally distributed data, median (25, 75 percentile) for non-normally distributed data, or frequency summary statistics for categorical data. The Shapiro-Wilk test and normality plot will evaluate the normality of distributions.

Dietary patterns will be identified using rotated principal component analysis, a statistical technique to reduce data and produce patterns based on the correlations between food groups (Newby and Tucker, 2004). The FFQ food group items will be further collapsed based on other studies investigating dietary patterns (Beck et al., 2018b, Schrijvers et al., 2016). Three separate analyses will be performed: FFQ1 to determine dietary patterns, the 4-day food diary to assess validity of the dietary patterns identified in FFQ1, and FFQ2 vs FFQ1 to assess reproducibility. Orthogonal varimax rotation will be used to facilitate interpretability of components. The number of components retained will be based on the scree plot, eigenvalue (>1), and interpretability of the dietary pattern. The Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's Test *P* values (to determine the presence of relationships between variables in the factor analysis) will be examined (Field, 2018).

Labelling of dietary patterns will be based on the interpretation of foods with high factor loadings for each dietary pattern (Bland and Altman, 1986).

Multivariate multiple regression analysis (Warton, 2008) will be used to determine the association between dietary patterns and various domains of cognitive function (dependent variable) while considering confounding factors. Possible confounding and interaction factors include age, gender, ethnicity, education, English as a second language, presence of chronic disease (including metabolic syndrome), socio-economic status, physical activity, body mass index, *APOE*-ε4 genotype, family history of dementia, smoking, alcohol intake, and past dietary intake. Finally, multiple logistic regression will be used to examine associations between dietary patterns and metabolic syndrome.

3.4. Discussion

Age-related cognitive decline is a continuum of natural cognitive changes that may progress into mild cognitive impairment or dementia. Rates of decline differ within a population. Delaying the onset of cognitive decline is the optimal strategy but where there is an earlier on set the ability to slow the decline is important. Delaying or slowing the decline may be abetted by modifiable lifestyle factors e.g., diet, physical activity. Therefore, an in-depth understanding of the diet (beyond an isolated food and nutrient approach) of older adults is warranted. The REACH study will broaden the current knowledge on dietary patterns and their associations with cognitive function and metabolic health in older adults in a New Zealand context.

Despite the cross-sectional design having limitations e.g., causality cannot be inferred, the study design has several strengths. The study recognises dietary patterns as a measure of the diet and acknowledges the whole diet is greater than the sum of its parts. Extra strengths come from the collection of data on the *APOE*-ε4 allele, physical activity levels and other known covariates to ensure that any association found is likely to be due to the dietary patterns identified. Additionally, the COMPASS battery of cognitive tests is administered on the computer minimising potential bias associated with administration of these tests by a researcher. The scoring of cognition and the assessment of dietary patterns will be done independently to minimise bias. While there is always bias associated with the type of participant attracted to such studies, the bias will be minimised by using a range of recruiting methods across the wider Auckland region to ensure a range of participant demographics are captured. Furthermore, the size of the study population ensures there is adequate power to detect a meaningful result.

The REACH study is the first to examine dietary pattern associations in older New Zealand adults. This first step paves the way for developing recommendations for New Zealanders to maintain

cognitive function, metabolic health and ultimately quality of life as they age. Additionally, it will provide a valuable base for hypothesis generation for future longitudinal studies and/or randomised controlled trials.

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Chapter Four: Relative validity and reproducibility of a food frequency questionnaire for assessing dietary patterns and food group intake in older New Zealand adults

After collecting the dietary data through the REACH food frequency questionnaire (FFQ) and before dietary patterns are derived. It is important to ensure the FFQ provides credible food group intake and is suitable to identify dietary patterns which represent the whole diet.

This chapter demonstrates the reproducibility and relative validity of the REACH FFQ and its ability to derive reproducible and relatively valid dietary patterns. This chapter is presented in manuscript format and has been accepted for publication in the Journal of the Academy of Nutrition and Dietetics. This journal supports Green Open Access which allows reproduction of the work with full acknowledgement of the original article.

Mumme, K., Conlon, C., von Hurst, P., Jones, B., de Seymour, J., Health, A-L., Stonehouse, W., Coad, J., Haskell-Ramsay, C., Beck, K. (2021) Relative validity and reproducibility of a food frequency questionnaire for assessing dietary patterns and food group intake in older New Zealand adults: The REACH study. Journal of the Academy of Nutrition and Dietetics. DOI: 10.1016/j.jand.2021.05.022.

To align with this thesis, there are slight changes to formatting, layout, and referencing style of the original manuscript.

4.1. Abstract

Background: Dietary pattern analysis considers the overall dietary intake and combinations of foods eaten. Valid and reproducible tools for determining dietary patterns are necessary to assess relationships between the diet and disease.

Objective: This study evaluated the relative validity and reproducibility of the REACH Study food frequency questionnaire (FFQ) specifically designed to identify dietary patterns in older adults.

Methods: A sub-set of participants, from the REACH study, completed two identical 109-item FFQs one month apart (FFQ1 and FFQ2) to assess reproducibility and a 4-day food record (4-DFR) between FFQ administrations to assess relative validity. Foods from each dietary assessment tool were assigned to 57 food groups. Principal component analysis was applied to the food group consumption reported in each dietary assessment tool to derive dietary patterns.

Participants/setting: Dietary data were collected (2018/19) from a subset of the REACH study (*n* 294, 37% men) aged 65-74 years, living in Auckland, New Zealand.

Main outcome measures: Median daily intakes of 57 food groups and dietary patterns of older adults living in New Zealand.

Statistical analysis performed: Agreement of dietary pattern loadings were assessed using Tucker's congruence coefficient. Agreement of dietary pattern scores and food group intakes were assessed using Spearman correlation coefficients (acceptable correlation rho = 0.20-0.49), weighted kappa statistic (κ_w) (acceptable statistic κ_w = 0.20-0.60), and Bland Altman analysis including mean difference, limits of agreement, plots, and slope of bias.

Results: Three similar dietary patterns were identified from each dietary assessment tool: 'Mediterranean style', 'Western', and 'prudent'. Congruence coefficients between factor loadings ranged from 0.54 to 0.80. Correlations of dietary pattern scores ranged from 0.47 to 0.59 (reproducibility) and 0.33 to 0.43 (validity) (all P<0.001); weighted kappa scores from 0.40 to 0.48 (reproducibility) and 0.27 to 0.37 (validity); limits of agreement from ± 1.79 to ± 2.09 (reproducibility) and ± 2.09 to ± 2.27 (validity); a negative slope of bias was seen in the 'prudent' pattern for reproducibility and validity (P<0.001).

Conclusions: The REACH FFQ generated dietary patterns with acceptable reproducibility and relative validity and therefore can be used to examine associations between dietary patterns and health outcomes in older New Zealand adults.

4.2. Background

The global population is ageing. Ageing alters the body's physiology, leading to changes in physical and cognitive health and a heightened risk of non-communicable diseases such as cancer, cardiovascular disease, and neurodegenerative diseases (FAO and WHO, 2019, World Health Organization, 2015, Walker et al., 2019). A healthy diet has been shown to positively influence ageing (FAO and WHO, 2019). Traditionally, associations between dietary intake and health outcomes have been explored using individual foods and nutrients, but people eat foods and nutrients in complex combinations as meals and snacks to form overall dietary patterns (Hu, 2002). There is increasing interest in utilizing dietary pattern analysis which considers the diversities and intricacies not captured by the complementary single nutrient and food-based approach. For example, nutrient bioavailability may change as food groups and nutrients interact with each other (FAO and WHO, 2019).

Dietary patterns can be used to examine dietary intake related to health outcomes. Dietary patterns have been explored in the older adult with respect to cognitive health (Chen et al., 2018, Solfrizzi et al., 2017), bone health (Fabiani et al., 2019), healthy ageing (Milte and McNaughton, 2016), and muscle health (Bloom et al., 2018, Granic et al., 2019). These studies suggest a 'healthy' dietary pattern is associated with positive health outcomes (Chen et al., 2018, Solfrizzi et al., 2017, Fabiani et al., 2019, Milte and McNaughton, 2016, Bloom et al., 2018, Granic et al., 2019). A 'healthy' dietary pattern, as reported in the literature, typically includes fruits, vegetables, whole grains, nuts and seeds, some dairy, and fish (Chen et al., 2018, Solfrizzi et al., 2017).

There are two main approaches when characterizing a dietary pattern. The '*a priori*' approach applies an index system based on dietary guidelines, e.g., the Healthy Eating Index (Krebs-Smith et al., 2018), or a diet specific to disease prevention, e.g., the Dietary Approaches to Stop Hypertension (DASH) index (Sacks et al., 2001), or a known dietary pattern, e.g., the Mediterranean Diet Index (Bach et al., 2006). The *a posteriori* approach employs statistical analysis techniques such as factor, principal component, or cluster analysis to derive a dietary pattern from dietary data (Hu, 2002). By simplifying the dietary data, this second method gives a view of dietary intake specific to a study population which may allow a better understanding of eating behaviours (Newby and Tucker, 2004). As the whole diet of the older New Zealand adult has not yet been explored, this study will focus on *a posteriori* dietary patterns.

The food frequency questionnaire (FFQ) is a key and acceptable epidemiological tool for collecting dietary data to create dietary patterns (Edefonti et al., 2019). Modified FFQs can economize on time and money but should be validated in their intended population (Cade et al., 2002). To measure the

relative validity of a FFQ, data from the FFQ (test) are compared to those from another dietary assessment tool (reference) (Gleason et al., 2010). The chosen reference tool, while still prone to measurement error, should have errors independent of the FFQ (Gleason et al., 2010). Food records are one recommended reference tool (Cade et al., 2002, Willett, 2012b, Gleason et al., 2010) where foods are recorded as eaten but unlike the FFQ are not dependent on participant memory (Cade et al., 2002, Willett, 2012b). The food record does have its own limitations including greater burden on the participant and the possibility that recording of the diet may alter eating behaviour (Willett, 2012b). Therefore, food record data can only be used to measure the relative validity of the FFQ. While the food record method has a greater degree of demonstrated validity it is not an exact true measure of dietary intake (Gleason et al., 2010). Reproducibility (or reliability) measures the ability of a FFQ to give the same results under similar circumstances (Gleason et al., 2010).

While it is common to examine the accuracy and reliability of an FFQ, there has not been a consistent effort to examine the validity and reproducibility of *a posteriori* dietary patterns obtained from those FFQs (Edefonti et al., 2019). Before examining associations between dietary patterns and health outcomes, the robustness of the dietary pattern derived from a validated FFQ should be assessed. Initially, methods were simple, e.g., correlation (Hu et al., 1999), but there are now a range of statistical tools available (Lombard et al., 2015) and methods continue to improve.

The main aim of this study is to evaluate the relative validity and reproducibility of a food frequency questionnaire specifically designed to identify dietary patterns in older adults.

4.3. Methods

4.3.1. Study participants

The purpose of the REACH study is to explore associations of *a posteriori* dietary patterns with cognitive function and metabolic syndrome. The REACH study protocol and methodology have been published previously (Mumme et al., 2019) (Chapter Three). Data for the REACH study were collected from a convenience sample of 371 community-dwelling adults (65-74 years) in Auckland, New Zealand between April 2018, and February 2019. These dates also apply to this current study. Participants were recruited through a range of methods including posters, flyers and through social media. Participants were excluded if colour blind (due to cognitive testing requiring colour recognition); they had had a diagnosis of dementia or any other condition which may impair cognitive function (e.g., stroke, traumatic head injury or brain injury), a neurological or psychiatric condition; or they were taking medication which may influence their cognitive function. The Massey University Human Ethics Committee granted ethical approval for the REACH study: Southern A,

Application 17/69. All REACH participants gave informed written consent. All participants in the REACH study were potentially participants in the FFQ validation study. This validation study included all REACH participants who provided three complete dietary assessments.

4.3.2. Dietary assessment

4.3.2.1. Food frequency questionnaire

Participants completed the online 109-item REACH FFQ twice, one month apart (FFQ1 and FFQ2). The FFQ covered dietary intake for the previous month. Participants completed FFQ1 at the Human Nutrition Research Unit, Massey University, Auckland and FFQ2 from their home. The FFQ was adapted from a validated New Zealand FFQ designed to assess iron related nutrition in young women (Beck et al., 2012). Adaptations to the original FFQ included combining 16 food categories to form 10 categories (e.g., 'breakfast cereals/porridge' was merged into 'cereal and grains'); the addition of extra food items unrelated to iron nutrition (e.g., confectionery); the addition of serving sizes; and changes to the frequency response options (e.g., adding high daily frequency (6+/day) to capture frequently consumed items, e.g., sugar in hot drinks). Serving sizes (one per food item) were based on commonly eaten amounts, based on guidance from FOODfiles, the New Zealand food composition database (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2016). The 109 food items in the FFQ were placed into 10 food categories in the final FFQ: "fruit", "vegetables", "meat and chicken", "fish and seafood", "eggs, nuts, soy, and legumes", "cereals and grains", "dairy products and alternatives", "non-alcoholic drinks", "alcohol and miscellaneous foods", and "snacks". For each food item, participants were asked how often they ate a serving of the item in the past month. The 10 response choices were: "I never eat this food", "Not this month but I have sometimes", "1-3 times per MONTH", "Once per WEEK", "2-3 times per WEEK", "4-6 times per WEEK", "once per DAY", "2-3 times per DAY", "4-5 times per DAY", and "6 plus times per DAY". The food items within the FFQ were cross checked with three other FFQs to ensure all relevant food groups for the New Zealand population were included (Sam et al., 2014, Beck et al., 2018a, Bingham et al., 1997). The final question was an open question inviting participants to add any recently consumed foods which were not in the 109-item FFQ. The frequency and portion sizing of these additional foods were incorporated into the 109-items by the researcher at the time of analysis. For example, Kombucha was added to 'herbal tea, fruit tea' and Chinese or Asian stir fries were split between noodles, meat, and vegetables. The FFQ was pre-tested in 10 older New Zealand men and women for understanding and readability but was not modified further.

4.3.2.2. Food record

REACH participants completed an estimated 4-day food record (4-DFR) in the month between administration of the two FFQs. This was usually within one to two weeks following the completion of FFQ1. The food record covered four consecutive and assigned days including one weekend day. Participants watched an instructional video at the Human Nutrition Research Unit before completing the 4-DFR. Participants also received written instructions on completing the food record and serving size photos for some food items were provided to assist with estimation of portion sizes (Nelson et al., 1997). On completion, the 4-DFR was mailed backed to the Human Nutrition Research Unit.

Trained nutritionists and dietitians entered data from the 4-DFR into FoodWorks 10 (Xyris Pty Ltd, 2019) and contacted participants if data were unclear or missing. Supplement intake was not included in the analysis. Where necessary, recipes were entered into FoodWorks 10 (Xyris Pty Ltd, 2019) alongside the number of servings the recipe provided. A common food log was used to ensure consistency of entry among the data enterers. All food record entries were checked by a single New Zealand Registered Dietitian for accurate data entry. The final overall review of data included data reports to check that entries were consistent and nutrient histograms to identify outliers. Outliers were checked back to the original food diaries for accuracy.

4.3.2.3. Data handling

Missing values from the FFQ (<1% of all FFQ food items) were imputed using the multiple imputation chained equations method (van Buuren, 2007) with 5 imputations and 20 iterations. Predictors used were food items, age, sex, education, and living situation (alone or with others).

The FFQ serving size and daily frequency (based on a 4-week month) were used to calculate the daily grams of food consumed for each food item for each participant. Energy values were obtained from FOODfiles (the New Zealand Food composition database) (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2016, Food Standards Australia New Zealand, 2019) based on a selected food to represent each of the 109 foods in the FFQ (e.g., nut butters were represented by peanut butter). Where appropriate, a composite of foods was selected (e.g., berries were represented by strawberries and blueberries because of differences in their composition). This task was done by three members of the REACH team. Each item from the 4-DFR was assigned to an equivalent item in the 109-item FFQ. Some mixed dishes from the 4-DFR could easily be included into a food item (e.g., cakes or soup) but some dishes were split into two or more food items (e.g., a casserole would be assigned to 'meat' and 'vegetable' food items based on its ingredients). Marginal foods from the 4-DFR, that is those not matching a food group, were excluded from the analysis (e.g., salt, pepper, artificial sweetener). Average daily energy intake was considered implausible if

<500 kcal (2,100 kJ) or >3,500 kcal (14,700 kJ) for women and <800 kcal (3,360 kJ) or >4,000 kcal (16,800 kJ) for men (Wijnhoven et al., 2018, Willett, 2012a). The FFQs and 4-DFR were further collapsed from 109-items to 57 food groups (Table 4.1), with food groups combined based on similarity of foods and culinary use (e.g., cakes and biscuits were combined because they are eaten in similar circumstances) (Newby et al., 2004).

Table 4.1: Fifty-seven food groupings used in the dietary pattern analysis (from the REACH 109-item food frequency questionnaire)

Food groups (*n* 57)	Food items
Beer	Beer, lager, cider (all varieties)
Other alcohol	Port, sherry, liquors; ready to drink alcoholic beverages; spirits e.g., gin, brandy, whiskey, vodka; white wine
Red wine	Red wine
Bran cereal	Bran based cereals, muesli, porridges e.g., rolled oats, oat bran, oatmeal, All-Bran®, Sultana Bran®
Refined grains	White bread and rolls including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin, crumpets, pizza bases, wraps, tortilla's, burrito, roti, rewena bread; white pasta, noodles e.g., spaghetti, canned spaghetti, vermicelli, egg noodles, rice noodles, instant noodles; white rice
Snacks	Crackers e.g., crisp bread, water crackers, rice cakes, cream crackers, Cruskits™, Meal Mates™, Vita-wheat™; muesli or cereal bar (all varieties)
Sweetened cereals	Other breakfast cereals e.g., Special K®, Light'n'Tasty™; sweetened cereals e.g., Nutri-Grain®, Froot Loops®, Honey Puffs™, Frosties®, Milo® Cereal, Coco Pops®; Weet-Bix™, cornflakes or rice bubbles
Whole grain cereals	Brown rice; couscous, polenta, congee, Bulgur wheat, quinoa e.g., tabbouleh; whole grain or multi grain bread and rolls including sliced and specialty breads; whole meal or wheat meal bread and rolls including sliced and specialty breads; whole meal pasta, noodles
Cheese	Cheese e.g., Cheddar, Colby, Edam, Tasty, blue vein, camembert, parmesan, gouda, feta, mozzarella, brie, processed; cottage cheese, ricotta cheese
Creamy dairy products	Cream, sour cream, cream cheese, cheese spreads
Milk	Cow's milk including milk as a drink, milk added to drinks (e.g., milky coffees), milk added to cereal
Other milks (non-dairy)	Soy milk, coconut milk, rice milk, almond milk
Sweetened dairy products	Ice cream; milk-based puddings e.g., rice pudding, custard, semolina, instant puddings, dairy food; smoothies, milk shakes (made from milk, yoghurt, ice cream), flavoured milk
Yoghurt	Yoghurt

Food groups (*n* 57)	Food items
Dried legumes	Beans (canned or dried) e.g., black beans, butter beans, haricot beans, kidney beans, cannellini beans, refried beans, baked beans, chilli beans; peas and lentils e.g., chickpeas, hummus, falafels, split peas, cow peas, dahl
Eggs	Eggs – boiled, poached, raw; eggs - fried, scrambled, egg-based dishes including quiche, soufflés, frittatas, omelettes
Nuts, seeds	Nut butters or spreads e.g., peanut butter, almond butter, pesto; nuts e.g., peanuts, mixed nuts, macadamias, pecan, hazelnuts, brazil nuts, walnuts, cashews, pistachios, almonds; seeds e.g., pumpkin seeds, sunflower seeds, pinenuts, sesame seeds, tahini
Soy-based foods	Tofu, soybeans, tempeh, vegetarian sausages / meat, vegetarian burger patty, textured vegetable protein
Oily fish	Albacore tuna, salmon, sardines, herring, kahawai, swordfish, carp, dogfish, gemfish, alfonsino, rudderfish, anchovies; mackerel, snapper, oreo, barracouta, trevally, dory, trout, eel
Processed fish	Crumbed fish e.g., patties, cakes, fingers, nuggets; fish fried in batter (from fish & chips shop)
White fish, shellfish	Green mussels, squid; shellfish e.g., cockles, kina, oysters, paua, scallops, shrimp/prawn, pipi, roe; tuna (canned), hoki, gurnard, hake, kingfish, cod, tarakihi, groper, flounder
Apples, pears	Apples, pears, nashi pears
Avocados, olives	Avocado; olives
Bananas	Banana
Berries	Strawberries, blackberries, cherries, blueberries, boysenberries, loganberries, cranberries, gooseberries, raspberries (fresh, frozen, canned)
Citrus fruit	Citrus fruits e.g., orange, tangelo, tangerine, mandarin, grapefruit, lemon, lime
Dried fruit	Dried fruit e.g., sultanas, raisins, currants, figs, apricots, prunes, dates
Other fruit	All other fruit e.g., feijoa, persimmon, tamarillo, kiwifruit, grapes, mango, melon, watermelon, pawpaw, papaya, pineapple, rhubarb
Stone fruit	Stone fruit e.g., apricots, nectarines, peaches, plums, lychees
Poultry	Chicken, turkey, or duck e.g., roast, steak, fried, steamed, BBQ, casserole, stew, stir fry, curry, mince dishes, frozen dinners
Processed meat	Corn beef (canned), boil up[a], pork bones, lamb flaps, povi masima[b]; ham, bacon, luncheon sausage, salami, pastrami, other processed meat; sausages, frankfurters, cheerios[c], hot dogs
Red meat	Beef, lamb, hogget, mutton, pork, veal e.g., roast, steak, fried, chops, schnitzel, silverside, casserole, stew, stir fry, curry, BBQ, hamburger meat, mince dishes, frozen dinners; liver, kidney, other offal (including pate)
Butter, coconut	Butter, ghee; coconut cream; coconut oil
Cakes, biscuits, and puddings	Biscuits, chocolate or cream filled; biscuits, plain; cakes, slices, pastries; non-milk-based puddings e.g., pavlova, sweet pastries, fruit pies, trifle; pancakes, waffles, sweet buns, scones, sweet muffins, fruit bread, croissants, doughnuts, brioche

Food groups (*n* 57)	Food items
Chocolate	Chocolate (all other varieties)
Confectionery	Jam, marmalade, honey, syrups, sweet spreads or preserves; sugar (all varieties) added to food/drinks; sweets, lollies
Salad dressings	Creamy dressings e.g., mayonnaise, tartar, thousand island, ranch dressing; light dressings e.g., French and Italian dressing, balsamic vinegar
Meat pies, chips	Hot potato chips, French fries, wedges; meat pies, sausage rolls; potato crisps
Sauces, condiments	Pickles, chutney, mustard; tomato sauce, barbeque sauce, sweet chilli sauce; white sauce, cheese sauce, gravies
Soup	Soup, homemade or canned
Spices	Spices e.g., turmeric, ginger, cinnamon
Vegetable oils	Margarine; vegetable oils
Yeast spreads	Marmite™, Vegemite™
Diet drinks	Diet soft/fizzy drinks e.g., Sprite® Zero, Diet Coke®, Coca-Cola® Zero Sugar; low calorie cordials
Juices	Fruit and vegetable juices (all varieties)
Sugary drinks	Cordials including syrups, powders e.g., Raro®; energy drinks e.g., Red Bull®, V®; hot chocolate, drinking chocolate, cocoa, Ovaltine™, Nesquik®, Milo®; soft/fizzy drinks e.g., Sprite®, Coke®; sports drinks e.g., Powerade®
Tea, coffee	Coffee (all varieties); herbal tea, fruit tea; tea
Water	Water including tap, bottled or sparkling water
Alliums	Onions, leeks, garlic
Carrots	Carrots
Cruciferous vegetables	Broccoli, cauliflower, Brussel sprouts, cabbage (all varieties)
Fresh, frozen legumes	Green beans, broad beans, runner beans; peas, green
Leafy cruciferous vegetables	Green leafy vegetables e.g., spinach, silver beet, swiss chard, watercress, puha, whitloof, chicory, kale, chard, collards, Chinese kale, bok choy, taro leaves (palusami)
Other vegetables	All other vegetables e.g., corn, pumpkin, mushrooms, capsicum, peppers, courgette, zucchini, gherkins, marrow, squash, asparagus, radish, eggplant, artichoke
Root vegetables	Kumara, taro, green banana, cassava e.g., boiled, mashed, baked, roasted; other root vegetables e.g., yams, parsnip, swedes, beetroot, turnips; potato e.g., boiled, mashed, baked, jacket, instant, roasted
Salad vegetables	Salad vegetables e.g., lettuce, cucumber, celery, sprouts
Tomatoes	Tomatoes (all varieties)

[a] traditional Māori (indigenous people of New Zealand) food consisting of boiled meat and vegetables
[b] brined beef brisket
[c] processed sausage
REACH = Researching Eating, Activity, and Cognitive Health

4.3.3. Construction of the dietary patterns

Principal component analysis explores and describes the dietary data of a specific population by reducing the dimensionality of diet components based on their correlation with one another, while keeping as much variation within the diet as possible (McCann et al., 2001). It removes the problem of multicollinearity between dietary components. To test the suitability of the data set for principal component analysis, Bartlett's test of sphericity measured the presence of relationships within the data, and the Kaiser-Meyer-Olkin (KMO) test measured the sampling adequacy.

Using R (R Core Team, 2019), the *psych* package (Revelle, 2020), and orthogonal varimax rotation (for ease of interpretation), dietary patterns from the data matrix were derived for FFQ1, FFQ2, and 4-DFR. Each food group within the factor (i.e., dietary pattern) received a factor loading based on correlations between the food groups and the dietary pattern. The loading reflects the importance of that food group within the pattern. The retained factors were based on the scree plot, eigenvalues >1.0, and interpretability. Each participant received a dietary pattern score, calculated from the sum of the factor loading for each food group, multiplied by the participant's daily consumption of each food group multiplied by the standardized coefficients of each food group. The dietary pattern names were descriptive of the prominent food groups from the FFQ1 derived patterns.

4.3.4. Other variables

Demographic data were collected using a self-administered questionnaire. Participants wore no shoes and light clothing while trained nutritionists took a single height and weight measurement. A stadiometer, Tanita electronic scales and International Society for the Advancement of Kinanthropometry (Marfell-Jones et al., 2012) methods were used to take the measurements. The International Physical Activity Questionnaire - short form (Craig et al., 2003) collected physical activity levels. A physical activity score was calculated using Metabolic equivalent of a task (MET-minutes) where one minute of activity is 3.3, 4.0 or 8.0 METs depending on exercise level of walking, moderate or vigorous activity, respectively. One MET is the rate of energy expended while at rest (Craig et al., 2003).

4.3.5. Statistical analysis

Statistical analysis was performed using R version 3.6.1 (R Core Team, 2019) and the following R packages: *tidyverse* (Wickham et al., 2019), *psych* (Revelle, 2020), and *s20x (Balemi et al., 2020)*. As many food group intakes (g/day) were right skewed, median values and 25th, 75th percentiles were

used to describe the food groups. The 4-DFR (reference) tested validity of FFQ1 (test) and its derived dietary patterns. FFQ2 (reference) tested reproducibility of FFQ1 (test) and its derived dietary patterns. The variables tested were food groups (g/day), dietary pattern (factor) loadings, and dietary pattern (factor) scores. Tucker's congruence coefficient examined the similarity of the dietary pattern loadings between test and reference derived dietary patterns. Dietary pattern validation studies lack an acceptable range for this coefficient and therefore this statistic may be open to interpretation.

Two ranking methods assessed relative validity and reproducibility of the REACH FFQ and its derived dietary patterns (Lombard et al., 2015). First, Spearman correlation co-efficient tested the relative linear association between the dietary pattern scores and food groups of the test and reference methods. A Spearman correlation co-efficient rho ≥ 0.50 indicated a good correlation, between 0.20 to 0.49 was acceptable and < 0.20 was a poor outcome (Lombard et al., 2015). Second, a weighted Cohen kappa score (Cohen, 1968) was obtained after grouping variables (dietary pattern scores and food groups) into tertiles for test and reference methods. The weight applied was 1 for correctly classified participants, 0.5 for adjacent classification, and 0 weighting for gross misclassification. A weighted kappa statistic (κ_w) > 0.60 indicated good agreement, between 0.20 and 0.60 was acceptable, and < 0.20 was poor agreement (Lombard et al., 2015).

Absolute agreement of each dietary assessment method and its derived dietary patterns was assessed (Lombard et al., 2015). First, Bland Altman graphs were used to plot the difference (x-axis) and mean (y-axis) for each test and reference value (e.g., x = difference between daily food group intake derived from FFQ1 and FFQ2 and y = mean of daily food group intake from FFQ1 and FFQ2). Two standard deviations of the mean difference specified limits of agreement (LoA). Spearman correlation coefficients were used to calculate the slope of bias using values on the x and y axes of the Bland Altman plot. A significant correlation was considered to indicate bias and not acceptable agreement (Bland and Altman, 1986). Second, a one-sample t-test examined whether the mean difference (e.g., mean(test) – mean(reference)) for daily food group intake was significantly different to zero. Effect sizes, from the mean difference test, were calculated using Cohen d (Cohen, 1988). An effect was small where 0.20 ≤ d < 0.50, medium where 0.50 ≤ d < 0.80, and large where d ≥ 0.80 (Cohen, 1988). A p-value<0.05 was considered statistically significant.

4.4. Results

4.4.1. Study population and characteristics

Of the 371 participants registered for the REACH study, four did not complete any dietary assessments, 31 did not complete FFQ2, 14 did not complete the 4-DFR and 15 did not complete FFQ2 or a 4-DFR. Further participants were removed from the study where they had >10 missing items on the FFQs (*n* 5) or an incomplete 4-DFR (*n* 8). No participants had an implausible daily energy intake. The characteristics of the resulting 294 participants are shown in Table 4.2. Participants were primarily of New Zealand European/European ethnicity with a mean (SD) age of 69.8 (2.6) years and 37% were male.

Table 4.2: Characteristics of participants in validation study (*n* 294)

Characteristic	Total, mean (SD) or *n* (%)
n	294
Age (years)	69.8 (2.6)
Sex (% male)	37
Education	
Secondary	68 (23%)
Post-secondary	118 (40%)
University	108 (37%)
Ethnicity	
Asian	8 (3%)
European	279 (95%)
Māori/Pacific	7 (2%)
Physical activity (MET minutes/week)	3,859 (2,747)
Daily energy intake (kcal)	
FFQ1	1,802 (515)
FFQ2	1,703 508)
4-DFR	1,941 (464)
BMI	26.1 (4.4)

4-DFR = 4-day food record (4 consecutive days, including one weekend day) completed in the month after FFQ1 completion (reference), BMI = body mass index, FFQ1 = initial food frequency questionnaire (test), FFQ2 = second food frequency questionnaire one month later (reference), MET = metabolic equivalent of a task. MET minutes/week based on 3.3 MET for walking, 4.0 MET for moderate activity and 8.0 MET for vigorous activity.

4.4.2. Dietary patterns

Principal component analysis found three dietary patterns from each dietary assessment method (FFQ1, FFQ2 and 4-DFR) using the 57 food groups. These explained 14-18% of the variation in the diet. The KMO measure of sampling adequacy was 0.63, 0.62 and 0.54 for FFQ1, FFQ2 and 4-DFR respectively, and Bartlett's test of sphericity was significant (P<0.001), indicating the data sets were suitable for principal component analysis. Table 4.3 displays the dietary pattern loadings.

Dietary pattern 1 was named 'Mediterranean style' and was characterized by salad vegetables; avocados, olives; alliums; nuts and seeds; oily fish; water; berries; tomatoes; and salad dressings. Tucker's congruence coefficient tested the similarity of loadings between FFQ1 and FFQ2 (phi = 0.66) and FFQ1 and 4-DFR (phi = 0.75). Dietary pattern 2 was named 'Western' and was characterized by processed meat; beer; meat pies and chips; confectionery; and vegetable oils. Tucker's congruence coefficient of loadings between FFQ1and FFQ2 was phi = 0.80 and between FFQ1 and 4-DFR was phi = 0.60. Dietary pattern 3 was named 'prudent' and was characterized by nuts and seeds; apples and pears; carrots; and legumes. Tucker's congruence coefficient of loadings between FFQ1 and FFQ2 was phi = 0.70 and between FFQ1 and 4-DFR was phi = 0.54.

Table 4.3: Factor loadings for three major dietary patterns from the REACH validation study. Dietary patterns[abc] identified using a food frequency questionnaire (FFQ1), a second food frequency questionnaire one month later (FFQ2) and the 4-day food diary (4-DFR). Dietary patterns from the REACH validation study, 294 participants.

Food group (*n* 57)	Mediterranean style			Western			Prudent		
	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR
Salad vegetables	**0.61**	**0.57**	**0.42**					0.28	
Other vegetables	**0.57**	0.21	**0.58**					**0.52**	0.17
Leafy cruciferous vegetables	**0.57**					-0.17	0.21	**0.50**	0.17
Avocados, olives	**0.52**	**0.33**	**0.51**		-0.19			0.21	
Alliums	**0.51**	**0.35**	**0.40**					**0.42**	**0.23**
Nuts, seeds	**0.46**	**0.31**	**0.45**				**0.31**	**0.37**	**0.33**
Oily fish	**0.43**	0.24	0.27		-0.21			**0.33**	
White fish, shellfish	**0.42**	0.23	0.15			-0.17		0.17	
Cruciferous vegetables	**0.40**		0.23				0.22	**0.63**	**0.44**
Water	**0.39**	0.28	**0.34**			-0.21		0.27	0.20
Berries	**0.36**	**0.52**	**0.34**		-0.18	-0.26	0.20	0.15	

Food group (*n* 57)	Mediterranean style			Western			Prudent		
	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR
Other fruit	**0.35**						0.17	**0.37**	0.17
Apples, pears	**0.32**			-0.17	-0.17		0.25	**0.38**	**0.51**
Carrots	**0.30**		0.17	-0.18			**0.51**	**0.67**	**0.52**
Tomatoes	0.28	**0.67**	**0.43**	0.24					-0.24
Spices	0.27		**0.31**			-0.22	0.25	**0.40**	0.19
Salad dressings	0.26	**0.56**	**0.32**	**0.43**	0.23				
Eggs	0.25				0.15	**-0.46**		0.20	-0.29
Dried fruit	0.24	0.21	0.25	0.20			**0.38**	**0.30**	
Butter, coconut	0.23						-0.17		-0.23
Yoghurt	0.22	**0.31**					0.21		**0.48**
Cheese	0.21	0.15		**0.52**	0.18	0.23			
Processed meat	-0.19			**0.64**	**0.47**	0.25		-0.22	**-0.36**
Sauces, condiments		0.20		**0.54**	**0.50**				-0.17
Beer	-0.20	**0.31**		**0.43**	**0.33**	**0.50**		-0.27	-0.25
Meat pies, chips	**-0.39**		-0.20	**0.36**	**0.58**	**0.41**		-0.15	-0.18
Cakes, biscuits, and puddings	**-0.36**			**0.34**	**0.54**	0.23	0.19		
Chocolate		0.24		**0.34**	**0.40**	0.21		0.24	
Stone fruit	0.15	0.20	**0.44**	**0.32**		0.18			-0.28
Confectionery	**-0.32**	-0.19		**0.32**	**0.45**	**0.30**			
Processed fish	-0.25			**0.31**	0.17	**0.30**			-0.22
Snacks				**0.31**	0.19	0.28		-0.15	
Red wine		0.25		**0.30**		**0.30**	-0.18	-0.22	-0.15
Red meat		-0.24	-0.16	0.29	**0.39**				
Vegetable oils			0.25	0.29	**0.41**	**0.36**	0.15		
Diet drinks	-0.20			0.24	0.26			-0.15	-0.18
Sweetened cereal	-0.26	-0.19		0.21	**0.32**	**0.31**	0.19		
Tea, coffee				0.20	**0.30**				0.18
Dried legumes			0.29				**0.66**	**0.37**	0.29
Fresh, frozen legumes					0.17		**0.64**	**0.53**	0.23
Soy-based foods							**0.60**		
Whole grains						0.29	**0.53**	0.28	0.17
Root vegetables			0.28		0.20	**0.30**	**0.35**	**0.44**	
Poultry					0.18		0.27	**0.32**	
Bran cereal		**0.35**					0.27		0.29

Food group (*n* 57)	Mediterranean style			Western			Prudent		
	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR	FFQ1	FFQ2	4-DFR
Refined grains					0.24		0.26		-0.20
Citrus fruit				-0.20			0.23	**0.36**	**0.36**
Bananas		0.15	0.20				0.18	0.19	**0.41**
Other milks (non-dairy)			0.23				0.17	0.17	0.16
Sugary drinks	-0.22	-0.22			0.20	**0.33**	0.15		
Other alcohol	0.15	0.16				-0.26	-0.25	-0.22	-0.25
Sweetened dairy products		0.28		0.17	0.16				
Creamy dairy				0.15	0.23	-0.19			-0.16
Soup		-0.19	**-0.35**			-0.15		**0.40**	**0.32**
Milk			-0.25		0.29	0.23			
Yeast spreads									
Juices		0.17	0.17			-0.16			-0.16
score range	-2.47 - 3.99	-2.34 - 3.25	-2.29 - 5.03	-2.41 - 8.25	-2.79 - 4.72	-2.46 - 3.45	-1.97 - 4.74	-2.34 - 3.76	-2.56 - 4.61
Variance[d] (%)	7	7	5	6	6	5	5	5	4

[a] sorted by loadings of FFQ1.
[b] loadings|<0.15| excluded for ease in interpretation, bold are **loadings ≥0.30 or ≤-0.30**.
[c] positive loadings are positively associated, and negative loadings are negatively associated with the dietary pattern. A higher loading means a greater contribution to the dietary pattern.
[d] total amount of variation explained by three dietary patterns: FFQ1=18%, FFQ2=18%, 4-DFR=14%.
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4.4.3. Reproducibility of dietary patterns derived from FFQ1

All Spearman correlation coefficients between the dietary pattern scores of the FFQ1 derived dietary patterns and the FFQ2 derived dietary patterns were significant (*P*<0.001). The coefficients suggest good reproducibility for 'prudent' and 'Western' (rho = 0.51 and 0.59) and acceptable reproducibility for 'Mediterranean style' pattern (rho = 0.47) (Table 4.4). The weighted kappa scores ranged from 0.40 to 0.48 suggesting acceptable agreement of dietary pattern scores between FFQ1 and FFQ2 (Table 4.4). The dietary pattern scores were standardized therefore the mean difference was zero, but limits of agreement ranged from ± 1.79 to ± 2.09 standard deviations for reproducibility. The Bland Altman plots (Figure 3) suggested the mean difference between the 'prudent' pattern scores for FFQ1 and FFQ2 decreased as the mean dietary pattern score increased and the Spearman correlation coefficient confirmed the negative slope of bias (*P*<0.001) (Table 4.4).

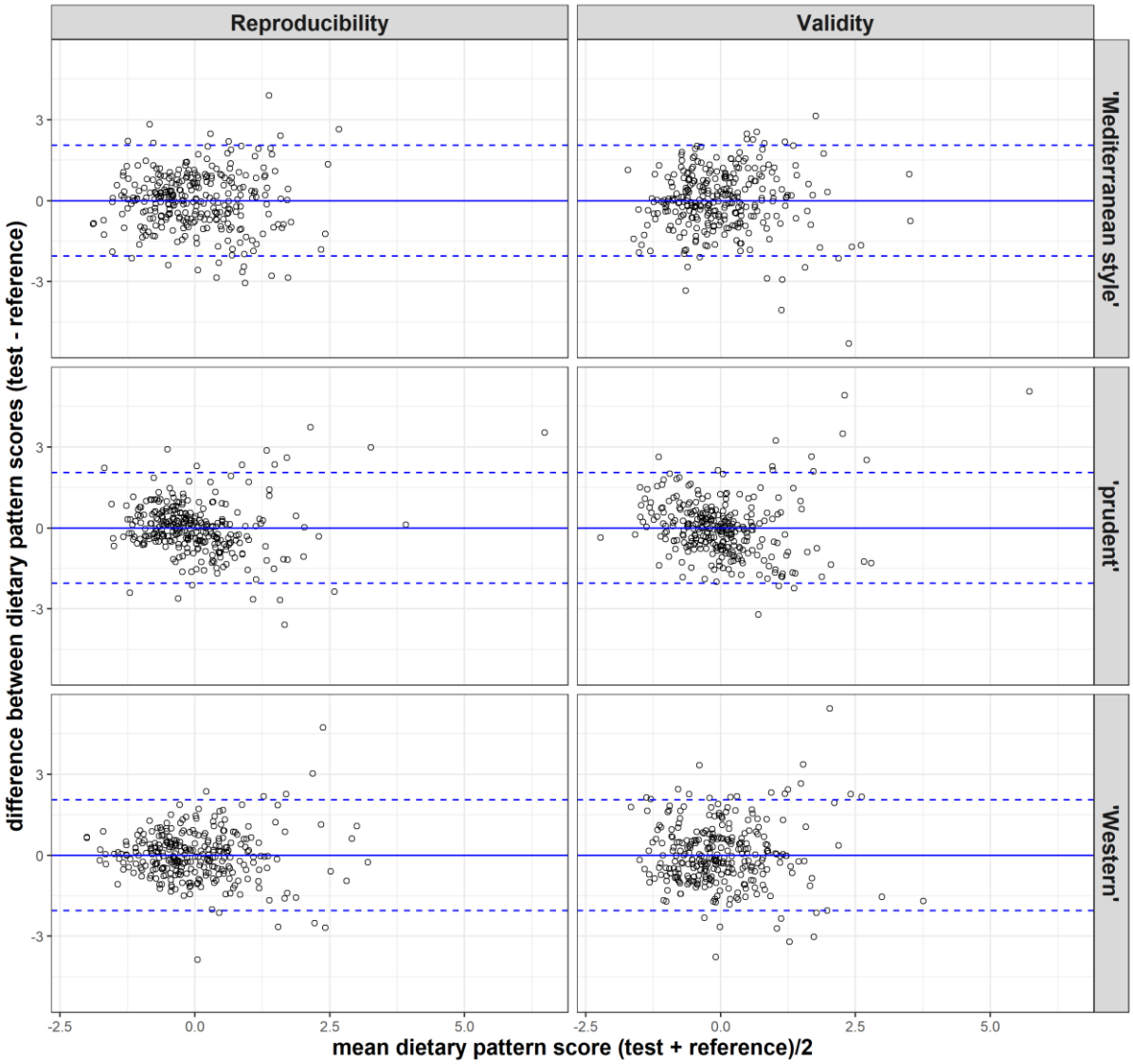

Figure 3: Bland Altman plots for reproducibility and validity of the three dietary pattern scores
The difference between the test (FFQ1) and reference (FFQ2 for reproducibility and 4-DFR for validity) dietary pattern scores are plotted against the mean dietary patterns score of the FFQ1 (test) and reference (FFQ2 for reproducibility and 4-DFR for validity) dietary assessments. The solid line represents the mean difference between the dietary assessment tools and the dashed lines represent the limits of agreement being ± 2 standard deviations. Data from the REACH (Researching Eating, Activity, and Cognitive Health) study (*n* 294). FFQ1 = initial food frequency questionnaire; FFQ2 = second food frequency questionnaire one month later; 4-DFR = 4-day food record (4 consecutive days, including one weekend day) completed in the month after FFQ1 completion.

Table 4.4: Reproducibility and validity statistics of dietary pattern scores derived from a food frequency questionnaire (FFQ1), a second food frequency questionnaire one month later (FFQ2) and the 4-day food diary (4-DFR), Data from the REACH study (*n* 294)

	Dietary pattern	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Limits of agreement[c]	Slope of bias[d] (rho)
Reproducibility	Mediterranean style: (FFQ1 v FFQ2)	0.47	0.40 (0.31, 0.50)	-2.09, 2.09	0.00
	Prudent (FFQ1 v FFQ2)	0.51	0.48 (0.39, 0.58)	-1.88, 1.88	-0.23 ***
	Western (FFQ1 v FFQ2)	0.59	0.48 (0.39, 0.58)	-1.79, 1.79	-0.04
Validity	Mediterranean style: (FFQ1 v 4-DFR)	0.34	0.28 (0.17, 0.39)	-2.20, 2.20	0.08
	Prudent (FFQ1 v 4-DFR)	0.43	0.37 (0.26, 0.47)	-2.09, 2.09	-0.25 ***
	Western (FFQ1 v 4-DFR)	0.33	0.27 (0.16, 0.37)	-2.27, 2.27	0.00

[a] All Spearman correlation coefficients $P<0.001$. Outcomes: good rho≥0.50; acceptable rho 0.20-0.50; poor rho<0.20

[b] Weighted kappa (K_w) outcomes: good $K_w \geq 0.60$; acceptable K_w 0.20-0.60; poor $K_w < 0.20$. CI = 95% confidence intervals.

[c] Limits of agreement being ±2 standard deviations of the mean difference of dietary pattern scores.

[d] A significant positive slope indicates the mean difference increases as the average intake increases. A significant negative slope indicates the mean difference decreases as the average intake increases

4-DFR = 4-day food record (4 consecutive days, including one weekend day) completed in the month after FFQ1 completion (validation reference), FFQ1 = initial food frequency questionnaire (test), FFQ2 = second food frequency questionnaire one month later (reproducibility reference), REACH = Researching Eating, Activity, and Cognitive Health.

Levels of significance: *$P<0.05$; **$P<0.01$; ***$P<0.001$

4.4.4. Validity of dietary patterns derived from FFQ1

All Spearman correlation coefficients between the dietary pattern scores of the FFQ1 derived dietary patterns and the 4-DFR derived dietary patterns were significant ($P<0.001$). The coefficients suggest acceptable relative validity: rho = 0.34, 0.43 and 0.33 for 'Mediterranean style', 'prudent' and 'Western' patterns (Table 4.4). The weighted kappa scores ranged from 0.27 to 0.37 suggesting acceptable agreement of dietary pattern scores between FFQ1 and 4-DFR (Table 4.4). Limits of agreement ranged from ± 2.09 to ± 2.27 standard deviations for validity. The Bland Altman plots (Figure 3) suggested the mean difference between the 'prudent' pattern scores for FFQ1 and 4-DFR decreased as the mean dietary pattern score increased and the Spearman correlation coefficient confirmed the negative slope of bias ($P<0.001$) (Table 4.4).

4.4.5. Reproducibility of FFQ1 food groups

All correlations between FFQ1 and FFQ2 food groups were significant ($P<0.01$). Correlation coefficients ranged from 0.49 ('stone fruit') to 0.85 ('bananas', 'beer' and 'other alcohol') with a mean correlation of 0.69 ± 0.09 (Table 4.5).

Weighted kappa scores ranged from 0.40 ('milk') to 0.85 ('beer') with an average score of 0.62 ± 0.09. Thirty food groups had good agreement ($\kappa_w > 0.60$) and 27 food groups had acceptable agreement ($0.20 \leq \kappa_w \leq 0.60$). No food groups had poor agreement for the comparison of FFQ1 and FFQ2 (Table 4.5).

Positive bias (as the average intake increased the mean difference increased) was seen in plots (not shown) and confirmed by correlation for 11 of the 57 food groups (19%). These were 'diet drinks', 'other fruit', 'refined grains', 'soup', 'processed meat', 'apples, pears', 'root vegetables', 'snacks', 'white fish and shellfish', 'soy-based foods' and 'dried legumes' (rho ranging from 0.04 to 0.23). No food groups showed negative bias (Table 4.5).

One sample t-tests examined whether the mean intake difference (FFQ1 – FFQ2) deviated significantly from zero resulting in 44 of the 57 food groups (77%) with non-significant results ($P>0.05$), suggesting similar intakes between FFQ1 and FFQ2. For the 13 items with significant differences, 'other fruit' had a small effect size (Cohen d = 0.23) with the remaining food groups with minimal effect (Cohen d < 0.20) (Table 4.5).

Table 4.5: Daily median intake (g/day) of 57 food groups (FFQ1 and FFQ2) from the initial food frequency questionnaire (FFQ1), the second food frequency questionnaire (FFQ2) and the reproducibility statistics. Data from the REACH study (*n* 294).

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	FFQ2 median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])	Slope of bias[d] (rho)
Beer	0.0 (0.0, 47.4)	0.0 (0.0, 47.4)	0.85	0.85 (0.85, 0.85)	-12.7 (-273.5, 248.2)	0.10
Other alcohol	9.1 (0.0, 35.4)	9.1 (0.0, 35.4)	0.85	0.82 (0.77, 0.87)	-2.8 (-69.1, 63.6)	0.08
Red wine	7.1 (0.0, 35.5)	7.1 (0.0, 35.5)	0.83	0.79 (0.75, 0.82)	0.7 (-69.8, 71.1)	0.02
Bran cereal	16.1 (1.6, 22.5)	16.1 (1.6, 22.5)	0.81	0.58 (0.47, 0.69)	1.2 (-19.9, 22.2)	0.11
Refined grains	13.3 (7.2, 26.8)	12.8 (6.0, 22.6)	0.76	0.65 (0.58, 0.73)	2.7 (-33.0, 38.4) *	0.15 **
Snacks	7.6 (2.3, 16.0)	5.7 (1.1, 12.1)	0.74	0.69 (0.62, 0.76)	2.1 (-24.9, 29.2) **	0.15 *
Sweetened cereals	0.0 (0.0, 5.6)	0.0 (0.0, 4.8)	0.71	0.72 (0.68, 0.76)	-0.0 (-20.1, 20.0)	0.00
Whole grains	28.7 (14.7, 46.1)	26.8 (13.6, 45.3)	0.63	0.54 (0.46, 0.63)	0.9 (-68.7, 70.5)	0.03
Cheese	9.8 (7.4, 16.0)	8.6 (7.4, 15.7)	0.70	0.62 (0.55, 0.70)	0.6 (-16.5, 17.8)	0.07
Creamy dairy products	0.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.53	0.50 (0.41, 0.60)	-0.1 (-3.4, 3.1)	0.08
Milk	258.0 (92.1, 6.0)	258.0 (92.1, 645.0)	0.70	0.40 (0.31, 0.49)	44.7 (-586.1, 675.5)	0.14
Other milks (non-dairy)	0.0 (0.0, 0.0)	0.0 (0.0, 18.2)	0.68	0.74 (0.74, 0.74)	-0.7 (-124.1, 122.7)	0.01
Sweetened dairy products	5.1 (0.0, 25.5)	5.1 (0.0, 25.5)	0.57	0.57 (0.48, 0.66)	-0.0 (-133.0, 133.0)	0.00
Yoghurt	46.6 (9.3, 130.6)	46.6 (9.3, 130.6)	0.83	0.59 (0.49, 0.68)	5.0 (-130.6, 140.7)	0.07
Dried legumes	13.9 (6.2, 27.9)	13.1 (6.2, 21.7)	0.63	0.54 (0.45, 0.63)	3.2 (-50.5, 56.9) *	0.12 *
Eggs	21.3 (12.8, 42.6)	25.6 (12.8, 42.6)	0.71	0.65 (0.58, 0.72)	-0.6 (-47.0, 45.8)	0.02
Nuts, seeds	8.0 (3.2, 16.4)	7.6 (2.8, 13.9)	0.80	0.72 (0.65, 0.78)	0.9 (-14.2, 15.9)	0.11
Soy-based foods	0.0 (0.0, 0.0))	0.0 (0.0, 0.0))	0.59	0.61 (0.61, 0.61)	0.7 (-20.8, 22.3)	0.07 *
Oily fish	14.0 (7.0, 23.0)	12.1 (7.0, 19.1)	0.63	0.56 (0.47, 0.65)	1.9 (-25.8, 29.5) *	0.13

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	FFQ2 median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])	Slope of bias[d] (rho)
Processed fish	0.0 (0.0, 10.4)	0.0 (0.0, 10.4)	0.56	0.53 (0.44, 0.62)	-1.7 (-47.4, 44.0)	0.07
White fish, shellfish	11.1 (5.5, 19.6)	11.1 (5.5, 19.6)	0.62	0.57 (0.48, 0.65)	0.8 (-28.2, 29.8)	0.06 *
Apples, pears	58.3 (11.7, 116.6)	58.3 (11.7, 58.3)	0.77	0.72 (0.65, 0.78)	8.8 (-108.1, 125.7) *	0.15 **
Avocados, olives	5.3 (2.6, 14.0)	5.3 (2.6, 14.0)	0.72	0.65 (0.57, 0.73)	1.2 (-33.3, 35.7)	0.07
Bananas	39.6 (9.9, 79.2)	39.6 (7.9, 79.2)	0.85	0.78 (0.78, 0.78)	4.0 (-95.4, 103.3)	0.08
Berries	5.6 (0.0, 28.0)	5.6 (0.0, 28.0)	0.59	0.53 (0.43, 0.63)	-0.1 (-62.7, 62.5)	0.00
Citrus fruit	53.4 (10.7, 106.7)	53.4 (10.7, 106.7)	0.67	0.64 (0.57, 0.71)	3.6 (-174.8, 181.9)	0.04
Dried fruit	2.4 (1.2, 6.1)	2.4 (1.2, 6.1)	0.68	0.67 (0.60, 0.74)	0.6 (-16.5, 17.8)	0.07
Other fruit	31.4 (6.3, 62.9)	12.6 (6.3, 62.9)	0.65	0.54 (0.45, 0.64)	10.6 (-79.5, 100.7) [e] ***	0.23**
Stone fruit	0.0 (0.0, 7.7)	0.0 (0.0, 15.4)	0.49	0.45 (0.34, 0.56)	-1.9 (-93.1, 89.4)	0.04
Poultry	25.5 (10.2, 25.5)	25.5 (10.2, 25.5)	0.63	0.54 (0.43, 0.66)	1.4 (-29.4, 32.2)	0.09
Processed meat	9.7 (0.0, 20.4)	9.7 (0.0, 19.3)	0.72	0.65 (0.58, 0.73)	1.4 (-22.4, 25.4)	0.11**
Red meat	41.1 (16.4, 41.1)	41.1 (16.4, 41.1)	0.63	0.56 (0.48, 0.65)	0.1 (-61.4, 61.3)	0.00
Butter, coconut	1.6 (0.3, 498)	1.9 (0.3, 4.9)	0.68	0.63 (0.55, 0.71)	-0.2 (-9.2, 8.8)	0.04
Cakes, biscuits, and puddings	18.6 (6.6, 36.1)	18.6 (8.3, 34.9)	0.68	0.58 (0.50, 0.67)	0.1 (-48.6, 48.9)	0.01
Chocolate	1.8 (1.8, 8.9)	3.6 (0.0, 8.9)	0.78	0.76 (0.72, 0.80)	0.2 (-13.7, 14.2)	0.03
Confectionery	2.7 (0.4, 7.7)	2.9 (0.4, 6.7)	0.75	0.68 (0.61, 0.75)	0.1 (-12.5, 12.7)	0.02
Salad dressings	3.2 (1.1, 7.2)	2.1 (1.1, 7.5)	0.70	0.59 (0.52, 0.67)	0.3 (-8.9, 9.5)	0.07
Meat pies, chips	12.1 (0.0, 24.3)	12.1 (0.0, 24.4)	0.70	0.65 (0.58, 0.72)	0.9 (-27.1, 29.0)	0.06
Sauces, condiments	3.5 (1.5, 7.1)	3.5 (2.2, 7.0)	0.68	0.61 (0.52, 0.69)	0.2 (-9.8, 10.3)	0.05
Soup	18.4 (0.0, 91.8)	18.4 (0.0, 36.7)	0.58	0.51 (0.42, 0.61)	18.1 (-193.8, 229.9) **	0.17**
Spices	0.9 (0.2, 1.9)	0.4 (0.2, 1.0)	0.67	0.61 (0.52, 0.69)	0.2 (-2.1, 2.6) **	0.18

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	FFQ2 median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])		Slope of bias[d] (rho)
Vegetable oils	4.7 (1.7, 6.5)	3.4 (1.7, 8.2)	0.69	0.66 (0.58, 0.74)	-0.2 (-9.3, 8.9)		0.04
Yeast spreads	0.4 (0.0, 2.1)	0.4 (0.0, 2.1)	0.77	0.67 (0.59, 0.75)	0.2 (-3.1, 3.4)		0.09
Diet drinks	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.70	0.71 (0.71, 0.71)	2.8 (-123.2, 128.8)		0.04***
Juices	0.0 (0.0, 18.7)	0.0 (0.0, 18.7)	0.53	0.53 (0.42, 0.64)	-0.7 (-101.5, 100.1)		0.01
Sugary drinks	0.0 (0.0, 36.2)	0.0 (0.0, 36.9)	0.72	0.73 (0.69, 0.77)	0.3 (-118.3, 118.9)		0.01
Tea, coffee	922.9 (668.8, 1294.6)	905.0 (625.0, 1290.7)	0.72	0.65 (0.58, 0.73)	47.6 (-576.7, 671.9)	*	0.15
Water	625.0 (625.0, 1125.0)	625.0 (343.8, 1125.0)	0.62	0.62 (0.55, 0.69)	53.5 (-645.9, 752.8)	*	0.15
Alliums	3.4 (1.3, 6.7)	3.4 (1.3, 6.7)	0.66	0.59 (0.52, 0.67)	0.3 (-6, 6.6)		0.09
Carrots	24.2 (24.2, 48.5)	24.2 (9.7, 48.5)	0.76	0.53 (0.44, 0.62)	2.7 (-30.6, 36.1)	**	0.16
Cruciferous vegetables	24.5 (24.5, 48.9)	24.5 (9.8, 48.9)	0.61	0.58 (0.50, 0.66)	2.8 (-44.6, 50.1)		0.11
Fresh, frozen legumes	21.7 (10.8, 50.3)	21.7 (10.8, 41.0)	0.64	0.57 (0.48, 0.66)	0.7 (-51.2, 52.6)		0.03
Leafy cruciferous vegetables	26.8 (5.4, 53.6)	10.7 (5.4, 26.8)	0.65	0.60 (0.52, 0.68)	2.8 (-51.9, 57.5)		0.10
Other vegetables	23.8 (9.5, 47.5)	23.8 (9.5, 47.5)	0.56	0.53 (0.43, 0.63)	3.0 (-60.2, 66.1)		0.09
Root vegetables	88.4 (46.2, 125.7)	79.6 (44.2, 113.3)	0.71	0.57 (0.50, 0.65)	7.2 (-89.2, 103.5)	*	0.14*
Salad vegetables	39.8 (15.9, 79.6)	39.8 (15.9, 79.6)	0.62	0.58 (0.50, 0.66)	4.1 (-90.9, 99.1)		0.08
Tomatoes	43.9 (17.6, 87.9)	43.9 (17.6, 87.9)	0.67	0.65 (0.59, 0.71)	1.9 (-116.8, 120.6)		0.03

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	FFQ2 median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])	Slope of bias[d] (rho)

[a] All Spearman correlation coefficients *P*<0.001. Outcomes: good rho≥0.50; acceptable rho 0.20-0.50; poor rho<0.20.

[b] Weighted kappa (K_w) outcomes: good K_w≥0.60; acceptable K_w 0.20-0.60; poor K_w<0.20. CI = 95% confidence intervals.

[c] Limits of agreement being ±2 standard deviations of the mean difference of dietary pattern scores.

[d] a significant positive slope indicates the mean difference increases as the average intake increases. A significant negative slope indicates the mean difference decreases as the average intake increases.

Effect size of daily intake mean difference measured with Cohen d: [e] small effect (0.20≤d<0.50).

FFQ1 = initial food frequency questionnaire (test), FFQ2 = second food frequency questionnaire one month later (reproducibility reference), REACH = Researching Eating, Activity, and Cognitive Health.

Levels of significance: **P*<0.05; ***P*<0.01; ****P*<0.001

4.4.6. Validity of FFQ1 food groups

All correlations between FFQ1 and 4-DFR food groups were significant ($P<0.01$). Correlation coefficients ranged from 0.18 ('sauces, condiments') to 0.72 ('bananas' and 'yoghurt') with a mean correlation of 0.45 ± 0.14 (Table 4.6).

Weighted kappa scores between the FFQ1 and 4-DFR food groups ranged from 0.14 ('cruciferous vegetables') to 0.65 ('sweetened cereals') with the average kappa score being 0.38 ± 0.13. 'Sweetened cereals', 'bananas', 'other milks (non-dairy)' and 'apples, pears' had good agreement between the methods ($\kappa_w > 0.60$), 50 food groups had acceptable agreement ($0.20 \leq \kappa_w \leq 0.60$), and three food groups had poor agreement ($\kappa_w < 0.20$) – 'processed fish', 'sauces, condiments' and 'cruciferous vegetables'.

Of the 57 food groups, positive bias was seen in plots and confirmed by correlation in 17 food groups (30%) ranging from 0.13 ('snacks') to 0.74 ('leafy cruciferous vegetables'). Twenty-seven food groups (47%) showed a negative bias (as the average intake increased the mean difference decreased), ranging from -0.13 ('other alcohol', 'other fruit') to -0.89 ('alliums') (Table 4.6).

One sample t-tests examined whether the mean intake difference (FFQ1 – 4DFR) deviated significantly from zero. Eighteen food groups (32%) had non-significant results ($P>0.05$) meaning similar intakes between FFQ1 and 4DFR. For the 39 items with significant differences, the effect size was large for 'leafy cruciferous vegetables' only (Cohen $d \geq 0.80$), medium for 'milk', 'fresh, frozen legumes', 'tea, coffee', 'refined grains', 'alliums', 'sauces, condiments' and 'salad vegetables' ($0.50 \leq d < 0.80$), but small for 20 food groups and minimal for 11 food groups (Table 4.6).

Table 4.6: Daily median intake (g/day) of 57 food groups (FFQ1 and 4-DFR) from the initial food frequency questionnaire (FFQ1), the 4-day food record (4-DFR) and the validation statistics. Data from the REACH study (*n* 294).

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	4-DFR median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])		Slope of bias[d] (rho)
Beer	0.0 (0.0, 47.4)	0.0 (0.0, 0.0)	0.64	0.60 (0.53, 0.66)	-2.9 (-167.7, 162.0)		0.11
Other alcohol	9.1 (0.0, 35.4)	0.0 (0.0, 49.6)	0.63	0.51 (0.42, 0.59)	-8.0 (-142.9, 126.9)	*	-0.13 *
Red wine	7.1 (0.0, 35.5)	0.0 (0.0, 49.7)	0.60	0.53 (0.43, 0.63)	-12.5 (-139.9, 114.9)	**	-0.23 ***
Bran cereal	16.1 (1.6, 22.5)	20.0 (0.0, 50.0)	0.70	0.54 (0.41, 0.66)	-26.7 (-142.1, 88.6) [e]	***	-0.78 ***
Refined grains	13.3 (7.2, 26.8)	39.5 (9.7, 80.4)	0.44	0.41 (0.31, 0.51)	-35.4 (-151.9, 81.1) [f]	***	-0.73 ***
Snacks	7.6 (2.3, 2.0)	4.5 (0.0, 14.4)	0.50	0.44 (0.34, 0.54)	3.4 (-30.1, 36.8)	**	0.13 *
Sweetened cereals	0.0 (0.0, 5.6)	0.0 (0.0, 8.0)	0.66	0.65 (0.59, 0.70)	1.0 (-29.1, 27.1)		-0.02
Whole grains	28.7 (14.7, 46.1)	56.3 (23.3, 90.9)	0.39	0.34 (0.24, 0.44)	-24.5 (-125.0, 75.9) [e]	***	-0.46 ***
Cheese	9.8 (7.4, 16.0)	15.0 (7.3, 27.7)	0.36	0.26 (0.15, 0.37)	-7.4 (-43.7, 28.9) [e]	***	-0.56 ***
Creamy dairy products	0.0 (0.0, 1.0)	0.0 (0.0, 3.4)	0.32	0.36 (0.22, 0.50)	-2.6 (-18.2, 13.0) [e]	***	-0.41 ***
Milk	258.0 (92.1, 6.0)	116.7 (31.3, 199.3)	0.60	0.28 (0.19, 0.36)	275.2 (-410.3, 960.6) [f]	***	0.72 ***
Other milks (non-dairy)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.53	0.62 (0.62, 0.62)	19.0 (-112.1, 150.2) [e]	***	0.58 ***
Sweetened dairy products	5.1 (0.0, 25.5)	0.0 (0.0, 25.0)	0.39	0.35 (0.25, 0.45)	-4.7 (-161.5, 152.2)		-0.05
Yoghurt	46.6 (9.2, 130.6)	21.5 (0.0, 59.3)	0.72	0.56 (0.45, 0.66)	37.5 (-109.7, 184.6) [f]	***	0.41 ***
Dried legumes	13.9 (6.2, 27.9)	1.0 (0.0, 22.5)	0.22	0.22 (0.11, 0.33)	5.5 (-70.5, 81.5)	*	0.06
Eggs	21.3 (12.8, 42.6)	26.2 (11.4, 47.6)	0.39	0.28 (0.17, 0.39)	-4.9 (-65.5, 55.7)	**	-0.37 ***
Nuts, seeds	8.0 (3.2, 16.4)	7.5 (0.0, 20.0)	0.54	0.49 (0.40, 0.58)	-3.0 (-37.8, 31.8)	**	-0.33 ***
Soy-based foods	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.30	0.26 (-0.23, 0.76)	1.3 (-25.0, 27.7)		0.50 ***
Oily fish	14.0 (7.0, 23.0)	0.0 (0.0, 31.1)	0.41	0.35 (0.25, 0.44)	-0.6 (-52.0, 50.8)		-0.29 ***
Processed fish	0.0 (0.0, 10.4)	0.0 (0.0, 0.0)	0.21	0.18 (0.02, 0.35)	-1.0 (-40.1, 38.1)		0.20 **

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	4-DFR median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])		Slope of bias[d] (rho)
White fish, shellfish	11.1 (5.5, 19.6)	0.0 (0.0, 23.8)	0.36	0.30 (0.19, 0.41)	-1.1 (-53.2, 51.0)		-0.20***
Apples, pears	58.3 (11.7, 116.6)	34.8 (0.0, 90.9)	0.68	0.62 (0.54, 0.70)	13.8 (-108.1, 135.8)[e]	***	0.19**
Avocados, olives	5.3 (2.6, 14.0)	0.0 (0.0, 20.9)	0.56	0.52 (0.43, 0.61)	-2.1 (-51.3, 47.1)		-0.17**
Bananas	39.6 (9.9, 79.2)	33.3 (0.0, 76.5)	0.72	0.64 (0.56, 0.72)	7.7 (-99.8, 115.1)	*	-0.04
Berries	5.6 (0.0, 28.0)	0.0 (0.0, 11.3)	0.52	0.40 (0.30, 0.49)	8.7 (-61.8, 79.1)[e]	***	0.33***
Citrus fruit	53.4 (10.7, 106.7)	5.7 (0.0, 58.6)	0.54	0.50 (0.41, 0.59)	36.7 (-116.1, 189.4)[e]	***	0.38***
Dried fruit	2.4 (1.2, 6.1)	0.0 (0.0, 6.9)	0.39	0.36 (0.25, 0.47)	-0.2 (-29.3, 28.9)		0.01
Other fruit	31.4 (6.3, 62.9)	19.3 (0.0, 71.6)	0.56	0.52 (0.43, 0.62)	-1.6 (-116.0, 112.9)		-0.13*
Stone fruit	0.0 (0.0, 7.7)	0.0 (0.0, 0.0)	0.46	0.46 (0.33, 0.59)	0.4 (-70.1, 70.8)		0.18**
Poultry	25.5 (10.2, 25.5)	25.0 (0.0, 52.2)	0.26	0.22 (0.06, 0.38)	-12.2 (-92.7, 68.4)[e]	***	-0.65***
Processed meat	9.7 (0.0, 20.4)	3.1 (0.0, 26.3)	0.51	0.44 (0.35, 0.54)	-2.0 (-47.3, 43.3)		-0.17**
Red meat	41.1 (16.4, 41.1)	37.5 (0.0, 71.2)	0.37	0.31 (0.20, 0.41)	-11.1 (-108.5, 86.3)[e]	***	-0.45***
Butter, coconut	1.6 (0.3, 4.9)	3.4 (0.0, 8.1)	0.55	0.46 (0.37, 0.56)	-2.6 (-23.6, 18.4)[e]	***	-0.26***
Cakes, biscuits, and puddings	18.6 (6.6, 36.1)	36.3 (7.5, 65.4)	0.43	0.38 (0.28, 0.48)	-20.0 (-4.0, 73.9)[e]	***	-0.47***
Chocolate	1.8 (1.8, 8.9)	0.0 (0.0, 7.4)	0.49	0.44 (0.34, 0.55)	1.0 (-21.1, 23.1)		0.10
Confectionery	2.7 (0.4, 7.7)	3.5 (0.0, 10.7)	0.50	0.44 (0.35, 0.54)	-2.1 (-23.5, 19.3)	**	-0.21***
Salad dressings	3.2 (1.1, 7.2)	1.3 (0.0, 5.4)	0.33	0.29 (0.17, 0.40)	0.7 (-16.3, 17.7)		0.02
Meat pies, chips	12.1 (0.0, 24.3)	7.5 (0, 44.5)	0.37	0.34 (0.23, 0.45)	-13.3 (-98.3, 71.8)[e]	***	-0.46***
Sauces, condiments	3.5 (1.5, 7.1)	9.0 (1.4, 27.2)	0.18	0.18 (0.07, 0.29)	-13.5 (-62.4, 35.3)[f]	***	-0.73***
Soup	18.4 (0.0, 91.8)	0.0 (0.0, 99.5)	0.46	0.40 (0.31, 0.49)	-8.1 (-266.9, 250.8)		-0.15**
Spices	0.9 (0.2, 1.9)	0.2 (0.0, 1.1)	0.26	0.24 (0.12, 0.35)	-0.3 (-7.9, 7.3)		0.02
Vegetable oils	4.7 (1.7, 6.5)	4.6 (1.2, 11.1)	0.35	0.31 (0.20, 0.42)	-2.1 (-18.0, 13.8)[e]	***	-0.35***

Food group (*n*=57)	FFQ1 median intake (g/day) (25th, 75th percentile)	4-DFR median intake (g/day) (25th, 75th percentile)	Spearman correlation coefficient[a] (rho)	Weighted kappa statistic[b] (95% CI)	Daily intake mean difference (g/day) (LoA[c])		Slope of bias[d] (rho)
Yeast spreads	0.4 (0.0, 2.1)	0.0 (0.0, 1.2)	0.52	0.44 (0.34, 0.54)	0.5 (-4.7, 5.7)	**	0.27***
Diet drinks	0.0 (0.0, 0.0)	0.0 (0.0, 0.0	0.30	0.37 (-0.09, 0.82)	15.8 (-151.0, 182.6)	**	0.62***
Juices	0.0 (0.0, 18.7)	0.0 (0.0, 19.5)	0.23	0.20 (0.05, 0.35)	-1.1 (-125.2, 123.1)		-0.03
Sugary drinks	0.0 (0.0, 36.2)	0.0 (0.0, 39.4)	0.55	0.56 (0.47, 0.64)	-3.8 (-168.7, 161.2)		0.07
Tea, coffee	922.9 (668.8, 1294.6)	709.6 (490.1, 946.6)	0.62	0.53 (0.44, 0.62)	228.7 (-498.3, 955.6)[f]	***	0.23***
Water	625.0 (625.0, 1125.0)	529.7 (275.0, 951.2)	0.58	0.43 (0.35, 0.51)	108.8 (-771.5, 989.1)[e]	***	-0.14*
Alliums	3.4 (1.3, 6.7)	11.6 (1.4, 28.7)	0.33	0.25 (0.15, 0.35)	-16.5 (-70.3, 37.3)[f]	***	-0.89***
Carrots	24.2 (24.2, 48.5)	13.8 (0.3, 33.8)	0.47	0.31 (0.21, 0.40)	9.4 (-46.5, 65.3)[e]	***	0.01
Cruciferous vegetables	24.5 (24.5, 48.9)	28.8 (6.9, 59.5)	0.21	0.14 (0.04, 0.24)	-11.2 (-114.7, 92.4)[e]	***	-0.48***
Fresh, frozen legumes	21.7 (10.8, 50.3)	0.0 (0.0, 10.1)	0.21	0.20 (0.10, 0.30)	23.2 (-42.9, 89.2)[f]	***	0.53***
Leafy cruciferous vegetables	26.8 (5.4, 53.6)	0.0 (0.0, 6.3)	0.44	0.36 (0.25, 0.47)	22.3 (-25.2, 69.7)[g]	***	0.74***
Other vegetables	23.8 (9.5, 47.5)	29.0 (1.7, 55.8)	0.37	0.27 (0.17, 0.37)	-5.8 (-99.2, 87.5)	*	-0.33***
Root vegetables	88.4 (46.2, 125.7)	54.9 (22.1, 99.2)	0.33	0.27 (0.16, 0.38)	28.1 (-103.5, 159.6)[e]	***	0.06
Salad vegetables	39.8 (15.9, 79.6)	14.4 (1.9, 44.1)	0.46	0.36 (0.27, 0.45)	27.81 (-80.3, 135.9)[f]	***	0.26***
Tomatoes	43.9 (17.6, 87.9)	23.8 (3.4, 50.0)	0.42	0.26 (0.16, 0.35)	26.1 (-104.8, 157.0)[e]	***	0.19**

[a] All Spearman correlation coefficients $P<0.001$. Outcomes: good rho≥0.50; acceptable rho 0.20-0.50; poor rho<0.20.

[b] Weighted kappa (K_w) outcomes: good $K_w \geq 0.60$; acceptable K_w 0.20-0.60; poor $K_w<0.20$. CI = 95% confidence intervals.

[c] Limits of agreement being ±2 standard deviations of the mean difference of dietary pattern scores.

[d] a significant positive slope indicates the mean difference increases as the average intake increases. A significant negative slope indicates the mean difference decreases as the average intake increases.

Effect size of daily intake mean difference measured with Cohen d: [e] small effect (0.20≤d<0.50); [f] medium effect (0.50≤d<0.80); [g] large effect (d≥0.80).

FFQ1 = initial food frequency questionnaire (test), 4-DFR = 4-day food record (4 consecutive days, including one weekend day) completed in the month after FFQ1 completion (validation reference), REACH = Researching Eating, Activity, and Cognitive Health.

Levels of significance: *$P<0.05$; **$P<0.01$; ***$P<0.001$

4.5. Discussion

This validation study has described three dietary patterns derived using principal component analysis from data collected through two administrations of the REACH FFQ and a 4-DFR in 294 older New Zealand adults. Overall, the FFQ demonstrated good reproducibility for the 'Western' and 'prudent' dietary patterns (good Spearman correlations and acceptable weighted Kappa) whereas, the 'Mediterranean style' dietary pattern had acceptable reproducibility (acceptable Spearman correlations and acceptable weighted Kappa). All dietary patterns had acceptable relative validity (acceptable Spearman correlations and acceptable weighted Kappa). Differences in dietary pattern scores across dietary assessment methods were consistent across participants with low versus high adherence to the 'Western' and 'Mediterranean style' dietary pattern, although the differences between dietary assessment tools did decrease as mean intake on the 'prudent' dietary pattern scores increased.

The first pattern consisted of vegetables, fruits, berries, nuts, seeds, and fish – all components of a Mediterranean diet (Bach-Faig et al., 2011) and was named 'Mediterranean style'. Other *a posteriori* dietary patterns have used the term 'Mediterranean' as their dietary pattern name. A 'Spanish-Mediterranean' pattern from the Spanish SUN cohort (Sanchez-Villegas et al., 2003) contained vegetables, fish, poultry, olive oils, nuts, and potatoes; a 'Mediterranean' pattern from a Greek cohort (Bountziouka et al., 2011) contained low-fat dairy, whole grains, fish and seafood, vegetables, and fruit; and another 'Mediterranean style' pattern from the United Kingdom Lothian Birth Cohort (Corley et al., 2013) contained vegetables, oil and dressings, fish, poultry, rice and water. The second pattern derived was named 'Western', having higher loadings on less healthy food groups and the third pattern was named 'prudent', having higher loadings on healthy food groups. It is common to find dietary patterns containing 'healthy' and 'less healthy' foods where the 'healthy' food pattern is characterized by higher intakes of fruits and vegetables and lower red and processed meat intakes, similar to the 'Mediterranean style' and 'prudent' patterns. The 'Western' pattern is similar to the 'less healthy' food patterns observed in other studies containing higher intakes of red and processed meat, refined grains, high-fat dairy and less fruits and vegetables (Fernandez-Villa et al., 2020, Edefonti et al., 2019).

Together, the three dietary patterns explained 18%, 18% and 14% of the variation in the FFQ1, FFQ2 and 4-DFR dietary data, respectively. The level of variation is dependent upon the number of food groups entered into the principal component analysis – this is a trade off as the number of food groups is inversely related to the percent variation explained. While 57 food groups is on the higher end of the food group range for dietary patterns (Edefonti et al., 2019), the resulting percent

variation explained is comparable to other studies with a higher food group count (Beck et al., 2018b, Thorpe et al., 2019, Roberts et al., 2018). Including more food groups can better represent the diversity of available foods.

These presented results for the reproducibility and validity of the de rived dietary patterns were comparable to other principal component analysis derived dietary pattern validation studies. Correlation coefficients for dietary pattern scores in earlier reproducibility studies have ranged from 0.55 to 0.84 (Beck et al., 2012, Hu et al., 1999, Mills et al., 2015, Nanri et al., 2012, Niedzwiedzka et al., 2019). These reproducibility studies covered 2 (Niedzwiedzka et al., 2019), 4 (Beck et al., 2012) and 5 weeks (Mills et al., 2015), and 1-year (Hu et al., 1999, Nanri et al., 2012) periods. The 'Western' pattern coefficient fell within this range (P<0.001, rho = 0.59) whereas the 'Mediterranean style' and 'prudent' pattern coefficients were slightly lower, but still significant (P<0.001, rho =0.47 and 0.51). Correlation coefficients for dietary pattern scores in earlier validity studies have ranged from 0.22 to 0.69 (Bountziouka et al., 2011, Mills et al., 2015, Okubo et al., 2010, Beck et al., 2012, Crozier et al., 2008, Nanri et al., 2012, Loy and Mohamed, 2013, Korkalo et al., 2019, Hu et al., 1999). All correlation coefficients fitted within this range (rho = 0.33 'Western' to 0.43 'prudent'). Weighted kappa statistics for dietary pattern scores in earlier dietary pattern validity studies have ranged from 0.45 to 0.65 (Beck et al., 2012, Liu et al., 2015) for reproducibility and 0.37 to 0.72 (Beck et al., 2012, Liu et al., 2015, Loy and Mohamed, 2013) for validity. The weighted kappa statistic for reproducibility was 0.40 for 'Mediterranean style' and 0.48 for 'Western' and 'prudent'. The validity scores were lower, ranging from 0.27 'Western' to 0.37 'prudent'. The limits of agreement for dietary pattern scores ranged from ± 1.79 to ± 2.09 for reproducibility and ± 2.09 to ± 2.27 for validity. This is within the range of other dietary pattern studies for validity (± 1.31 to ± 2.41) (Ambrosini et al., 2011, Asghari et al., 2012, Beck et al., 2012, Bountziouka et al., 2011, Crozier et al., 2008, Liu et al., 2015, Loy and Mohamed, 2013, Okubo et al., 2010) but outside the range for reproducibility (± 0.88 to ± 1.46) (Beck et al., 2012, Liu et al., 2015). This suggests the mean of the FFQ1 dietary pattern scores and FFQ2 dietary pattern scores had greater variability and thus poorer reproducibility compared with other studies.

The FFQ food groups showed good reproducibility, based on a mean correlation of 0.69 (good) and mean weighted kappa of 0.62 (good), and acceptable relative validity, based on a mean correlation of 0.45 (acceptable) and mean weighted kappa of 0.38 (acceptable), though caution is required when measuring precise food group intakes as many food groups had Bland Altman plots showing bias or a mean difference significantly different to zero. A higher relative validity compared with absolute validity is expected as FFQs have better ranking ability (relative) than determining absolute intake of food groups at an individual level (McNaughton et al., 2005). The ability to rank

participants is imperative in studies exploring the association between the diet and disease (Willett, 2012b, Lombard et al., 2015). Higher reproducibility compared with validity is expected (Edefonti et al., 2019). Reproducibility uses a repeated dietary assessment tool while validation requires two different dietary assessment tools which have differences in administration, diet period covered, number of food items collected, different data preparation processes for principal component analysis, and different types of error (Willett, 2012b). These differences were demonstrated in this study where the average correlation coefficient and weighted kappa were higher in FFQ1 v FFQ2 (rho = 0.69 and $\kappa_w = 0.62$) than the FFQ1 v 4-DFR (rho = 0.45 and $\kappa_w = 0.38$). Earlier studies validating an FFQ in an older population have found similar magnitudes in reproducibility with average correlation coefficients ranging from 0.61 to 0.70 (Hu et al., 1999, Khani et al., 2004) and in validity with average correlation coefficients ranging from 0.33 to 0.46 (Hu et al., 1999, Khani et al., 2004, Talegawkar et al., 2015, Kobayashi et al., 2019, Eysteinsdottir et al., 2012).

The chosen reference method, a consecutive 4-day food record (including one weekend day), was used to test the validity of the FFQ for measuring food groups and their derived dietary patterns. A consecutive 4-DFR may include left-overs and meals reflecting the previous day, thus limiting the within person variation and reducing the diversity of correlations available for principal component analysis. Correlations within the data drive the principal component analysis and may explain the lower KMO measure of sampling adequacy for the 4-DFR data (KMO = 0.54) compared with the FFQ1 data (KMO = 0.63). Liu et al. (2015) and Hong et al. (2016) found similar food intake across three days while using a three consecutive day 24-hr recall and a lower KMO for their 24-hr recall data compared with their FFQ data. A four-day period also does not capture infrequently consumed foods. This affected food items such as 'beer', 'fish', 'berries', 'dried fruit', 'stone fruit', 'fresh, frozen legumes' and 'leafy cruciferous vegetables' which were reported to have been consumed over the month in the FFQ data but appeared infrequently in the 4-DFR, reducing the apparent validity of the FFQ for measuring food groups and their derived dietary patterns.

A one-month interval was chosen between FFQs. The interval was long enough for participants to not recall the initial FFQ responses and short enough to minimize any substantial changes in the diet (Cade et al., 2002). The FFQ2 covered the month when the 4-DFR was completed so may have provided better validity as recommended by Cade et al. (2002), and demonstrated by Hu et al. (1999) and Liu et al. (2015), but the FFQ1 was chosen as the test dietary assessment tool to avoid any influence the completion of the food record may have had on responses to the FFQ2. The choice of FFQ1 over FFQ2 has been reported in other studies (Appannah et al., 2014, Beck et al., 2012, Korkalo et al., 2019, Loy and Mohamed, 2013, Mills et al., 2015, Khani et al., 2004).

Earlier dietary pattern validation studies have not previously explored the similarity of the dietary pattern loadings using an objective statistical methodology (Edefonti et al., 2019). Where the loadings were acknowledged, it was typical to visually assess them and report the loadings as 'similar' (Hong et al., 2016, Beck et al., 2012, Okubo et al., 2010), 'comparable' (Crozier et al., 2008) or 'consistent' (Liu et al., 2015) with any variation likely due to methodologic differences or random statistical variations (Willett, 2012b). Khani et al. (2004) calculated mean differences between dietary pattern loadings for three patterns but did not use statistical analysis to determine whether the mean differences were significantly different to zero. Evaluating the similarity of dietary pattern loadings requires a clear statistical method, such as that reported in the current study. To date, this has been a gap in the methodology of dietary pattern validation. Tucker's congruence coefficient is normally used as a comparison index between factor loadings (Lorenzo-Seva and ten Berge, 2006). Studies investigating dietary patterns have used Tucker's congruence coefficient to explore the generalizability of a pattern across a larger population (Johnson et al., 2018, Judd et al., 2014, Eng et al., 2018) or the reproducibility of a dietary pattern in the same (Ancira-Moreno et al., 2020) or a similar (Castelló et al., 2016, Ancira-Moreno et al., 2020) population, or a different population with ethnic (Whitton et al., 2018) or gender (Begdache et al., 2020) differences. The statistical coefficient cut-off point for factor similarity is generally high with a coefficient phi ≥ 0.80 or 0.85 (Lorenzo-Seva and ten Berge, 2006) though one dietary pattern study considered phi ≥ 0.50 as acceptable (Judd et al., 2014). This study used Tucker's congruence coefficient to test for loading similarities between dietary patterns derived from different dietary assessment tools, and found coefficients ranged from 0.54 to 0.80. As loadings have not previously been compared statistically in dietary pattern validation studies, a suitable range of congruence coefficient acceptability is yet to be established, therefore more research is recommended in this area of dietary pattern validation.

Tucker's congruence coefficient found the dietary pattern loadings for FFQ1 and 4-DFR 'Western' and 'prudent' dietary patterns to be least similar (phi ≤ 60). This may be because the food items associated with these loadings may be consumed with higher frequency e.g., "2-3 times per DAY", "4-5 times per DAY", or "6 plus times per DAY" thus, the FFQ data maybe distorted when converted to grams per day. Also, the 4-DFR resulted in reduced diversity of foods because similar meals were being eaten over consecutive days. Both these items may affect the correlations which drive the principal component analysis. The KMO measure reflects the reduced data sampling adequacy as the 4-DFR had a lower KMO measure than the FFQ1 (0.54 v 0.63).

Validation and reproducibility studies require several statistical tests to cover the facets of validity and determine the level of confidence in the test method. Using various approaches to consider ranking (relative) ability and absolute agreement of the dietary assessment tools was a strength in

this study. Other areas of strength include the analysis of the dietary pattern loadings to ensure similarity of dietary patterns alongside examining the similarity and agreement of dietary pattern scores. There was a high completion rate with 79% of participants completing all three dietary assessments. Limitations include the subjective decisions that are made when deriving the dietary patterns, such as: food grouping, rotation method, number of factors to retain, factor loading interpretation, and naming of dietary patterns. Three dietary patterns from 57 food groups explained 18% of variation in the diet, minor dietary patterns were not reported as they were less interpretable and explained a smaller percent of diet variation. Additionally, the dietary patterns are specific to this cohort. There is no defined gold standard method in validation studies (Cade et al., 2002) but comparing a FFQ and 4-DFR limits common measurement errors such as question interpretation and memory reliance found in FFQs but not when completing a 4-DFR. However, the 4-DFR had limitations with consecutive days potentially comprising similar dietary intakes. While the sample was a convenience sample, the sample size (*n* 294) was considerably higher than the recommended 100 to 200 participants for validation studies (Willett, 2012b, Cade et al., 2002). Future use of the FFQ may require further validation if used in another population.

4.5.1. Conclusion

To conclude, this study used a variety of statistical tools to examine relative validity and reproducibility of a food frequency questionnaire designed to identify dietary patterns in older adults. In addition, the study's dietary pattern validation method objectively examined the similarities of the dietary pattern loadings from the test and reference dietary assessment tools, though further research for this approach is recommended. The findings suggest the REACH FFQ is reproducible and relatively valid with the ability to rank dietary intake over a range of food groups, making this dietary assessment tool suitable to collect data for the construction of *a posteriori* dietary patterns. Additionally, the derived FFQ dietary patterns were reproducible and relatively valid when tested against dietary patterns derived using a 4-DFR. The REACH dietary patterns derived from the FFQ are therefore appropriate for use in the examination of associations between the diet and disease in an older New Zealand population.

4.6. References

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Chapter Five: Dietary patterns, their nutrients, and associations with socio-demographic and lifestyle factors in older New Zealand adults

After examining the reproducibility and relative validity of the dietary assessment tool and its derived dietary patterns, further characteristics of the dietary patterns could be identified to bring a broader understanding of the patterns and who were likely to be following them.

This chapter presents the REACH dietary patterns and the nutrients associated with those patterns. Associations between the dietary patterns and socio-demographic and lifestyle factors were explored. This chapter is presented in manuscript format and was published in a special issue of Nutrients – Selected Papers from 2019 Annual Scientific Meeting of the Nutrition Society of New Zealand: Beyond Nutrition – kei tua i te kaitōtika) (November 2020). This open access article is distributed under a Creative Commons Attribution Licences which permits unrestricted reproduction, provided the work is properly cited.

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To align with this thesis, there are slight changes to formatting, layout, and referencing style of the original manuscript.

5.1. Abstract

Background: Dietary patterns analyse combinations of foods eaten. This cross-sectional study identified dietary patterns and their nutrients.

Methods: Associations between dietary patterns and socio-demographic and lifestyle factors were examined in older New Zealand adults. Dietary data (109-item food frequency questionnaire) from the REACH study (*n* 367, 36% male, mean age = 70 years) were collapsed into 57 food groups. Using principal component analysis, three dietary patterns explained 18% of the variation in diet. Dietary pattern associations with sex, age, employment, living situation, education, deprivation score, physical activity, alcohol, and smoking, along with energy-adjusted nutrient intakes, were investigated using regression analysis.

Results: Higher 'Mediterranean style' dietary pattern scores were associated with being female, higher physical activity, and higher education ($P<0.001$, $R^2 = 0.07$). Higher 'Western' pattern scores were associated with being male, higher alcohol intake, living with others, and secondary education ($P<0.001$, $R^2 = 0.16$). Higher 'prudent' pattern scores were associated with higher physical activity and lower alcohol intake ($P<0.001$, $R^2 = 0.15$). There were positive associations between beta-carotene equivalents, vitamin E, and folate and 'Mediterranean style' dietary pattern scores ($P<0.001$, $R^2 \geq 0.26$); energy intake and 'Western' scores ($P<0.001$, $R^2 = 0.43$); and fibre and carbohydrate and 'prudent' scores ($P<0.001$, $R^2 \geq 0.25$).

Conclusion: Socio-demographic and lifestyle factors were associated with dietary patterns. Understanding relationships between these characteristics and dietary patterns can assist in health promotion.

5.2. Background

Non-communicable diseases are a large contributor to the global burden of disease in the ageing population, so it is important to understand the role of associated and modifiable risk factors, such as nutrition, which may minimise this burden (FAO and WHO, 2019, World Health Organization, 2015). Dietary pattern analysis explores the complete diet, complementing the traditional single food or nutrient approach (Newby and Tucker, 2004), and is commonly used to examine diet–disease associations e.g., bone mineral density (Fabiani et al., 2019), cognitive health (Chen et al., 2018), and sarcopenia (Bloom et al., 2018) in older adults.

There are two main approaches to dietary pattern analyses. A hypothesis driven approach (*a priori*) uses a pre-defined scoring system, often based on dietary guidelines, to determine adherence to a diet e.g., the Healthy Eating Index (Kennedy et al., 1995). The second approach is data driven (*a posteriori*), reducing the dimensionality of many food groups to a few patterns while keeping as much variability within the diet as possible. Using dietary data from the study population, the *a posteriori* approach characterises the diet and eating habits specific to the study population rather than relying on current knowledge, as with the *a priori* approach (Hu, 2002).

Several studies in older adults have explored dietary patterns and associated socio-demographic and lifestyle factors. Higher education, income, and physical activity have consistently been associated with 'healthy', 'vegetable based', and 'prudent' dietary patterns (Allès et al., 2016, Andreeva et al., 2016, Bamia et al., 2005, Cai et al., 2007, Kell et al., 2015, Markussen et al., 2016, Park et al., 2005, Pryer et al., 2001, Thorpe et al., 2016, Bishop et al., 2020), whereas smoking is associated with 'Western', 'junk', and 'traditional/white bread' dietary patterns (Allès et al., 2016, Andreeva et al., 2016, Cai et al., 2007, Markussen et al., 2016, Park et al., 2005, Thorpe et al., 2016). In a New Zealand population of adults (15+ years), associations between socio-demographic factors and 'healthy' and 'traditional' dietary patterns were found (Beck et al., 2018). Age was positively associated with both a 'healthy' and 'traditional' dietary pattern, therefore, more research to understand the specific dietary patterns of the older New Zealand population would be of interest. Ageing is associated with a number of physiological, psychological, and other changes, including loss of functionality, changes in living situation, e.g., loss of spouse, and possible dietary changes to support a health condition, such as lowering blood pressure (World Health Organization, 2015). Older populations also have distinct challenges and dietary needs e.g., higher calcium requirements (National Health and Medical Research Council et al., 2006), and therefore, may have their own unique dietary patterns compared with the general population. There is limited research investigating the dietary patterns of older adults living in New Zealand. Targeting nutrition

interventions based on demographics may improve dietary intervention outcomes, especially when the demographics are specific to a sub-group of a population (Beck et al., 2018).

The aim of this study was to identify and describe the dietary patterns in an older, community-dwelling New Zealand population, including the nutrient differences across the dietary patterns, and to examine associations between dietary patterns and socio-demographic and lifestyle factors.

5.3. Methods

5.3.1. Study design and participants

The REACH study is a cross-sectional study that aims to explore associations of *a posteriori* dietary patterns with cognitive function and metabolic syndrome in older adults. The protocol and methodology of the REACH study have been published (Mumme et al., 2019) and are outlined here. The study population was a convenience sample, which included 65- to 74-year-old men and women living independently (i.e., in the community) in Auckland, New Zealand. Exclusion criteria included a diagnosis of any condition which may impair cognitive function or any event in the previous two years which may impact dietary intake. Informed written consent was obtained from all REACH participants. Massey University Human Ethics Committee granted ethical approval: Southern A, Application 17/69. All participants visited the Massey University Human Nutrition Unit in Auckland on one occasion.

5.3.2. Socio-demographics and lifestyle data

Socio-demographic and lifestyle data were collected by written questionnaire during the visit to the Human Nutrition Unit. A written questionnaire captured data about age, sex, ethnicity, highest education level, work situation (employed or volunteering, not working), living situation (alone, with others), deprivation score (Exeter et al., 2017), food insecurity (Parnell et al., 2001), physical activity (Craig et al., 2003), smoking status, and alcohol beverage intake.

The New Zealand Indices of Multiple Deprivation and the participant's residential address determined the area deprivation score based on seven domains: employment, income, crime, housing, health, education, and geographical access (Exeter et al., 2017). Eight indicator statements specific to a New Zealand population determined the level of food insecurity (Parnell et al., 2001). The International Physical Activity Questionnaire (short form) (Craig et al., 2003) measured physical activity levels. A physical activity score was calculated using metabolic equivalent of a task (MET-minutes), where one minute of activity is 3.3, 4.0, or 8.0 MET-minutes depending on exercise level: walking, moderate activity, and vigorous activity, respectively. One MET is the rate of energy

expended while at rest (Craig et al., 2003). Alcohol beverage intake (g/day) was calculated from the 109-item Food Frequency Questionnaire (FFQ) described below.

5.3.3. Dietary assessment

Dietary data were collected between April 2018 to February 2019 using an online 109-item FFQ representing the previous month's diet. The FFQ has been shown to have acceptable validity and reproducibility for determining dietary patterns (Mumme et al., 2021) and nutrient intakes (Yu, 2019). Daily intake (g/day) of each food item was calculated using frequency and serving sizes from the FFQ. The 10 frequency choices were "I never eat this food", "Not this month but I have sometimes", "1–3 times per month", "Once per week", "2–3 times per week", "4–6 times per week", "once per day", "2–3 times per day", "4–5 times per day", and "6 plus times per day". Portion sizes were guided by FOODfiles, the New Zealand Food composition database (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2016). Energy and nutrient values for each food item for each participant were calculated using the FOODfiles database (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2016) based on a representative food within that food item. For example, edam cheese represented the 'cheese' food item. Where necessary, a composite of foods was selected to represent the food item, e.g., 'bran-based cereals' was based on muesli, porridge, and sultana cereal. Average daily energy intake was considered implausible if <2,100 kJ (500 kcal) or >14,700 kJ (3,500 kcal) for women and <3,360 kJ (800 kcal) or >16,800 kJ (4,000 kcal) for men (Wijnhoven et al., 2018).

All nutrient values were adjusted for energy intake using the residual method. With this method, energy adjusted nutrient intakes are calculated as the residuals of a regression model where total energy intake is the independent variable and the absolute nutrient intake is the dependent variable (Willett, 2012). The daily intake of the 109 food items was collapsed into 57 food groups for dietary pattern analysis. Four members of the research team decided the food groups based on similarity of foods, their nutrient profile, and culinary use, e.g., nuts and seeds are eaten in similar circumstances (Newby et al., 2004) (Table 4.1).

5.3.4. Construction of dietary patterns

Based on correlations between food groups, principal component analysis reduces the dimensionality of food groups while retaining most of the variation within the diet. The data set was checked for suitability for principal component analysis using the Bartlett's test of sphericity, measuring the presence of relationships within the data, and the Kaiser–Meyer–Olkin, which measures the sampling adequacy.

Using R version 3.6.1 (R Core Team, 2019), the principal() function in the *psych* package (Revelle, 2020), and orthogonal varimax rotation (for ease of interpretation), dietary patterns from the data matrix of the 57 food groups (g/day) were derived from the FFQ. The factors (dietary patterns) retained were based on the scree plot, eigenvalues >1.0, and interpretability. Factor loadings for each food group represented the correlation between the factor (dietary pattern) and the food group. A factor loading ≥0.30 or ≤-0.30 was considered significant for this sample size (Stevens, 2009). Dietary pattern names were based on food groups with higher loadings and the diet that the food groups typified. Standardised dietary pattern scores were calculated for each participant for each dietary pattern using the regression method.

5.3.5. Statistical Analysis

Statistical analysis was performed using R version 3.6.1 (R Core Team, 2019) and R packages: *tidyverse* (Wickham et al., 2019), *car* (Fox and Sanford, 2019), and *s20x* (Balemi et al., 2020). Equality of variance and normality of residuals for regression models were assessed visually by graphing residuals and fitted values. No data were transformed prior to statistical analysis.

Participant characteristics were described by mean (standard deviation) for continuous characteristics, with a roughly symmetric distribution; median (25^{th}, 75^{th} percentile) for other continuous data; or number and percentage for categorical data. The Welch two-sample t-test or Pearson chi-squared test examined differences between the sexes for characteristic variables. With relatively large sample sizes in each group (women: *n* 235, men: *n* 132), the group means had approximately normal distributions as required by the t-test. Only categorical variables with adequate samples in each category were considered for the Chi-squared test. As the population was homogenous in terms of ethnicity and food security (Table 5.1), these two variables were not included in association analyses.

Linear regression was used to determine associations between energy adjusted nutrients (residuals method (Willett, 2012)) and dietary patterns. The adjusted R^2 was used to characterize the effect size of the associations. As multiple statistical tests were performed (*n* 96), Bonferroni adjustments were made where the p-values were multiplied by the number of tests. Adjusted *P*-values<0.05 were considered significant.

Multiple linear regression analysis was used to investigate associations between each dietary pattern score (dependent variable) and socio-demographic and lifestyle factors (independent variables). These included sex (male, female), age (years), physical activity score (tertiles), education (secondary, post-secondary, university), employment status (yes, no), living situation (alone, with others), index of multiple deprivation (score), alcohol consumption (g/day alcohol beverage intake),

and smoking status (current or past, no). Variables in the full regression model were checked for collinearity using the variance inflation factor (Fox and Sanford, 2019). Scores ranged from 1.01 to 1.23. As the average score was not substantially greater than one, no variables were considered collinear (Field, 2012). Sex interactions were tested for each categorical independent variable. The full regression model included all independent variables plus significant interaction terms. Using a backwards stepwise process, the term with the largest *P*-value was removed until all independent variables were significant. As several statistical tests were performed, a *P*-value <0.01 was considered statistically significant.

5.4. Results

5.4.1. Participants

A total of 371 participants took part in the REACH study. Four people were excluded due to not providing FFQ data. All participants had energy intakes within plausible parameters (Mumme et al., 2021, Wijnhoven et al., 2018). Most participants were New Zealand European and other (94%), and almost all were considered to be food secure (96%). Table 5.1 presents participant characteristics. Males were significantly older (*P*<0.01), and more likely to have a university education (*P*<0.001) and to live with others (*P*<0.001). They also consumed more alcohol beverages (*P*<0.001) and had a higher energy intake (*P*<0.01) than females.

Table 5.1: Characteristics of the participants (*n* 367) and the differences between males and females

Characteristic	Total mean (SD), median (25, 75) or *n* (%)	Male mean (SD), median (25, 75) or *n* (%)	Female mean (SD), median (25, 75) or *n* (%)
n	367	132	235
Age (years)‡**	69.7 (2.6)	70.1 (2.4)	69.4 (2.6)
Highest level of education‡***			
Secondary[a]‡	83 (23%)	18 (14%)	65 (28%)
Post-secondary	148 (40%)	49 (37%)	99 (42%)
University‡	136 (37%)	65 (49%)	71 (30%)
Employed (paid or volunteer)	179 (49%)	55 (42%)	124 (53%)
Ethnicity			
Asian	11 (3%)	5 (4%)	6 (3%)
European/other	346 (94%)	122 (92%)	224 (95%)
Māori/Pacific	10 (3%)	5 (4%)	5 (2%)
Index of Multiple Deprivation score[b]	3,831 (2,766)	3,943 (2,939)	3,768 (2,668)
Dietary pattern score			
Mediterranean style‡***	0.00 (1.00)	-0.22 (1.07)	0.13 (0.94)
Western‡**	0.00 (1.00)	0.45 (1.1)	-0.25 (0.84)

Prudent	0.00 (1.00)	-0.03 (1.2)	0.02 (0.87)
Living situation‡***			
alone	107 (29%)	18 (14%)	89 (38%)
with others	260 (71%)	114 (86%)	146 (62%)
Physical activity (MET minutes/week)[c]	3,097 (1,680, 5,118)	3,086 (1,774, 5,464)	3,107 (1,663, 5,037)
Smoker			
Yes (current or past)	78 (21%)	29 (22%)	49 (21%)
No	289 (79%)	103 (78%)	186 (79%)
Daily energy intake (kJ)‡**	7,578 (2,129)	8,044 (2,275)	7,315 (2,000)
Daily alcohol beverage intake (energy adjusted g/day)‡***	62 (18, 120)	100 (33, 212)	50 (12, 88)
Food security			
Secure	352 (96%)	129 (98%)	223 (95%)
Moderately secure	13 (4%)	2 (2%)	11 (5%)
Insecure	2 (1%)	1 (1%)	1 (0%)

‡ significant difference between sexes. Differences calculated using Welch two-sample t-test (continuous) or Pearson Chi-squared test (categorical).
P-value: *<0.05, **<0.01, ***<0.001
[a] 'no qualification' (n 9) and 'secondary' (n 74) aggregated because of small numbers
[b] Index of Multiple Deprivation (Exeter et al., 2017), low number = least deprived, range = 11 to 5,636
[c] Physical activity MET minutes/week based on 3.3 MET for walking, 4.0 MET for moderate activity and 8.0 MET for vigorous activity, MET = metabolic equivalence of a task

5.4.2. Dietary patterns

Principal component analysis identified three dietary patterns from the FFQ data, which explained 18% of the variation in dietary intake. The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.66, and Bartlett's test of sphericity was significant (P<0.001), indicating the dietary data set was suitable for principal component analysis. Table 5.2 displays the dietary pattern loadings, range of dietary pattern scores, eigenvalues, and the variance explained by each dietary pattern.

Table 5.2: Factor loadings for three major dietary patterns from the REACH study (n 367)

Food groups (n 57)[abc]	Mediterranean style	Prudent	Western
Salad vegetables	**0.64**		
Leafy cruciferous vegetables	**0.57**	0.23	
Other vegetables	**0.56**		
Avocados, olives	**0.51**		
Alliums	**0.47**	0.15	
Nuts, seeds	**0.45**	0.26	
White fish, shellfish	**0.45**		
Oily fish	**0.42**		
Berries	**0.41**		

Food groups (*n* 57)[abc]	Mediterranean style	Prudent	Western
Water	**0.40**	0.18	-0.16
Salad dressings	**0.39**	-0.18	**0.35**
Cruciferous vegetables	**0.39**	0.24	
Eggs	**0.34**		
Cheese	**0.33**	-0.18	**0.34**
Tomatoes	**0.33**		
All other fruit	**0.32**	0.22	
Dried legumes	0.15	**0.68**	
Soy-based foods		**0.65**	
Fresh, frozen legumes		**0.54**	0.20
Whole grains		**0.51**	0.24
Carrots	0.28	**0.48**	
Spices	0.23	**0.30**	
Processed meats		-0.29	**0.59**
Sauces, condiments	0.23		**0.52**
Cakes, biscuits and puddings	-0.26		**0.51**
Meat pies, chips	-0.28		**0.47**
Processed fish			**0.41**
Confectionery	-0.22		**0.39**
Vegetable oils			**0.36**
Beer		-0.21	**0.35**
Chocolate			**0.35**
Sweetened cereal	-0.19		**0.30**
Stone fruit	0.29		0.18
Apples, pears	0.26	0.28	
Dried fruit	0.23	0.25	
Butter, coconut	0.23	-0.20	
Yoghurt	0.19	0.16	
Root vegetables	0.17	0.29	0.24
Red wine	0.15	-0.27	0.16
Refined grains		0.29	0.21
Other milks (non-dairy)		0.28	
Poultry		0.21	0.15
Citrus fruit		0.21	
Bran cereal		0.20	
Bananas		0.17	
Tea, coffee		-0.21	0.21
Other alcohol		-0.21	

Food groups (*n* 57)[abc]	Mediterranean style	Prudent	Western
Red meat			0.29
Diet drinks			0.28
Sugary drinks			0.25
Milk			0.25
Snacks			0.24
Sweetened dairy products			0.20
Yeast spreads			
Creamy dairy			
Juices			
Soup			
Score range	-2.32 to 4.26	-2.49 to 8.31	-1.93 to 3.83
Variance explained	7.20	5.30	5.60
Eigenvalue	4.12	3.04	3.18

[a] **Loadings ≥0.30**. A higher loading indicates a greater contribution to the dietary pattern.
[b] Loadings|<0.15| excluded for ease in interpretation.
[c] Positive loadings are positively associated, and negative loadings are negatively associated with the dietary pattern.

Dietary pattern 1 included 'Mediterranean style' food groups. Positive loadings (≥ 0.30) were salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs; cheese; tomatoes; and all other fruit (Table 5.2). The 'Mediterranean style' dietary pattern was positively associated with energy, polyunsaturated and monounsaturated fats, fibre, total fat, cholesterol, folate, potassium, magnesium, selenium, iron, beta-carotene equivalents, vitamin A, vitamin E, vitamin C, and vitamin B6. Negative associations were observed with carbohydrate (Figure 4).

Dietary pattern 2 included 'Western' food groups. Positive loadings (≥0.30) were processed meat; sauces and condiments; cakes, biscuits, and puddings; meat pies and chips; processed fish; confectionery; vegetable oils; beer; chocolate; salad dressings; cheese; and sweetened cereal (Table 5.2). The 'Western' dietary pattern was positively associated with energy and sodium intake, and negatively associated with fibre, polyunsaturated fats, magnesium, potassium, folate, vitamin E, vitamin C, and beta-carotene equivalents (Figure 4).

Dietary pattern 3 included 'prudent' food groups. Positive loadings (≥0.30) were dried legumes; soy-based foods; fresh and frozen legumes; whole grains; carrots; and spices (Table 5.2). The 'prudent'

dietary pattern was positively associated with energy, fibre, carbohydrate, polyunsaturated fats, magnesium, iron, folate, thiamine, beta-carotene equivalents, vitamin E, and vitamin C and negatively associate with alcohol, saturated fat, total fat, cholesterol, monounsaturated fat, calcium, iodine, riboflavin, and vitamin B12 (Figure 4).

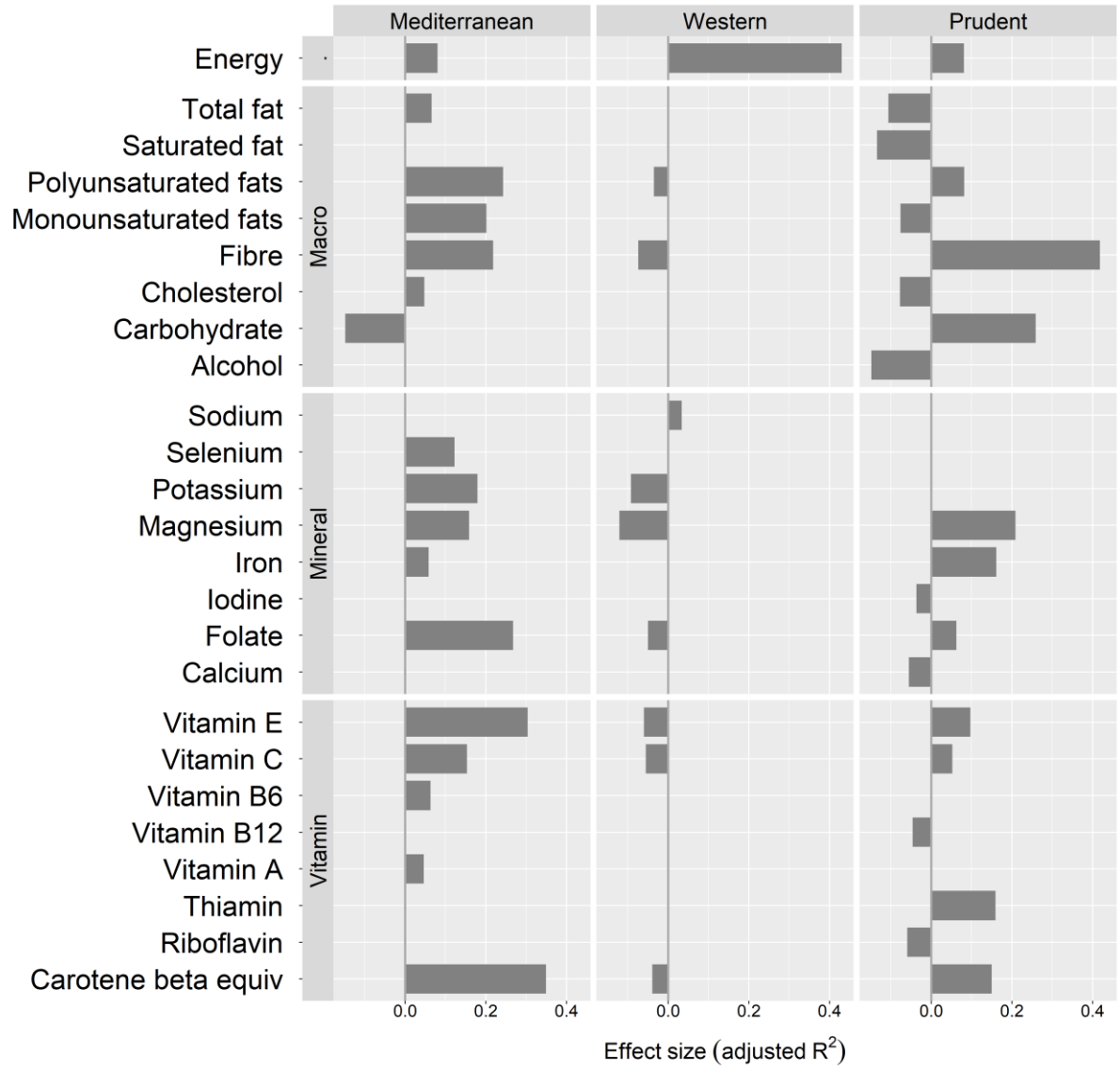

Figure 4: Associations between the dietary patterns and nutrient content.
The plot shows the effect size of correlations between nutrients and each dietary pattern i.e., linear change as dietary pattern scores increase. Nutrients are adjusted for energy intake using the residual method. Bars to the right of zero show a positive nutrient intake correlation to dietary pattern scores and bars to the left show a negative nutrient intake correlation to dietary pattern scores. The size of the bar shows the magnitude of the effect (adjusted R^2). All nutrients shown are significant after Bonferroni adjustment (adjusted *P*-value<0.05). Protein, sugar, zinc, phosphorus, retinol, niacin, and niacin equivalent were analysed but showed no associations. No interactions between sex and dietary pattern to nutrients were present.

A validation study using a subset of the REACH study (*n* 294) found dietary patterns obtained from the validated REACH FFQ to be reproducible and valid (Mumme et al., 2021). Additionally, the dietary patterns obtained from the validation study were comparable to those found in this manuscript. Tucker's congruence coefficient (phi) between the loadings of the FFQ derived dietary patterns (REACH FFQ validation subset vs. REACH full cohort) were 0.96, 0.91, and 0.88 for 'Mediterranean style', 'Western', and 'prudent' patterns, respectively.

5.4.3. Dietary patterns and socio-demographic and lifestyle factors

The 'Mediterranean style' pattern was positively associated with being female and having a higher physical activity tertile and a higher education (i.e., post-secondary or university). The 'Western' pattern was positively associated with being male, having a higher alcohol intake, and living with others. For males, secondary education predicted higher adherence to the 'Western' pattern compared with post-secondary or university education. This was not true for females (interaction, $P<0.01$).

The 'prudent' pattern was positively associated with a higher level of physical activity and lower alcohol intake (Table 5.3).

Table 5.3: Multiple linear regression model exploring association between dietary patterns and socio-demographic and lifestyle factors

'Mediterranean style' pattern Coefficient	Estimate	Standard error	*P*-value
Intercept	-0.37	0.14	0.007
Sex male	-0.42	0.11	0.001
Physical activity medium	0.21	0.12	0.097
Physical activity high	0.42	0.12	<0.001
Education post-secondary	0.39	0.13	0.004
Education university	0.44	0.14	0.002
Reference group (Intercept) is female, low physical activity and secondary education Adjusted R^2 = 0.07, *P*<0.001			
'Western' pattern Coefficient	Estimate	Standard error	p-value
Intercept	-0.37	0.12	0.003
Sex male	1.22	0.25	<0.001
Education post-secondary	0.13	0.15	0.371
Education university	0.33	0.16	0.035
Living alone	-0.30	0.11	0.006
Alcohol intake	0.00	0.00	0.005
Male : Education post-secondary	-0.86	0.29	0.003
Male : Education university	-0.83	0.29	0.004
Reference group (Intercept) is female, secondary education, living with others, lower alcohol intake Adjusted R^2 = 0.16, *P*<0.001			
'prudent' pattern Coefficient	Estimate	Standard error	p-value
Intercept	0.13	0.09	0.155
Physical activity medium	0.09	0.12	0.425
Physical activity high	0.37	0.12	0.002
Alcohol intake	-0.00	0.00	<0.001
Reference group (Intercept) is low physical activity and high alcohol intake Adjusted R^2 = 0.15, *P*<0.001			

5.5. Discussion

In our study of community-dwelling older adults living in Auckland, New Zealand, three dietary patterns were identified: 'Mediterranean style', 'Western', and 'prudent'. Positive associations were found between physical activity and both patterns containing healthy food groups i.e., 'Mediterranean style' and 'prudent.' Females were more likely to adhere to the 'Mediterranean style' pattern and males to the 'Western' pattern. Education (positive association with the 'Mediterranean style' pattern, negative association with the 'Western' pattern), alcohol consumption (positive association with 'Western', negative association with 'prudent'), and living alone (negative association with 'Western') were all associated with at least one dietary pattern.

There are different approaches to analysing sex in dietary pattern analysis, one being to derive separate patterns for men and women. The other, as followed in this study, is to derive combined sex dietary patterns with sex as a variable in the statistical analysis. The low dimensional summary of sex differences produced in this study makes the second approach more favourable. However, within this study, women were more likely to adhere to the 'Mediterranean style' and men to the 'Western' dietary pattern. Men and women are known to eat differently, and women have been shown to eat more fruit and vegetables than men in a general population (Baker and Wardle, 2003, Mc Morrow et al., 2016), and in a 51- to 70-year-old New Zealand population (but not 71+ years) (University of Otago and Ministry of Health, 2011). This may be due to women having greater nutrition knowledge (Baker and Wardle, 2003, Parmenter et al., 2000). However, studies in older adults do not always show a defined trend between sex and dietary patterns, as older women may follow 'vegetable-based' (Bamia et al., 2005), 'fruit and milk' (Park et al., 2005), 'sweet and fat dominated' (Bamia et al., 2005) or 'Western' (Allès et al., 2016) patterns, and men may follow 'fat and meat' (Whitelock and Ensaff, 2018) or 'prudent' (Parsons et al., 2019) patterns. The Three-City and NuAge studies did not find any sex differences in 'healthy', 'traditional', or 'Western' patterns (Allès et al., 2016).

Sex interactions between dietary patterns and socio-demographic or lifestyle factors are either not reported or not commonly examined. In this study, we found a significant sex interaction with education ($P<0.01$) when predicting the 'Western' pattern score. Having only a secondary education predicted a higher 'Western' score in men than women. In contrast, higher education predicted a higher 'Mediterranean style' score in both men and women. Higher education, an important determinant to eating a nutritious diet (Allès et al., 2016, Besora-Moreno et al., 2020, Granic et al., 2015, Hoenink et al., 2020), may bring better nutrition knowledge and an ability to earn a higher income allowing an opportunity to purchase healthier foods (Wardle et al., 2000). Dietary pattern

and education associations (excluding the sex interaction) found in the current study are consistent with other studies in older adults. 'Mixed', 'fat and meat', 'Western', and 'traditional' dietary patterns have frequently been associated with a lower education (Andreeva et al., 2016, Markussen et al., 2016, Park et al., 2005, Pryer et al., 2001), while dietary patterns comprising more healthy food groups, such as 'vegetable based', 'fruit and milk', 'plant-based', or 'healthy', are frequently associated with a higher education (Allès et al., 2016, Andreeva et al., 2016, Bamia et al., 2005, Cai et al., 2007, Park et al., 2005, Thorpe et al., 2016), although some exceptions have been reported. For example, 'convenience' (Kell et al., 2015), 'Continental' (Markussen et al., 2016), or 'Western' (Sanchez-Villegas et al., 2003) patterns have been associated with higher education in older adults.

Associations between dietary patterns and alcohol beverage intake are not often examined in older adults, possibly as alcohol beverages are usually included in the dietary pattern as a food group. For example, 'alcohol and salads' (REGARDS cohort, USA) (Kell et al., 2015), 'Western' (NutriNet-Sante cohort, France) (Andreeva et al., 2016), and 'Continental' (Norwegian Breast Screening Programme) (Markussen et al., 2016) patterns had positive loadings (≥ 0.30) for beer, wine, and alcoholic beverages, and negative loadings (≤ -0.30) were reported for wine in a 'Western' (Norwegian Breast Screening Programme) (Markussen et al., 2016) pattern. Using a daily alcohol beverage intake, the current study explored associations beyond the alcohol and food correlations found in a dietary pattern to determine whether alcohol was associated with the dietary pattern score in its own right. The 'prudent' and 'Mediterranean style' patterns did not have any significant food group loadings containing alcohol, yet alcohol beverage intake was lower in participants adhering to the 'prudent' pattern (P<0.001), and had no association to the 'Mediterranean style' pattern (P=0.93). Beer loaded significantly on the 'Western' pattern (loading = 0.35), and alcohol beverage intake was significantly higher in participants adhering to the 'Western' pattern (P<0.001). Two large studies, a multi-ethnic cohort (aged 45-75 years) in the United States (Park et al., 2005) and men (aged 40-74 years) in China (Cai et al., 2007), found higher alcohol intake in participants adhering to 'fat and meat', 'vegetables', and 'meat' dietary patterns, and lower intake in 'fruit and milk' and 'fruit' patterns.

In the general population, alcohol use and smoking behaviours co-occur regardless of the amount of alcohol consumed (Meader et al., 2016). Park et al. (2005). and Cai et al. (2007) also examined smoking associations and found that, of the five dietary patterns (with an alcohol association), four had parallel associations with smoking. The fifth pattern, 'vegetables', had a positive association with alcohol but a negative association with smoking. The current study did not show associations between dietary patterns and smoking (P>0.06), although there was a positive association between alcohol use and smoking (P=0.008, adjusted R^2 = 0.02).

No associations were observed between dietary patterns and age within the current study. Contrasting results have been reported in other studies in an older population (Andreeva et al., 2016, Bamia et al., 2005, Bishop et al., 2020, Cai et al., 2007, Markussen et al., 2016, Park et al., 2005, Pryer et al., 2001, Thorpe et al., 2016). The narrow age band of the REACH study (65-74 years) may have precluded observing any associations. The Wellbeing Eating and Exercise for a Long Life (WELL) study, an Australian study in 55- to 65-year-olds, reported a 'red meat, processed meat, white bread and hot chips' pattern was preferred by the younger men in that cohort (Thorpe et al., 2016).

No associations were observed between dietary patterns and the multiple deprivation scores. The Newcastle 85+ study found a 'low meat' dietary pattern to be associated with living in an affluent area according to the deprivation index, but this was attenuated when education was included in the model (Granic et al., 2015). Our deprivation score is based on residential address, but this has limitations, as several of our participants lived with family, which may not reflect their personal financial status. Another variable used to measure socio-economic factors is income. Other studies in older adults found higher income and education to be associated with healthy food group patterns ('fruit' and 'vegetable' patterns (males only) (Cai et al., 2007), and 'alcohol/salads' and 'plant-based' patterns (Kell et al., 2015)). In the Three-City and NuAge studies (Allès et al., 2016), a 'healthy' dietary pattern was associated with education but not income.

Our study found that living alone was more prevalent in women than men (χ^2 = 22.9, P<0.001). Additionally, participants living alone scored low on the 'Western' pattern and had no associations with the 'Mediterranean style' or 'prudent' patterns, hence may have a unique dietary pattern not captured by our analysis. Further enquiry may be required to investigate this. Living situations can change in older adults. The death of a spouse can dramatically change a lifestyle from living and sharing meals with someone to learning to cook and shop and eating alone. Living alone does not always mean an absence of nutrition knowledge or desire to eat well (Host et al., 2016), as shown in the handful of studies investigating the effect of living alone on dietary patterns in the older adult (Allès et al., 2016, Andreeva et al., 2016, Pryer et al., 2001). Two 'healthy' patterns have been associated with living alone (Allès et al., 2016, Andreeva et al., 2016), and a third study based in the United Kingdom found no association between dietary patterns and living situation (Pryer et al., 2001). In contrast, living alone has been associated with a higher nutrition risk through a reduced appetite, lower motivation to cook, and preparing simpler meals or perhaps eating more convenient foods (Wham and Bowden, 2011, Whitelock and Ensaff, 2018). This may be more likely for widowers living alone, as their spouse may have shopped and prepared meals (Wham and Bowden, 2011).

In a New Zealand context, a handful of studies have examined dietary patterns and socio-demographic factors. With regards to education and sex, our findings agree with earlier work by our group (Beck et al., 2018), where a higher education was positively and negatively associated with 'healthy' and 'traditional' patterns, respectively, and females were likely to follow the 'healthy' pattern, whereas males followed the 'traditional' pattern in a representative sample of New Zealand adults (*n* 4657, aged 15+ years). Alcohol was not considered as a stand-alone variable in that study, but the 'healthy' pattern had beer, cider, bitters, wine with a negative load (loading = -0.36), and there were negative associations with smoking and area deprivation (Beck et al., 2018). Other New Zealand dietary pattern and socio-demographic studies have primarily been in younger New Zealand women, pre-conception (Lim et al., 2020) and or in pregnancy (Thompson et al., 2010, Wall et al., 2016), and in young children (Noble et al., 2015).

In the current study, socio-demographic and lifestyle factors were associated with 7%, 16%, and 15% of the variation (adjusted R^2, Table 5.3) in the 'Mediterranean style', 'Western', and 'prudent' patterns, respectively. The education and sex variables and their interaction explained most of the variation in the 'Western' pattern, and the negative alcohol beverage intake association explained most of the variation in the 'prudent' pattern. Not all studies report the adjusted R^2 for their multiple regression models. This is unfortunate, as socio-demographic and lifestyle factors do not occur singularly (Noble et al., 2015, Prendergast et al., 2016) and understanding the magnitude of impact for the variety of factors affecting diet and health outcomes can create more efficient and effective public health interventions. For the studies that have reported the variation explained, the R^2 ranged from 1 to 44% (Esmaili et al., 2015, Krieger et al., 2019, Whichelow and Prevost, 1996). Other factors explaining food choice include quality and price of food available, family preferences and taste, trying to eat healthy (Lennernäs et al., 1997), and physical disability limiting access to food (Bishop et al., 2020, Darmon and Drewnowski, 2008).

By understanding how demographic and lifestyle factors influence dietary patterns in the older New Zealand adult, nutrition interventions and health policy can target subsets of the population to shift people along the scales towards a healthier pattern (Beck et al., 2018). For example, men and those with a low education status. Alternatively, these subsets of the population explained most of the variation in the 'Western' dietary pattern which was characterised highly by processed meats; sauces and condiments; and cakes, biscuits, and puddings. These food groups contribute high amounts of saturated fat, sugar, and salt. Encouraging the reformulation of foods perhaps through a government led initiative to reduce the saturated fat, sugar and sodium content could provide health benefits without participant input (Steele et al., 2020, Mackay et al., 2021).

Exploring dietary patterns by nutrient content helps achieve an in depth understanding of the differences between the dietary pattern scores and daily nutrient intake. Additionally, this descriptor may add value if investigating diet–disease associations. As expected, a high fibre intake was associated with a dietary pattern rich in vegetables, fruit, and whole grains, such as the 'Mediterranean style' and 'prudent' patterns. The 'Mediterranean style' pattern was strongly associated with unsaturated fats and vitamin E, likely from high loadings of nuts, seeds, avocados, olives, and oily fish. The 'Western' pattern was strongly associated with energy intake and had small negative associations with fibre, potassium, and magnesium. The 'prudent' pattern was associated with a low-fat, high carbohydrate profile, which was supported by high frozen or fresh legumes, and whole grains loadings.

Hu et al. (1999) examined the correlations between dietary pattern scores and nutrient intake in their inaugural validation study of dietary patterns. The 'prudent' pattern in the Health Professional Follow-up study (males, aged 45-75 years) (Hu et al., 1999), characterised by vegetables, legumes, whole grains, fruit, and fish, had similar nutrient associations to our 'prudent' pattern, such as higher fibre and lower total fat. While their 'Western' pattern, characterised by processed and red meat, high-fat dairy products, and refined grains, showed similarities to our 'Western' pattern, Hu et al. also observed a positive association with total and saturated fats that we did not. The nutrient associations with the 1946 British Birth cohort study (53+ years) (McNaughton et al., 2005) patterns 'health aware' and 'refined' were similar to those for our 'Mediterranean style' and 'Western' patterns. The 'healthy—France' and 'healthy—Quebec' nutrient patterns (from the Three-City and NuAge studies, aged 65+ years) had similar nutrient contents to the REACH 'prudent' pattern, with increased carbohydrate, fibre, iron, and magnesium and reduced saturated and monounsaturated fat intake (Allès et al., 2019). Those two patterns also showed increased protein and calcium intake, but these were not apparent for our 'prudent' pattern, which showed no or a reduced association with these nutrients.

A major strength of this study is the reproducibility and relative validity of the dietary patterns. The FFQ was validated specifically for dietary patterns (Mumme et al., 2021) as well as nutrient intake (Yu, 2019). Additionally, a high response rate was achieved, and this study focused on obtaining an in-depth understanding of a specific life stage. Limitations of this study include the subjective decisions required for principal component analysis, such as food grouping, rotation method, number of factors to retain, factor loading interpretation, and naming of dietary patterns. *A posteriori* dietary patterns are specific to a study population and cannot be generalised. Three dietary patterns (57 food groups) explained 18% of variation in the diet, and minor dietary patterns were not reported, as they were less interpretable and explained a small percent of diet variation.

When calculating the nutrient intake, the nutrients allocated to each food item were representative of the food item rather than attempting to capture all foods. Lastly, a convenience sample was used, limiting the variability in some variables e.g., ethnicity and the generalisability of this study's results. As study participants were volunteers, they may have been more health conscious than the general population, and perhaps this was a reason why two of the three dietary patterns contained healthy foods. Future studies could supplement these findings with additional determinants of diet, such as diet cost and physical functionality, to broaden the dietary pattern picture in the older adult. Additionally, a study in a larger, more representative population group (as demonstrated in Beck et al. (2018)) with a wider age range would allow further exploration of ethnicity, living situations, and alcohol consumption.

5.5.1. Conclusion

In conclusion, this study is the first to investigate dietary patterns in the older New Zealand population. Dietary patterns were associated with socio-demographic and lifestyle factors in the REACH cohort. A 'Mediterranean style' pattern was associated with being female and having higher physical activity and higher education; a 'Western' pattern was associated with being male, having higher alcohol intake, living with others, and having only secondary education; and a 'prudent' pattern was associated with higher physical activity and lower alcohol intake. Nutrition policy and public health nutrition should understand associations between dietary patterns and socio-demographic and lifestyle factors, so interventions can target subsets of the population to perhaps shift people along the scales towards a healthier pattern (Beck et al., 2018) or specific food groups can be targeted for healthier reformulation.

5.6. Graphical abstract

A graphical abstract was developed after this paper was published. The abstract was an exercise to visually describe the paper. It was used in social media postings and Nutrients have added it as a figure to the publication.

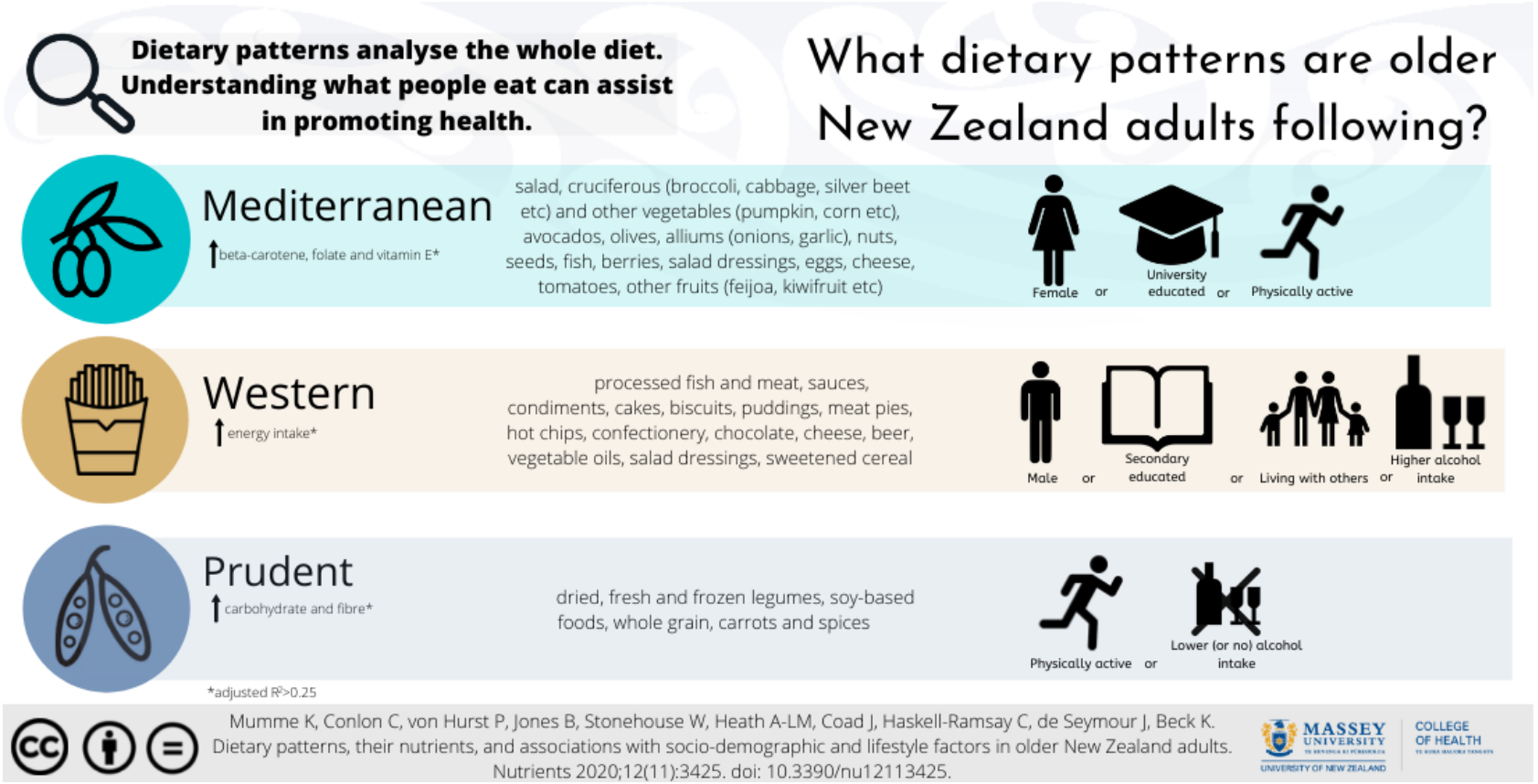

Figure 5: Graphical abstract for "Dietary patterns, their nutrients, and associations with socio-demographic and lifestyle factors in older New Zealand adults"

5.7. References

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Chapter Six: Dietary patterns and cognitive function study

This chapter presents the main finding of the REACH study – are there associations between the dietary patterns and cognitive function in the older adult? The chapter is presented in manuscript format. This manuscript is currently under review with the European Journal of Nutrition (submitted 17 May 2021).

Mumme, K., Conlon, C., von Hurst, P., Jones, B., Haskell-Ramsay, C., de Seymour, J., Stonehouse, W., Heath, A.-L. M., Coad, J., Mugridge, O., Slade, C., Gammon, C., & Beck, K. 2020. Dietary patterns and cognitive function in older New Zealand adults: the REACH study. *European Journal of Nutrition* (under review)

To align with this thesis, there are slight changes to formatting, layout, and referencing style of the currently submitted manuscript.

6.1. Abstract

Background: The global population is ageing. Evidence shows dietary patterns may be associated with cognitive status in older adults.

Objective: This cross-sectional study investigated associations between dietary patterns and cognitive function in older adults in New Zealand.

Methods: The REACH study included 359 participants (65-74 years, 36% male) living independently in Auckland, New Zealand. Valid and reproducible dietary patterns were derived, using principal component analysis, from dietary data collected by a 109-item validated food frequency questionnaire. Six cognitive domains (global cognition, attention and vigilance, executive function, episodic memory, working memory, spatial memory) were tested using COMPASS (Computerised Mental Performance Assessment System). Associations between dietary patterns and cognitive scores, adjusted for age, sex, education, physical activity, energy, and Apolipoprotein E -ε4 status were analysed using multiple linear regression analysis.

Results: Three dietary patterns explained 18% of dietary intake variation – 'Mediterranean style' (comprising: salad vegetables, leafy cruciferous vegetables, other vegetables, avocados and olives, alliums, nuts and seeds, white fish and shellfish, oily fish, and berries); 'Western' (comprising: processed meats, sauces and condiments, cakes, biscuits and puddings, meat pies and chips, and processed fish); and 'prudent' (comprising: dried legumes, soy-based foods, fresh and frozen legumes, whole grains, and carrots). No associations between any cognitive domain and dietary pattern scores were observed. Global cognitive function was associated with being younger and having a university education.

Conclusion: In this cohort of community-dwelling, older adults in New Zealand, current dietary patterns were not associated with cognitive function.

6.2. Background

Age-related cognitive decline, mild cognitive impairment and dementia are progressive, increase with age, and have limited pharmacological and non-pharmacological treatments (Horr et al., 2015). With an ageing population worldwide, it is important that specific lifestyle and dietary strategies are found that may prevent or slow cognitive decline and the onset of dementia (Winblad et al., 2016), thereby reducing the burden of these conditions.

Age and genetic factors, for example being an Apolipoprotein E *(APOE)* -ε4 carrier, are non-modifiable risk factors for age-related cognitive decline (Winblad et al., 2016, Small et al., 2004, Wisdom et al., 2011). Modifiable risk factors include physical activity, smoking, and diet (Norton et al., 2014, Stephan and Brayne, 2014). Many individual foods and nutrients have been identified which affect cognitive function (Solfrizzi et al., 2017, Cao et al., 2016, Francis and Stevenson, 2013, Wu et al., 2017). However, the diet consists of many foods working interactively and synergistically.

The dietary pattern approach provides a complementary method to the 'traditional' nutrient approach of assessing associations between diet and disease and acknowledges the complexities of food combinations (Hu, 2002, Milte and McNaughton, 2016). *A priori* dietary patterns use a dietary index created from known nutritional knowledge (Newby and Tucker, 2004), whereas *a posteriori* techniques use statistical methods such as principal component analysis to reduce measures of many foods within a study population into dietary patterns (Hu, 2002, Newby and Tucker, 2004). Adherence to *a priori* dietary patterns, such as the Mediterranean Diet, Dietary Approaches to Stop Hypertension (DASH) and the Mediterranean-DASH diet Intervention for Neurodegenerative Delay (MIND) diets have shown associations with reduced cognitive decline and Alzheimer Disease rates (Solfrizzi et al., 2017, Chen et al., 2018).

More specifically, studies exploring links between *a posteriori* dietary patterns and cognitive function have reported mixed findings. In older adults, higher cognitive function or reduced risk of cognitive impairment has been associated with dietary patterns comprising vegetables, fruits, and fish in European or North American (Kesse-Guyot et al., 2012, Samieri et al., 2008, Parrott et al., 2013, Corley and Deary, 2020, Kesse-Guyot et al., 2014), Australian (Ashby-Mitchell et al., 2015, Chen et al., 2020) and Asian populations (Okubo et al., 2017, Yin et al., 2018, Yu et al., 2018). Conversely, poorer cognitive function has been associated with 'Western' (Parrott et al., 2013, Chen et al., 2020, Ashby-Mitchell et al., 2015) and 'traditional' (Corley and Deary, 2020) patterns; although in some instances, no associations were found with 'traditional' (Kesse-Guyot et al., 2012), 'health aware' (Corley et al., 2013), 'rice/pork' (Qin et al., 2015) and 'sweet foods' (Corley et al., 2013) patterns.

Inconsistencies in reported results are often cited as being due to methodological differences (Corley and Deary, 2020, Allès et al., 2012, Corley et al., 2013). Valid dietary tools, including valid dietary patterns, and a comprehensive battery of cognitive tests should be used (Allès et al., 2012, Chen et al., 2018). Known risk factors, including physical activity and the Apolipoprotein E -ε4 (*APOE*-ε4) allele, are not always considered as confounders (Chen et al., 2018).

A dietary pattern is population specific and while dietary patterns have been studied in the New Zealand context (Thompson et al., 2010, Wall et al., 2016, Beck et al., 2013, Schrijvers et al., 2016, Beck et al., 2018, Saeedi et al., 2018), no studies have investigated dietary patterns and their associations with cognitive function in an older New Zealand population. Therefore, the REACH study aimed to investigate associations between cognitive function and dietary patterns in older adults in the New Zealand population. To ensure a robust methodology, this study controlled for relevant confounders, included a battery of cognitive tests examining a broad range of domains and used valid dietary patterns.

6.3. Methods

6.3.1. Study design and participants

The REACH study is a cross-sectional study based in Auckland, New Zealand. The full protocol, with methods, has been published (Mumme et al., 2019) and an outline of the method is provided here. Massey University Human Ethics Committee granted ethical approval: Southern A, Application 17/69, and all participants provided written informed consent.

During 2018, a convenience sample of community-dwelling males and females, aged 65-74 years, was recruited to the REACH study. Screening, via telephone, ensured inclusion criteria were met (proficient in English, and without diagnosis of dementia, stroke, head, or brain injury, or a neurological or psychiatric condition). After an overnight fast, recruited participants attended the Human Nutrition Research Unit, Massey University, Auckland, to complete a validated food frequency questionnaire (FFQ) and cognitive testing. Other data collected were health and demographic data, clinical data (e.g., blood pressure), a fasted blood sample, anthropometric and physical activity data. Data were collected between April 2018 and February 2019.

6.3.2. Cognitive tests

Cognitive testing took place at the Massey University cognitive suite which controlled for noise and temperature to minimise any distraction. The tests were undertaken at a similar time of day (morning) and after breakfast to minimise any effects food may have on cognition (Galioto and Spitznagel, 2016).

Firstly, a trained assessor administered the Montreal Cognitive Assessment (MoCA) on a one-to-one basis. MoCA is a clinically available and validated tool that takes 10 minutes to evaluate global cognitive function (Nasreddine et al., 2005). MoCA was used to provide comparisons with other studies and as a descriptor.

Secondly, cognitive function (main outcome) was assessed with the Computerised Mental Performance Assessment System (COMPASS-Northumbria University, Newcastle upon Tyne, UK), a software platform for the presentation of classic and bespoke computerised cognitive tasks. This platform has previously demonstrated sensitivity to dietary effects in other studies (Kennedy et al., 2017b, Veasey et al., 2013, Kennedy et al., 2017a, Jackson et al., 2020), including older adults (Haskell-Ramsay et al., 2018) and a New Zealand population (Stonehouse et al., 2013). The tasks were presented on desktop computers with all stimuli (e.g., arrow, words) randomised across participants and a variety of methods used to collect responses: mouse and cursor, a four-button coloured response pad, and pen and paper for word recall. This broad battery of tests assessed five domains: **attention and vigilance** (the ability to concentrate while ignoring other stimuli and the ability to maintain attention and alertness over time); **executive function** (the ability to coordinate cognitive responses including planning; initiating and inhibiting responses; cognitive flexibility; abstract thinking and rule acquisition); **episodic memory** (the ability to retain memories that can be consciously recorded); **working memory** (the ability to hold information while carrying out more complex cognitive tasks); and **spatial memory** (the ability to remember the position or location of objects). The results of these domains were combined to assess overall **global cognition**. Table 6.1 provides more details on the cognitive domains and associated tasks.

To maintain consistency, two assessors followed a strict protocol when administering COMPASS. The assessor verbally described the format of the test, the use of the response pads, and each cognitive task, and was available to answer any questions. Before the main test, there was a 15-minute practice session to familiarise participants with the cognitive tests, followed by a 5-minute break before the actual assessment, which took approximately 40 minutes.

The scores from each cognitive test were inspected, cleaned e.g., removing a test that had been restarted due to participant taking a break, and a z-score created. Test scores were combined into five domains based on the average of all tests belonging to that domain. Likewise, the global domain score was the average of all tests. During the scoring, correct responses were positive and reaction times and false alarms were negative, so a high score represented better performance (Table 6.1).

Table 6.1: COMPASS battery of cognitive tests used in the REACH study.
Tasks are presented in order of completion and their cognitive domains.

Domain	Task	Descriptor	Scoring
Spatial memory	Computerised location learning	A 5x5 grid containing pictures of 10 objects is shown – display time of 15 seconds followed by an interval of 10 seconds. An empty grid is then shown. Participants must relocate the objects to the correct location shown to them previously, with no time limit for responding. This is repeated five times during the learning phase – interval of 5 seconds between each trial.	Total displacement score for all learning trials and learning index
Episodic memory	Word presentation	A series of words are displayed on the screen - 15 words with display time of 1 second and interstimulus interval of 1 second.	
Episodic memory	Immediate word recall	Participants are instructed to write down the presented words in a 60 second period.	Number correct.
Episodic memory	Picture presentation	A series of pictures are displayed on the screen – 15 pictures with display time of 2 seconds and interstimulus interval of 1 second.	
Attention and vigilance	Simple reaction time	An upwards pointing arrow is displayed on the screen at irregular intervals. Participants must respond as quickly as possible when the arrow appears – 50 stimuli.	Reaction time (ms).
Attention and vigilance	Digit vigilance test	A fixed number appears on the right of the screen and a series of changing numbers appear on the left of the screen at the rate of 150 per minute. Participants are required to make a response when the number on the left matches the number on the right. This task lasted for 3 minutes.	Accuracy (%), reaction time for the correct responses (ms) and false alarms (number).
Attention and vigilance	Choice reaction time	An arrow pointing either to the left or right appears in the centre of the screen at irregular intervals. Participants must respond as quickly and accurately as possible when the arrows appear by pressing the corresponding button – 50 stimuli.	Accuracy (%), reaction time for the correct responses (ms).
Executive function	Stroop	A series of four words ('red', 'blue', 'yellow' or 'green') appears randomly on the screen, one at a time. Participants are to identify the colour of the word (red, blue, yellow, or green). For example, if the word 'blue' appears in yellow, click the 'yellow' response key – 60 congruent and incongruent stimuli in random order.	Accuracy (%), reaction time for the correct responses (ms).

Domain	Task	Descriptor	Scoring
Episodic memory	Delayed word recall	Participants are instructed to write down the words that were presented at the beginning of the assessment in a 60 second period.	Number correct.
Episodic memory	Delayed picture recognition	All target pictures shown earlier during Picture presentation, plus an equal number of decoys are displayed on the screen one at a time. Participants select 'Yes' or 'No' if they remember seeing the picture earlier or not.	Accuracy (%) and reaction time for the correct responses (ms).
Episodic memory	Delayed word recognition	All target words shown earlier during Word presentation, plus an equal number of decoys are displayed on the screen one at a time. Participants select 'Yes' or 'No' if they remember seeing the word earlier or not.	Accuracy (%) and reaction time for the correct responses (ms).
Spatial memory	Computerised learning recall	Participants are again asked to place the objects, from the first computerised location learning task, in the correct location on the empty grid with no further prompting.	Delayed displacement and delayed recall - difference between displacement score on the final learning trial and the delayed trial.
Working memory	Corsi blocks test	Nine blue squares on a black background are arranged on the screen. Some blue squares will change to red and back to blue in a sequence. Participants are to remember this sequence. When the mouse arrow appears in the middle of the screen, participants are to click the boxes in the exact sequence in which they were presented, responding as quickly and as accurately as they can.	Span score.

COMPASS = Computerised Mental Performance Assessment System, REACH = Researching Eating, Activity, and Cognitive Health.

6.3.3. Food frequency questionnaire

A validated 109-item food frequency questionnaire (FFQ) (Mumme et al., 2021) collected dietary data (frequency and serving size) via an online platform. A daily consumption quantity (grams/day) was calculated for each food item for each participant. Missing values from the FFQ (<1% of all FFQ items) were imputed using the multiple imputation chained equations method and the *mice* package (van Buuren and Groothuis-Oudshoorn, 2011) with five imputations and 20 iterations. Predictors used were food items, age, sex, education and living situation (alone or with someone). A representative food was allocated to each FFQ item and energy intake was calculated with reference to the New Zealand FOODfiles(TM) 2016 food composition database (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health). Average daily energy intake was considered implausible if <2,100 kJ or >14,700 kJ for women and <3,360 kJ or >16,800 kJ for men (Willett, 2012b).

A validation study of the REACH FFQ and the three dietary patterns reported acceptable relative validity and reproducibility in a sub-sample of the REACH cohort (*n* 294) (Mumme et al., 2021). A 4-day food record was used to validate the FFQ, and reproducibility was tested by administering the FFQ a second time, one month later.

6.3.4. Construction of dietary patterns

The 109 food items (g/day) were collapsed into 57 food groups. The food groups were decided by four team members and based on similarity of foods, culinary usage, and their previous association with cognitive outcome (Table 4.1). The data set was suitable for principal component analysis after checking the Bartlett's test of sphericity measuring the presence of relationships within the data (P<0.0001) and the Kaiser-Meyer-Olkin (KMO), which measures the sampling adequacy (KMO = 0.66). Principal component analysis was used to explore and describe the dietary data by reducing the dimensionality of the diet components based on the correlation with one another while retaining as much variation within the diet as possible (McCann et al., 2001).

Using R, version 3.6.1 (R Core Team, 2019), the *psych* package (Revelle, 2020) and orthogonal varimax rotation, the data matrix of 57 food groups (g/day) was analysed. Three factors (dietary patterns) were obtained based on the scree plot, eigenvalue (> 1) and interpretability of the factors. Factor loadings measure the relative contribution (correlation) of a food group to a dietary pattern. Positive loadings contribute to dietary patterns, whereas negative loadings have an inverse association to the dietary patterns. Food groups with factor loadings ≥ 0.30 or ≤ -0.30 were considered significant contributors to the pattern for a sample size of 300 (Stevens, 2009). A

standardised dietary pattern score was calculated per participant per dietary pattern using the regression method. Labelling of dietary patterns was based on highly correlated food groups and the type of diet those food groups characterised.

6.3.5. *APOE* -ε4 analysis

A qualified phlebotomist drew fasted venous blood samples into 6 ml BD Vacutainer® K2EDTA tubes (cat 367873). Whole blood (~5 ml) was stored at -80 °C until genotyping which was performed by an external genetic testing service (Grafton Clinical Genomics, Auckland, New Zealand). An automated system (QiaSymphony) extracted the DNA using magnetic rods to shift nucleic acids through purification/wash steps and a final elute phase. Based on a sample input of 200 uL of whole blood and an elution volume of 100 uL, the DSP DNA Mini Kit (for DNA extraction) ensured the yield and concentration was sufficient for sample processing on the Genotyping platform. *APOE* -ε2, -ε3 and -ε4 (SNP ID rs7412 and rs429358) alleles were detected using the Agena® MassARRAY® system, a MALDI-TOF mass spectrometry system (Agena Bioscience Inc).

6.3.6. Other variables

Written questionnaires collected demographic, health and lifestyle data. Demographic data included age, ethnicity, education (secondary, post-secondary, university), living situation (with others, alone), first language, and index of multiple deprivation (score). Health data included family history of dementia or cognitive impairment (yes, no), history of mental health (yes, no), past and current disease (acute, chronic), medication (list), and daytime sleepiness (how often are you excessively sleepy during the day? [never, rarely, frequently, often]). Lifestyle data included physical activity level, smoking history (no, yes [current, past]), and supplement use (list).

The New Zealand Indices of Multiple Deprivation (IMD) and participant's residential address determined the area deprivation score based on seven domains: employment, income, crime, housing, health, education, and geographical access (Exeter et al., 2017). Polypharmacy was considered as five or more daily medicines (Masnoon et al., 2017). Alcohol beverage intake (g/day) was calculated from the 109-item FFQ and adjusted for energy intake (Willett, 2012a). The International Physical Activity Questionnaire - short form (Craig et al., 2003) was used to assess physical activity levels. A physical activity score was calculated using Metabolic equivalent of a task (MET-minutes) where one minute of activity is 3.3, 4.0 or 8.0 METs, depending on an exercise level of walking, moderate or vigorous activity, respectively. One MET is equivalent to the rate of energy expended while at rest (Craig et al., 2003). Waist circumference, blood pressure, fasting blood glucose and blood lipids were measured using standardised procedures as per the REACH protocol (Mumme et al., 2019) and criteria recommended by the American Heart Association/National

Health, Lung and Blood Institute Scientific Statement determined the presence of metabolic syndrome (Grundy et al., 2005).

6.3.7. Statistical analysis

Statistical analysis was performed using R, version 3.6.1 (R Core Team, 2019) and R packages: *car* (Fox and Sanford, 2019), *Hmisc* (Harrell and et al, 2020), *pwr* (Champely, 2020), *s20x* (Balemi et al., 2020), and *tidyverse* (Wickham et al., 2019). No data were transformed prior to statistical analysis. An *a priori* power calculation determined a sample size of 346 participants had 80% power to detect a small effect size (Pearson r = 0.15) with a 5% significance threshold between cognitive domains and dietary pattern scores.

Participant data, with a roughly symmetric distribution, were described with mean (SD) or median (25, 75 percentile) for continuous data, or frequency summary statistics for categorical data. The Welch two-sample t-test or Pearson chi-squared test examined differences between the sexes for characteristic variables. With a relatively large sample size in each group (women: *n* 229, men: *n* 130) the group means had approximately normal distributions as required by the t-test. Only categorical variables with an expected count > 5 in each category were considered for the Chi-squared test.

Multiple regression analysis examined the associations between the dietary pattern scores (independent variable) and the scores from the six domains of cognitive function (dependent variables) while considering confounding factors. The process of selecting confounders in the multiple regression analysis is outlined in. Figure 6. As the population was homogenous in terms of ethnicity and first language, these two variables were excluded from further analysis. Possible confounding variables underwent simple regression between each domain and each confounder. Variables with $P>0.20$ were removed from modelling. The remaining variables ($P\leq0.20$) were placed through a stepwise regression (direction = "both") with all cognitive domains. Based on the outcomes of the stepwise regression, two models were prepared. First was an unadjusted model with each cognitive domain and all dietary pattern scores (Model 0). The final model included each cognitive domain (as response) and three dietary pattern scores, age, sex, education level, daily energy intake, physical activity and *APOE*-ε4 (Model 1). A p-value<0.05 was considered statistically significant. Variables in the final regression model were checked for collinearity using the variance inflation factor (Fox and Sanford, 2019). Scores ranged from 1.0 to 1.6, so no variables were considered collinear.

Interactions were explored between dietary patterns and sex, education, *APOE*-ε4 status and energy intake (sex specific tertiles), and between education and *APOE*-ε4 status (Lopez et al., 2017),

and age and *APOE*-ε4 status (Wisdom et al., 2011). Residual statistics (residuals vs fitted; scale-location; residuals vs leverage (Cook's distance)) was examined to ensure linearity, homogeneity, and any undue influence of individual cases on the final model.

MoCA scores less than 26 (out of 30) may indicate memory loss and the potential to influence the recall of foods eaten in the last month thus the possibility of introducing measurement errors into dietary intake data (Smith et al., 2007, Nasreddine et al., 2005). Therefore, to rule out reverse causation, where the cognitive status may affect dietary choice or recall when completing the FFQ, a sensitivity analysis was done with participants with MoCA scores ≥ 26. Multiple regression examined the association between dietary pattern scores and the global domain while considering the same confounders as in model 1.

The attention and vigilance, executive function, and episodic memory scores contained elements of reaction time and accuracy. To ensure speed and accuracy did not off-set each other, a post hoc analysis explored associations between total reaction time scores and total accuracy scores as the response variables and three dietary pattern scores, age, sex, education level, daily energy intake, physical activity and *APOE*-ε4 as the exposure variable. Multiple regression analysis was used, like model 1 in the main analysis.

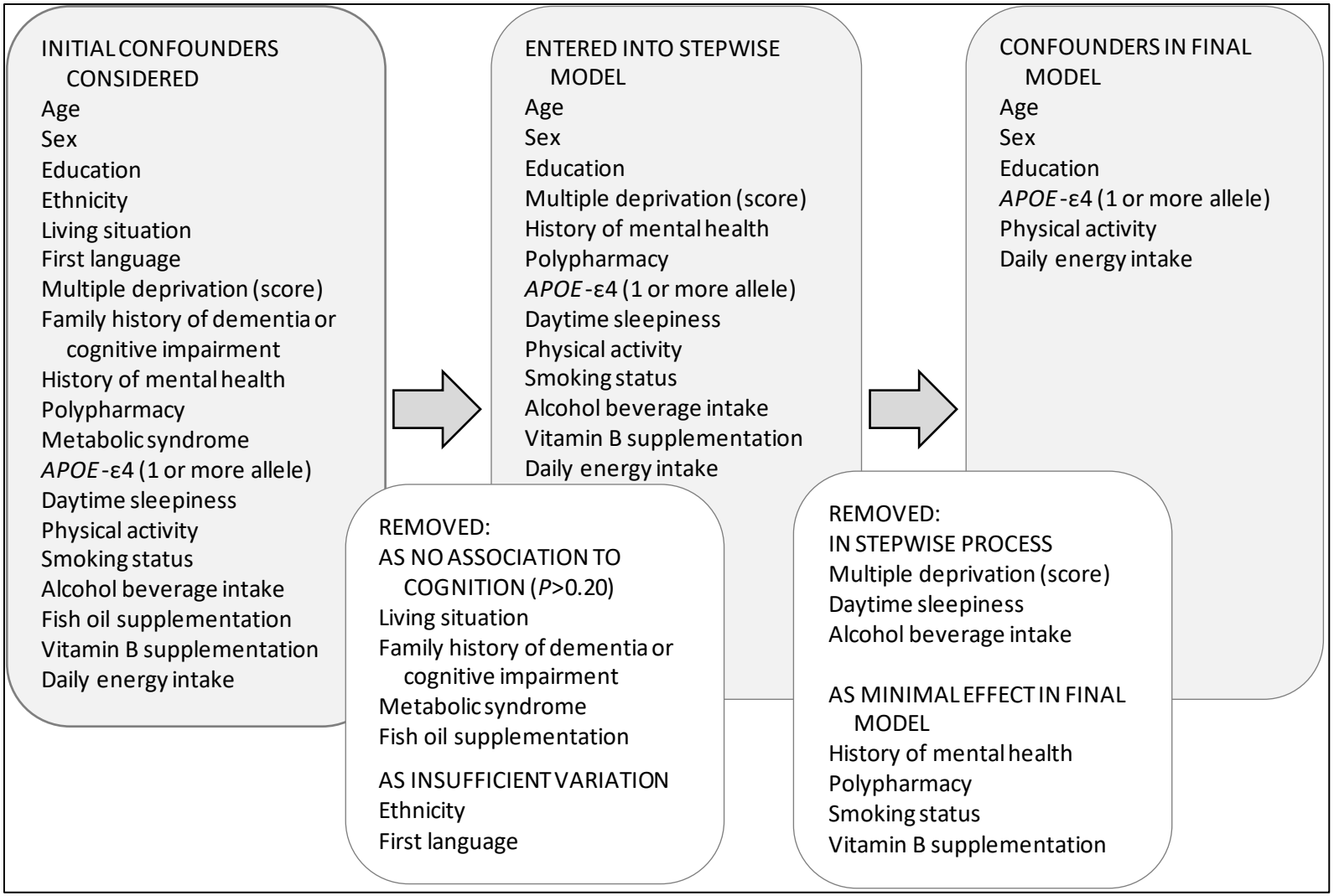

Figure 6: The selection process of confounders for multiple linear regression with dietary patterns and cognitive function.

6.4. Results

6.4.1. Participants

A total of 371 participants were enrolled in the REACH study (Figure 7). Twelve participants were excluded due to previous stroke or traumatic head injury (not removed at screening; *n* 7), no cognition data (*n* 3) or no FFQ data (*n* 2). All participants had plausible energy intakes. Males represented 36% of the remaining 359 participants and compared with females, were older, had a higher education level, a higher energy and alcoholic beverage intake, and were more likely to live with others (Table 6.2). The MoCA score was 26 or above for 67% of participants (n 242) (Table 6.2). Cognitive z-scores are described in Table 6.3. Only the episodic memory score had a difference between male and females, where females had a higher score ($P<0.01$) (Table 6.3).

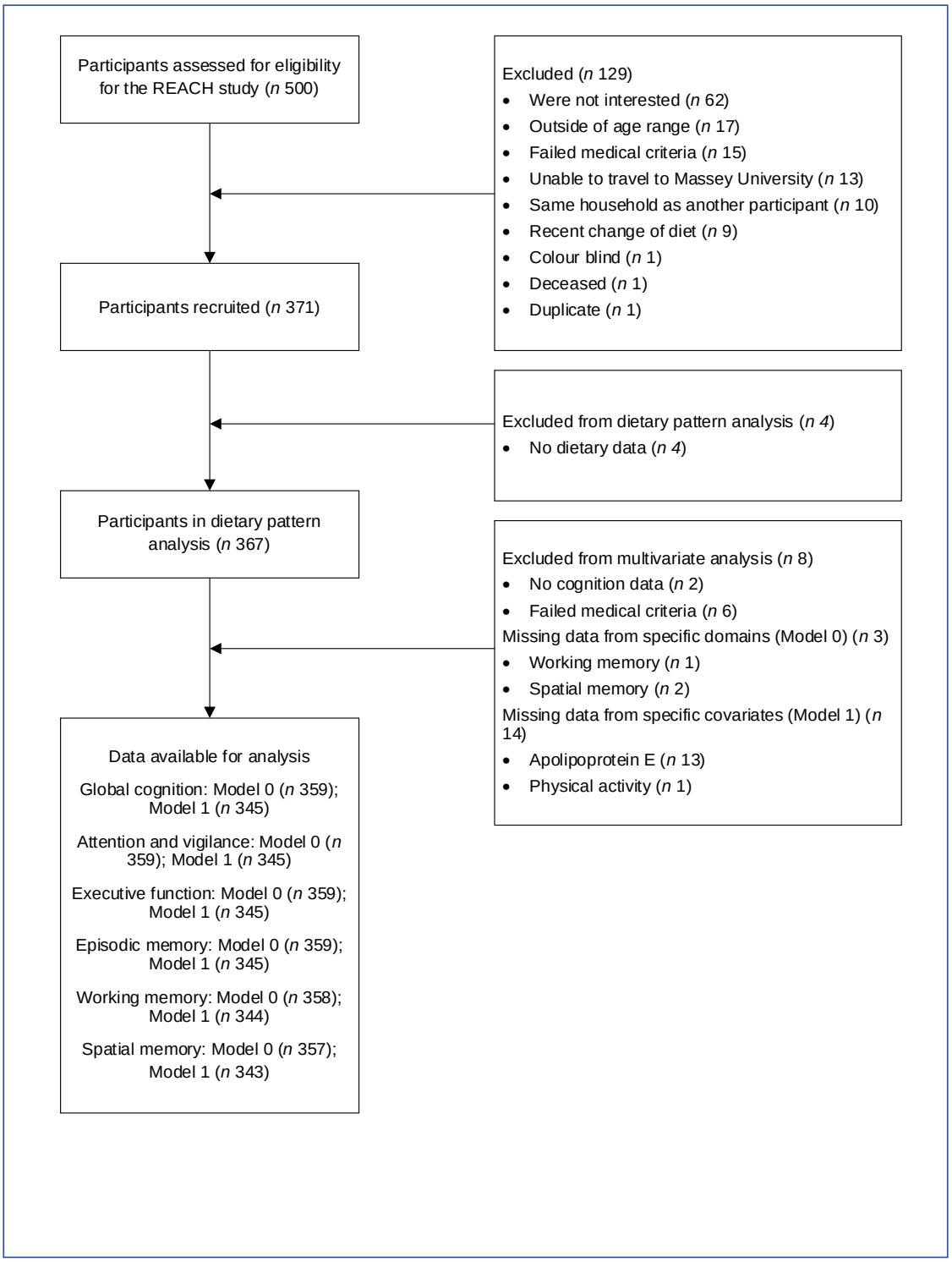

Figure 7: Flow of participants in the dietary pattern and cognitive function study

Table 6.2: Characteristics of the study participants in the cognitive function study (*n* 359) and the differences between males and females

Characteristic	Total	Male	Female
n	359	130	229
Age (mean (SD), years)[a]*	69.7 (2.6)	70.1 (2.4)	69.4 (2.6)
Sex (% male)	36		
Education (n (%))[a]***			
Secondary[a, b]	80 (22)	18 (14)	62 (27)
Post-secondary	147 (41)	49 (38)	98 (43)
University[a]	132 (37)	63 (48)	69 (30)
Employed (n (%), paid or volunteer)	174 (48)	54 (42)	120 (52)
First language (n (%))			
English	340 (95)	121 (93)	219 (96)
Other	19 (5)	9 (7)	10 (4)
Ethnicity (n (%))			
Asian	11 (3)	5 (4)	6 (3)
European	338 (94)	120 (92)	218 (95)
Māori/Pacific	10 (3)	5 (4)	5 (2)
Index of Multiple Deprivation (Exeter et al., 2017) (mean (SD))[c]	2145 (1417)	2039 (1507)	2206 (1364)
Living (n (%))[a]***			
Alone[a]	105 (29)	18 (14)	87 (38)
With others[a]	254 (71)	112 (86)	142 (62)
APOE-ε4 (n (%))			
Yes	98 (27)	32 (25)	66 (29)
1 allele	92 (26)	31 (24)	61 (27)
2 alleles	6 (2)	1 (1)	5 (2)
No	248 (69)	93 (72)	155 (68)
No data	13 (4)	5 (4)	8 (3)
Polypharmacy (n (%))[d]	31 (9)	16 (12)	15 (7)
Metabolic Syndrome (n (%))	56 (16)	18 (14)	38 (17)
BMI (mean (SD) kg/m^2)[e]	26.3 (4.5)	26.8 (4.0)	26.0 (4.8)
Normal (n (%) <25 kg/m2)[a]*	148 (41)	40 (31)	108 (47)
Overweight (n (%) 25-30 kg/m2)[a]*	153 (43)	68 (52)	85 (37)
Obese (n (%) >30 kg/m2)	57 (16)	21 (16)	36 (16)
Dietary pattern score (mean (SD))			
Mediterranean style[a]**	0.0 (1.0)	-0.2 (1.1)	0.1 (0.9)
Western[a]***	0.0 (1.0)	0.4 (1.1)	-0.3 (0.8)
Prudent	0.0 (1.0)	-0.0 (1.2)	0.0 (0.9)
Physical activity (mean (SD), MET[f] minutes/week)[g, h]	3845 (2775)	3947 (2949)	3786 (2676)
Smoker (n (%))			
Yes (current and 'used to')	76 (21)	28 (22)	48 (21)

Characteristic	Total	Male	Female
No	283 (79)	102 (78)	181 (79)
Daily energy intake (mean (SD), kJ)[a]**	7563 (2121)	8021 (2267)	7304 (1992)
Daily alcohol beverage intake (median (25, 75 quartiles), g/day)[a]***,[k]	62 (18, 121)	100 (32, 213)	50 (13, 89)
Montreal Cognitive Assessment[m] (Nasreddine et al., 2005) (mean (SD))	26.4 (2.5)	26.1 (2.6)	26.5 (2.5)

[a] differences between sexes calculated using the Welch two-sample t-test (continuous variable) and chi-squared test (categorical variables). *P*-value: *<0.05, **<0.01, ***<0.001
[b] for education 'no qualification' (*n* 7) and 'secondary' (*n* 73) were aggregated due to small numbers
[c] low score = least deprived, range = 11 to 5585
[d] 5 or more medicines per day (Masnoon et al., 2017)
[e] male score missing (*n* 1)
[f] metabolic equivalent of task
[g] female score missing due to incomplete data (*n* 1)
[h] MET minutes/week based on 3.3 MET for walking, 4.0 MET for moderate activity and 8.0 MET for vigorous activity
[k] energy adjusted (Willett, 2012a)
[m] range = 12 to 30

Table 6.3: Descriptive statistics of the cognitive and dietary pattern scores

	Total			Males (*n* 130)		Females (*n* 229)	
	n	Mean (SD)	minimum, maximum	Mean (SD)	minimum, maximum	Mean (SD)	minimum, maximum
Cognition scores (z-scores)							
Global	359	0.02 (0.94)	-3.85, 2.14	-0.04 (0.88)	-3.85, 1.76	0.06 (0.97)	-3.51, 2.14
Attention and vigilance	359	0.02 (0.97)	-5.01, 2.14	0.13 (0.92)	-5.01, 1.74	-0.04 (0.99)	-3.26, 2.14
Executive function	359	0.02 (0.96)	-6.13, 1.28	0.02 (0.82)	-2.72, 1.20	0.02 (1.03)	-6.13, 1.28
Episodic memory[a]**	359	0.02 (0.96)	-6.50, 2.85	-0.21 (1.01)	-6.50, 2.08	0.15 (0.90)	-2.73, 2.85
Working memory	358[b]	0.01 (1.01)	-5.39, 2.46	0.11 (0.87)	-4.03, 2.46	-0.04 (1.08)	-5.39, 2.46
Spatial memory	357[c]	0.01 (0.98)	-3.53, 1.56	-0.02 (0.91)	-2.40, 1.48	0.03 (1.01)	-3.53, 1.56
Dietary pattern scores (z-scores)							
Mediterranean style[a]**	359	0.00 (1.00)	-2.32, 4.27	-0.22 (1.07)	-2.12, 4.27	0.12 (0.94)	-2.32, 2.86
Western[a]***	359	0.00 (1.00)	-1.93, 3.83	0.44 (1.10)	-1.93, 3.83	-0.26 (0.84)	-1.89, 3.43
Prudent	359	0.00 (1.01)	-2.49, 8.31	-0.03 (1.21)	-2.31, 8.31	0.01 (0.87)	-2.49, 4.51

[a] differences between sexes calculated using the Welch two-sample t-test. *P*-value: *<0.05, **<0.01, ***<0.001.
[b] one female score missing due to computer malfunction.
[c] two female scores missing due to computer malfunction (*n* 1); anxiety in location learning task (*n* 1)

6.4.2. Dietary patterns

Principal component analysis identified three dietary patterns from the FFQ data which explained 18% of the variation in dietary intake. Table 5.2 displays the dietary pattern loadings, eigenvalues and the variance explained by each dietary pattern

Dietary pattern 1, named 'Mediterranean style', was characterised by salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs; cheese; tomatoes; and all other fruit. Dietary pattern 2, named 'Western', was characterised by processed meats; sauces and condiments; cakes, biscuits, and puddings; meat pies and chips; processed fish; confectionery; vegetable oils; beer; chocolate; salad dressings; cheeses; and sweetened cereal. Dietary pattern 3, named 'prudent', was characterised by dried legumes; soy-based foods; fresh and frozen legumes; whole grains; carrots; and spices (Table 5.2).

The descriptive statistics for the dietary pattern scores are shown in Table 6.3. Males had a lower score in the 'Mediterranean style' (P=0.003) and a higher score in the 'Western' pattern (P<0.001) than females (Table 6.3). There were no differences with any dietary pattern scores between *APOE*-ε4 carriers and non-carriers (data not shown, all P>0.18). The nutrient profile for each of the dietary patterns has been described elsewhere (Mumme et al., 2020), but briefly, 'Mediterranean style' dietary pattern scores were positively associated with beta-carotene equivalents, vitamin E and folate intake (all P<0.001, all $R^2 \geq 0.26$); 'Western' dietary pattern scores were positively associated with daily energy intake (P<0.001, $R^2 = 0.43$); and 'prudent' dietary pattern scores were positively associated with fibre and carbohydrate intake (both P<0.001, both $R^2 \geq 0.25$) (Mumme et al., 2020).

These dietary patterns have been validated with a subset of the REACH study participants *(n* 294) (Mumme et al., 2021) (Chapter Four). The dietary pattern loadings obtained from the validation study subset were comparable to the REACH full cohort reported here. Tucker's congruence coefficient (phi) between the loadings of the FFQ derived dietary patterns (REACH validation subset v REACH full cohort) were 0.96, 0.91 and 0.88 for 'Mediterranean style', 'Western' and 'prudent' patterns respectively.

6.4.3. Dietary pattern associations with cognitive function

In the unadjusted model (multiple regression analysis, model 0), there were no significant associations between dietary pattern scores and any cognitive domains. No associations between dietary pattern scores and any cognitive domains were uncovered after age, sex, education, energy intake, physical activity and *APOE*-ε4 were added into the final model (model 1) (Table 6.4). There

were no interactions between the dietary patterns and sex, education, *APOE*-ε4 or energy intake nor between education and *APOE*-ε4 status, and age and *APOE*-ε4 status.

Model 1 in Table 6.4 showed for every one year a participant ages, the global and episodic and working memory was associated with a decrease in the z-score between 0.00 and 0.09 SD. Being female was associated with an increased episodic memory z-score of between 0.23 and 0.67 SD compared with being male. Having a university education was associated with an increased global z-score (between 0.29 and 0.81 SD); attention and vigilance z-score (between 0.01 and 0.57 SD); executive function z-score (between 0.13 and 0.67 SD); episodic memory z-score (between 0.29 and 0.82 SD); working memory z-score (between 0.19 and 0.77 SD); but not spatial memory compared with a secondary education. Having at least one *APOE*-ε4 allele was associated with a decreased episodic memory z-score of between 0.05 and 0.47 SD. Statistical models for each cognitive domain are shown in Table 6.5 to Table 6.10.

Table 6.4 Multiple linear regression for Model 1[a], showing associations between dietary patterns and cognitive domains

Coefficient	Global[b]	Attention and vigilance[b]	Executive function[b]	Episodic memory[b]	Working memory[c]	Spatial memory[d]
Intercept[e]	3.48 (0.86, 6.12) *	2.07 (-0.76, 4.91	2.62 (-0.16, 5.39)	3.02 (0.35, 5.69) *	3.39 (0.44, 6.35) *	0.64 (-2.31, 3.59)
Mediterranean style	-0.02 (-0.12, 0.09)	0.01 (-0.11, 0.12)	-0.01 (-0.12, 0.10)	-0.03 (-0.14, 0.08)	-0.03 (-0.15, 0.09)	0.01 (-0.11, 0.13)
Western	0.11 (-0.03, 0.25)	0.01 (-0.14, 0.16)	0.07 (-0.08, 0.22)	0.12 (-0.02, 0.27)	0.07 (-0.09, 0.23)	0.14 (-0.02, 0.30)
Prudent	0.01 (-0.10, 0.11)	0.02 (-0.10, 0.13)	-0.01 (-0.12, 0.10)	-0.01 (-0.12, 0.09)	0.03 (-0.08, 0.15)	0.04 (-0.08, 0.16)
Age	-0.05 (-0.08, -0.01) *	-0.03 (-0.07, 0.01)	-0.03 (-0.07, 0.01)	-0.04 (-0.08, 0.00) *	-0.04 (-0.09, 0.00) *	0.00 (-0.04, 0.04)
Sex						
Male (reference)						
Female	0.17 (-0.05, 0.39)	-0.18 (-0.42, 0.05)	0.06 (-0.17, 0.29)	0.45 (0.23, 0.67) ***	-0.10 (-0.35, 0.14)	0.08 (-0.16, 0.32)
Education						
Secondary (reference)						
Post-secondary	0.13 (-0.12, 0.39)	0.09 (-0.18, 0.36)	0.07 (-0.20, 0.33)	0.15 (-0.11, 0.40)	0.15 (-0.13, 0.43)	-0.07 (-0.35, 0.21)
University	0.55 (0.29, 0.81) ***	0.29 (0.01, 0.57) *	0.40 (0.13, 0.67) **	0.56 (0.29, 0.82) ***	0.48 (0.19, 0.77) **	0.01 (-0.28, 0.30)
Energy intake	-0.00 (-0.00, -0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)
APOE-ε4[f]						
no allele (reference)						
one or more allele	-0.14 (-0.34, 0.07)	-0.01 (-0.23, 0.22)	0.15 (-0.07, 0.37)	-0.26 (-0.47, -0.05) *	0.10 (-0.13, 0.34)	-0.23 (-0.46, 0.00)
Physical activity	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)
Model adjusted R^2	0.08***	0.01	0.04**	0.11***	0.04**	0.00

[a] Model 1 is adjusted for age, sex, education, energy intake, *APOE*-ε4 and other dietary pattern scores; *P*-value: *<0.05, **<0.01, ***<0.001.

[b] *n* 345, β estimate (95% CI); missing data: *APOE*-ε4 (*n* 13); physical activity (*n* 1).

[c] *n* 344, β estimate (95% CI); missing data: *APOE*-ε4 (*n* 13); physical activity (*n* 1); computer malfunction (*n* 1).

[d] *n* 343, β estimate (95% CI); missing data: *APOE*-ε4 (*n* 13); physical activity (*n* 1); computer malfunction (*n* 1); anxiety (*n* 1).

[e] Reference group (Intercept) is male, secondary education, and 1 or more *APOE*-ε4 allele.

[g] Apolipoprotein E-ε4.

Table 6.5: Multiple linear regression model showing associations between dietary patterns and global domain

Global Domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.02 (-0.07, 0.12)	3.49 (0.86, 6.12) **
Mediterranean style	0.01 (-0.09, 0.11)	-0.02 (-0.12, 0.09)
Western	0.04 (-0.05, 0.14)	0.11 (-0.03, 0.25)
Prudent	-0.03 (-0.12, 0.07)	0.01 (-0.1, 0.11)
Age		-0.05 (-0.08, -0.01) *
Sex		
Male (reference)		
Female		0.17 (-0.05, 0.39)
Education		
Secondary (reference)		
Post-secondary		0.13 (-0.12, 0.39)
University		0.55 (0.29, 0.81) ***
Energy intake		-0.00 (-0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		-0.14 (-0.34, 0.07)
Physical activity		0.00 (0.00, 0.00)
Adjusted R^2	-0.01	0.08 ***

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

Table 6.6: Multiple linear regression model showing associations between dietary patterns and attention and vigilance domain

Attention and vigilance domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.02 (-0.08, 0.12)	2.07 (-0.76, 4.91)
Mediterranean style	0.04 (-0.06, 0.14)	0.01 (-0.11, 0.12)
Western	0.07 (-0.03, 0.17)	0.01 (-0.14, 0.16)
Prudent	0.01 (-0.09, 0.11)	0.02 (-0.10, 0.13)
Age		-0.03 (-0.07, 0.01)
Sex		
Male (reference)		
Female		-0.18 (-0.42, 0.05)
Education		
Secondary (reference)		
Post-secondary		0.09 (-0.18, 0.36)
University		0.29 (0.01, 0.57) *
Energy intake		0.00 (0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		-0.01 (-0.23, 0.22)
Physical Activity		0.00 (0.00, 0.00)
Adjusted R^2	0.00	0.01

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

Table 6.7: Multiple linear regression model showing associations between dietary patterns and executive function domain

Executive function domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.02 (-0.08, 0.12)	2.62 (-0.16, 5.39)
Mediterranean style	-0.03 (-0.13, 0.07)	-0.01 (-0.12, 0.10)
Western	0.04 (-0.06, 0.14)	0.07 (-0.08, 0.22)
Prudent	-0.02 (-0.12, 0.08)	-0.01 (-0.12, 0.10)
Age		-0.03 (-0.07, 0.01)
Sex		
Male (reference)		
Female		0.06 (-0.17, 0.29)
Education		
Secondary (reference)		
Post-secondary		0.07 (-0.20, 0.33)
University		0.40 (0.13, 0.67)**
Energy intake		0.00 (0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		0.15 (-0.07, 0.37)
Physical Activity		0.00 (0.00, 0.00)
Adjusted R^2	0.00	0.04**

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

Table 6.8: Multiple linear regression model showing associations between dietary patterns and episodic memory

Episodic memory domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.02 (-0.08, 0.12)	3.02 (0.35, 5.69)*
Mediterranean style	0.02 (-0.08, 0.12)	-0.03 (-0.14, 0.08)
Western	0 (-0.1, 0.1)	0.12 (-0.02, 0.27)
Prudent	-0.04 (-0.14, 0.06)	-0.01 (-0.12, 0.09)
Age		-0.04 (-0.08, 0.00)*
Sex		
Male (reference)		
Female		0.45 (0.23, 0.67)***
Education		
Secondary (reference)		
Post-secondary		0.15 (-0.11, 0.40)
University		0.56 (0.29, 0.82)***
Energy intake		0.00 (0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		-0.26 (-0.47, -0.05)*
Physical Activity		0.00 (0.00, 0.00)
Adjusted R^2	0.00	0.11***

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

Table 6.9: Multiple linear regression model showing associations between dietary patterns and working memory domain

Working memory domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.01 (-0.09, 0.12)	3.39 (0.44, 6.35)*
Mediterranean style	-0.06 (-0.17, 0.04)	-0.03 (-0.15, 0.09)
Western	0.04 (-0.06, 0.15)	0.07 (-0.09, 0.23)
Prudent	0 (-0.11, 0.1)	0.03 (-0.08, 0.15)
Age		-0.04 (-0.09, 0.00)*
Sex		
Male (reference)		
Female		-0.10 (-0.35, 0.14)
Education		
Secondary (reference)		
Post-secondary		0.15 (-0.13, 0.43)
University		0.48 (0.19, 0.77)**
Energy intake		0.00 (0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		0.10 (-0.13, 0.34)
Physical Activity		0.00 (0.00, 0.00)
Adjusted R^2	0.00	0.04**

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

Table 6.10: Multiple linear regression model showing associations between dietary patterns and spatial memory domain

Spatial memory domain		
Coefficient	Model 0[a]	Model 1[b]
Intercept[c]	0.01 (-0.09, 0.11)	0.64 (-2.31, 3.59)
Mediterranean style	0.00 (-0.11, 0.10)	0.01 (-0.11, 0.13)
Western	0.02 (-0.08, 0.12)	0.14 (-0.02, 0.30)
Prudent	-0.01 (-0.11, 0.1)	0.04 (-0.08, 0.16)
Age		0.00 (-0.04, 0.04)
Sex		
Male (reference)		
Female		0.08 (-0.16, 0.32)
Education		
Secondary (reference)		
Post-secondary		-0.07 (-0.35, 0.21)
University		0.01 (-0.28, 0.30)
Energy intake		0.00 (0.00, 0.00)
APOE -ε4[d]		
no allele (reference)		
one or more allele		-0.23 (-0.46, 0.00)
Physical Activity		0.00 (0.00, 0.00)
Adjusted R^2	0.00	0.00

[a] *n* 359, β estimate (95% CI).
[b] *n* 345, β estimate (95% CI); missing data: *APOE* -ε4 (*n* 13); physical activity (*n* 1).
[c] Reference group (Intercept) is male, secondary education, and 1 or more *APOE* -ε4 allele (as applicable).
[d] *APOE* -ε4 = Apolipoprotein E -ε4.
P-value: *<0.05, **<0.01, ***<0.001

6.4.4. Sensitivity and post hoc analysis

A sensitivity analysis, using multiple regression, explored associations between dietary pattern scores and global cognition scores in a population with a MoCA score ≥ 26 (*n* 242). Similarly, to the full dataset, this analysis found no association with any dietary pattern though a higher global cognition score was positively associated with a university education (β = 0.47, *P*=0.003) and lower daily energy intake (β = 1.04e-04, *P*=0.01) (adjusted R^2 = 0.09, *P*<0.001). The association between younger participants and global cognitive function in the full data set (β = -0.05, *P*<0.05) was not observed in the sensitivity analysis.

A post-hoc analysis did not find any associations between total reaction time and total accuracy scores, and any dietary pattern (*P*>0.05). However, fast reaction times were associated with a university education (β = -0.32, *P*<0.01) and better accuracy scores were associated with being

younger (β = -0.04, *P*<0.001), being female (β = 0.19, *P*=0.01), and having a university education (β = 0.26, *P*<0.01) (data not shown).

6.5. Discussion

REACH, a cross-sectional study that characterised dietary patterns in a healthy, older (65-74 years), community-dwelling population in Auckland, New Zealand, is the first to identify *a posteriori* dietary patterns and to explore their associations with six cognitive domains in this population. Three validated dietary patterns explained 18% variation of the population's diet – 'Mediterranean style', 'Western' and 'prudent'. This study found no associations among any of the six cognitive domains assessed and dietary pattern scores. Sex, *APOE*-ε4, education, energy intake or *APOE*-ε4*education did not significantly modulate the relationship between dietary patterns and cognitive function. Cognition test results were associated with age, sex, education, and the *APOE*-ε4 allele.

While studies have found associations between dietary patterns and cognitive function in older adults (Chen et al., 2018, Milte and McNaughton, 2016, Solfrizzi et al., 2017), some published studies have shown no relationship (Osawa et al., 2017, Allès et al., 2019, Sugawara et al., 2015), and there is the possibility of further null findings remaining unpublished (Allès et al., 2012). Explanations for the null findings reported by published studies included: possible inadequacy of a clinical screening tool to accurately reflect cognitive function (Osawa et al., 2017, Sugawara et al., 2015); inadequate statistical power (Sugawara et al., 2015); or the inability of one 24-hr recall to give an accurate picture of the true diet (Allès et al., 2019). Even though the current study used a broad array of cognitive tests, had adequate statistical power, and used valid tools to create dietary patterns, it still did not find any association between cognitive function and dietary patterns.

Current dietary patterns, as described in this study, may not reflect dietary patterns consumed in earlier years. Furthermore, dietary intake in earlier years (compared with current) may have more impact on cognitive function in later years (Benton, 2010). In a sub-sample of the SU.VI.MAX (the Supplémentation en Vitamines et Minéraux Antioxydant Study), dietary data were collected 13 years prior to testing participants' cognitive function (mean age at baseline = 52 years, *n* ~3000) (Kesse-Guyot et al., 2014, Kesse-Guyot et al., 2012). Positive associations were reported between multiple cognitive domains and a 'carotenoid-rich' (Kesse-Guyot et al., 2014) and 'healthy' (Kesse-Guyot et al., 2012) dietary pattern, particularly where energy intake, in the 'healthy' pattern, was below the sex-specific median[21] (Kesse-Guyot et al., 2012). An Australian study, used a sub-sample of the Older People, Omega-3 and Cognitive Health study (EPOCH) (*n* 352, 65+ years) (Hosking et al., 2014) and

[21] Male energy intake median = 2,492 kcal (10,458 kJ), Female energy intake median = 1,805 kcal (7,602 kJ).

reported dietary patterns, derived from recalled dietary data from different life stages (childhood, early adulthood, adulthood, and middle age), were associated with cognitive performance in later life. The data in that study were adjusted for *APOE*-ε4 status and other dietary patterns, including the current diet (Hosking et al., 2014). The techniques used to assess long-term dietary intakes were novel and require further testing to confirm their validity but may represent a useful approach to assessing diet intake where longitudinal data collection is not possible. In contrast, the Atherosclerosis Risk in Communities (ARIC) study (*n* 13,588, mean age at baseline = 55 years) reported dietary patterns collected at baseline were not associated with cognitive function (measured 3 years later) or cognitive decline (approximately 20 years later) (Dearborn-Tomazos et al., 2019).

Corley et al. (2013) suggested the link between dietary patterns and cognitive performance is not causal. In other words, dietary patterns do not influence cognitive performance. Instead, childhood IQ and adult socio-economic status have a greater impact on cognition status than diet. With many factors affecting cognition status, diet (at one point in time) may not be a major determinant. Instead, reported associations between dietary patterns and cognition may be due to significant confounders being absent in the analysis. For example, Chen et al. (2018) reported 47% of dietary pattern studies (both randomised controlled trials and prospective cohorts*)* with an outcome of cognitive function and/or dementia excluded the *APOE*-ε4 allele from their analysis. Many studies do not report the full models so the significance of the diet (and other factors) to cognition is not known. In the current study, age, sex, education, and *APOE*-ε4 status, but not dietary patterns, influenced episodic memory score but only explained 11% of its variation (adjusted R^2).

Age-related cognitive decline begins at varying ages and may occur at varying rates (Salthouse, 2009). Childhood intellect, with its variability, can also be expected to exist in later years (Deary et al., 2004). Thus, the concept of cognitive reserve is likely to influence current cognitive status, possibly through mediation (Clare et al., 2017). Cognitive reserve buffers against brain disease and age-related decline through cumulative lifetime experiences and genetic factors that influence the efficiency and capacity of the brain networks to protect and preserve cognitive function (Richards and Deary, 2005). Lifetime experiences include education, childhood intelligence, socio-demographic factors (throughout life) and activities that provide cognitive, social and physical stimuli (Pettigrew and Soldan, 2019, Richards and Deary, 2005). In addition, other experiences associated with cognitive decline include midlife exposures to vascular events such as hypertension, smoking, obesity, and type 2 diabetes (Debette et al., 2011). Whilst several factors that could impact cognitive reserve were included in the current study, cognitive reserve as a whole was not measured and may have influenced the current cognitive function of the REACH study participants.

There were limitations to this study. A convenience sample was recruited and not representative of the New Zealand older population. The final dietary patterns were influenced by the many arbitrary, though carefully thought through, decisions e.g., food groupings, number of factors extracted, method of rotation, labelling of factors, therefore common methods were followed. Dietary data were collected over a 10-month period, but any seasonal variation is likely to be small and cancelled out by food grouping (Parr et al., 2006).

The study has strengths. The variability in cognitive function was minimised by testing at the same time each day; by controlling noise and temperature; and by providing a breakfast prior to testing. This study may be the first to introduce a breakfast prior to cognitive testing when exploring dietary pattern and cognitive function associations in older adults. In adults, research in this area is limited (Edefonti et al., 2017) though emerging studies have shown consuming breakfast can impact memory (Galioto and Spitznagel, 2016). Ten tests were used, assessing six domains, allowing more depth than a single test of global cognition (e.g., MoCA or Mini-mental state exam). A sensitivity analysis showed those with lower MoCA scores, and perhaps a reduced ability to recall the diet, did not impact global cognition findings. Important confounders were considered in this study including *APOE*-ε4 and physical activity. Though our study was small, it was adequately powered and used validated tools to measure dietary intake, physical activity, and cognitive function.

6.5.1. Conclusion

The previously observed associations of dietary patterns with cognitive function were not significant in this older cohort of adults living in Auckland, New Zealand. Age, education, sex, and *APOE*-ε4 were more relevant to cognitive function than the dietary patterns consumed by the REACH cohort. Earlier, rather than current, life experiences, including dietary patterns, may impact cognitive function in later years and future studies may need to consider these variables. The REACH study provides baseline data for a possible longitudinal study which may better show any associations of dietary patterns with cognitive decline and demonstrate changing dietary patterns in the older adult.

6.6. References

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Chapter Seven: Dietary patterns and metabolic syndrome study

This chapter presents the secondary finding of the REACH study – are there associations between the dietary patterns and metabolic syndrome in the older adult? The chapter is presented in manuscript format. This manuscript has been submitted to British Journal of Nutrition. This journal supports Green Open Access which allows the submitted manuscript under review to be included in this thesis.

Mumme, K., Conlon, C., von Hurst, P., Jones, B., Haskell-Ramsay, C., Stonehouse, W., Heath, A.-L. M., Coad, J., & Beck, K. 2020. Dietary patterns and metabolic syndrome in older New Zealand adults: the REACH study. *British Journal of Nutrition* (under review)

To align with this thesis, there are slight changes to formatting, layout, and referencing style of the currently submitted manuscript.

7.1. Abstract

Background: Metabolic syndrome is common in older adults and may be modified by the diet.

Objective: The aim of this study was to examine associations between *a posteriori* dietary patterns and metabolic syndrome in an older New Zealand population.

Methods: The REACH study included 366 participants (65-74 years, 36% male) living independently in Auckland, New Zealand. Dietary data was collected using a 109-item food frequency questionnaire with demonstrated validity and reproducibility for assessing dietary patterns, using principal component analysis. Metabolic syndrome was defined by the National Cholesterol Education Program Adult Treatment Panel III. Associations between dietary patterns and metabolic syndrome, adjusted for age, sex, index of multiple deprivation, physical activity, and energy intake were analysed using logistic regression analysis.

Results: Three dietary patterns explained 18% of dietary intake variation – 'Mediterranean style' (salad/leafy cruciferous/other vegetables, avocados/olives, alliums, nuts/seeds, shellfish and white/oily fish, berries), 'prudent' (dried/fresh/frozen legumes, soy-based foods, whole grains, carrots), and 'Western' (processed meat/fish, sauces/condiments, cakes/biscuits/puddings, meat pies/hot chips). No associations were seen between 'Mediterranean style' [OR = 0.75 (95% CI 0.53, 1.06), *P*=0.11] or 'prudent' [OR = 1.17 (95% CI 0.83, 1.59), *P*=0.35] patterns and metabolic syndrome after co-variate adjustment. The 'Western' pattern was positively associated with metabolic syndrome [OR = 1.67 (95% CI 1.08, 2.63), *P*=0.02]. There was also a small association between an index of multiple deprivation [OR = .04 (95% CI 1.02, 1.06), *P*<0.001] and metabolic syndrome.

Conclusion The current study provides further support for a Western dietary pattern being a risk factor for metabolic syndrome in an older population.

7.2. Background

Metabolic syndrome is a cluster of interrelated symptoms including insulin resistance, central adiposity, hypertension, dyslipidaemia, and hyperglycaemia (Eckel et al., 2010). These metabolic abnormalities are associated with an increased risk of developing type 2 diabetes mellitus (Ford et al., 2008), and with poorer cardiovascular disease outcomes (Gami et al., 2007, Mottillo et al., 2010). The global prevalence of metabolic syndrome is estimated to be three times that of type 2 diabetes mellitus, with one billion people estimated to have metabolic syndrome (Ogurtsova et al., 2017).

Age is one risk factor for metabolic syndrome (DiBello et al., 2009, Gentles et al., 2007, Cameron et al., 2007, Barbaresko et al., 2014, Panagiotakos et al., 2007, Cho et al., 2011, Wang et al., 2017, Asadi et al., 2019, Iwasaki et al., 2019, Osadnik et al., 2020, Hassannejad et al., 2018) along with the modifiable risk factors of diet and physical activity (Eckel et al., 2010, Rodriguez-Monforte et al., 2017). Evidence points to a diet high in fibre, and monounsaturated and polyunsaturated fats, being protective against metabolic syndrome (Chen et al., 2018, Esposito et al., 2004). However, diets contain combinations of foods, and a dietary pattern approach is able to identify additive or synergistic effects of foods and nutrients on health outcomes in a way that a measurement of a single food or nutrient cannot (Hu, 2002).

Several meta-analyses have explored associations between *a posteriori* dietary patterns (determined using factor or cluster analysis, or reduced rank regression) and metabolic syndrome. These meta-analyses had slightly different selection criteria but consistently found *a posteriori* dietary patterns containing food groups that would be considered unhealthy had a pooled odds ratio for metabolic syndrome between 1.18 [95% CI 1.08, 1.30] and 1.28 (95% CI 1.17, 1.40) in cross-sectional studies (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017) and a relative risk of 1.29 (95% CI 1.09, 1.52), representing moderate quality evidence, in cohort studies (Jayedi et al., 2020a). While associations between *a posteriori* dietary patterns containing healthy food groups and metabolic syndrome reported a pooled odds ratio for metabolic syndrome between 0.83 (95% CI 0.76, 0.90) and 0.86 (95% CI 0.79, 0.91) in cross-sectional studies (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017), the pooled evidence in cohort studies had a relative risk of 0.76 but was graded as low quality (95% CI 0.50, 1.15) (Jayedi et al., 2020a). Meta-analyses further stratifying the data by geography and sex did not find associations between dietary patterns containing "healthy" food groups and metabolic syndrome in Western cultures (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017) or in males (Rodriguez-Monforte et al., 2017).

There has been only one study exploring dietary patterns and metabolic syndrome in adults in the Australasia region - in Australia (*n* 2415, aged 45+ years) (Bell et al., 2015). A 'healthy' (whole grains,

fresh and dried fruit, low-fat dairy; and low in fried potatoes, alcohol, and soft drinks) dietary pattern was positively associated with a metabolically healthy profile [OR = 1.16 (95% CI 1.04, 1.29)] (Bell et al., 2015). No associations were seen for 'red meat and vegetable' [OR = 0.99 (95% CI 0.89, 1.10)] or 'refined and processed' [OR = 0.92 (95% CI 0.81, 1.04)] dietary patterns and metabolic syndrome (Bell et al., 2015).

Moreover, few studies internationally have been undertaken that were specific to the higher risk, older population. Studies have been conducted with adults older than 50 years (China, *n* 1006) (Sun et al., 2014) and populations with a mean age greater than 60 years (Hailili et al., 2020, Barbaresko et al., 2014, di Giuseppe et al., 2019). These studies reported inverse associations between dietary patterns with healthy food groups and metabolic syndrome. For example, a pattern containing red dates, gouji berries, dried fruit, nuts, and grains in a Chinese population (Urumqi cohort, *n* 4265) was protective (Hailili et al., 2020), as was one high in fruit and vegetables and low in red and processed meats in a German cohort (*n* 853) (di Giuseppe et al., 2019). In contrast, metabolic syndrome was positively associated with dietary patterns containing milk tea but not yoghurt in the Urumqi cohort (Hailili et al., 2020); legumes, beef, processed meat, and bouillon in a German population (*n* 905); (Barbaresko et al., 2014) and a 'Western' cluster (*n* 343) compared with a 'healthy' cluster (*n* 353) in an older Chinese population (Sun et al., 2014).

A posteriori dietary patterns are unique to a particular population. While dietary patterns have been identified in a representative sample of New Zealand adults (Beck et al., 2018, Steele et al., 2020), research is also needed to explore dietary patterns within specific sub-groups of the population. Older adults living in New Zealand are likely to have different dietary patterns than younger adults due to cohort effects (Beck et al., 2018) but will also differ from older adults in other countries due to the unique food supply and cultural elements of New Zealand. Moreover, it is necessary to examine associations between dietary patterns and diet-related health outcomes particularly as the risk of metabolic syndrome increases with age. This study aims to examine associations between *a posteriori* dietary patterns and metabolic syndrome in an older New Zealand population.

7.3. Methods

7.3.1. Study design and participants

This cross-sectional study includes participants from the REACH study where the primary aim was to explore associations between dietary patterns and cognitive function. This secondary outcome explores the associations between those same dietary patterns and metabolic syndrome in the older adult. A protocol describing the REACH study methodology was published earlier (Mumme et al.,

2019). Community-dwelling adults (aged 65-74 years) throughout the wider Auckland region, New Zealand, were invited to participate. Exclusions were based on the primary outcome of the REACH study i.e., any factors affecting cognitive function (Mumme et al., 2019). In addition, people were excluded if they came from the household of another REACH participant or had experienced any event in the past two years which had a substantial impact on dietary intake or cognitive function, e.g., death or illness of a family member.

Signing of informed consent forms and data collection took place at the Human Nutrition Research Unit, Massey University, Auckland, New Zealand, from April 2018 to February 2019. On the REACH research day, researchers collected health, demographic, lifestyle, physical activity, blood pressure, and anthropometric data, and a fasted blood sample. A food frequency questionnaire (FFQ) was completed by participants at this visit. The sample size of *n* 367 was based on the primary REACH outcome of cognitive function. Funding was provided by the Health Research Council of New Zealand, Grant 17/566. Ethical approval was granted by Massey University Human Ethics Committee: Southern A, Application 17/69.

7.3.2. Anthropometric data and blood pressure

For the height, weight, and hip and waist circumference measurements participants wore light clothing and no shoes. Height and weight were measured using a calibrated stadiometer and Tanita Electronic Scales. Waist and hip circumference were measured using a Lufkin W600PM flexible steel tape measure. Two measurements were taken for hip and waist. The mean value was used unless the second measurement differed by 1 cm or more from the first measurement. In this instance, a third measurement was taken and the median value used. The International Society for the Advancement of Kinanthropometry (ISAK) methods (Marfell-Jones et al., 2012) were followed. Blood pressure was measured using a Digital Automatic Blood Pressure Monitor (Omron HEM-907). Participants rested quietly (seated) for five minutes before the first measurement and there was a one-minute rest period before the second measurement. The mean blood pressure measurement was used unless either systolic or diastolic measurements differed by more than 5 mmHg from the first measurement. In this instance, a third measurement was taken, and the median value used. A whole-body scan using a Dual-emission X-ray absorptiometry (Hologic, Discovery QDR series), calibrated daily, measured muscle and fat mass, and calculated body fat % (Hiol et al., 2021).

7.3.3. Blood sampling and analysis

A qualified phlebotomist drew a fasted blood sample at the research facility. Whole blood was used to measure fasting blood glucose (HemoCue Glucose 201RT), lipid profile (total cholesterol, triglycerides, HDL-cholesterol) and HbA1c (both using Cobas b101 system (La Roche Ltd, 2018)).

7.3.4. Health, demographic, and physical activity data

Health, demographic, lifestyle, and physical activity information were obtained by written questionnaires during the research day visit. Data were checked for completeness and plausibility. Any queries were followed up on the research day or within a few days by phone or email. Demographic data included age, sex, ethnicity, education (secondary, post-secondary, university), living situation (with others, alone), first language, and index of multiple deprivation (score). Health data included past and current disease (acute, chronic), medication (list), and daytime sleepiness (how often are you excessively sleepy during the day? [never, rarely, frequently, often]) (Jaussent et al., 2012). Lifestyle data included physical activity level, smoking history (no, yes [current, past]), and supplement use (list).

The New Zealand Indices of Multiple Deprivation and participant's residential address determined the area deprivation score based on seven domains (Exeter et al., 2017). Polypharmacy was considered as five or more daily medicines (Masnoon et al., 2017). The International Physical Activity Questionnaire - short form (Craig et al., 2003) was used to assess physical activity levels. A physical activity score was calculated using Metabolic equivalent of a task (MET-minutes) where one minute of activity is 3.3, 4.0 or 8.0 METs depending on an exercise level of walking, moderate or vigorous activity, respectively. One MET is equivalent to the rate of energy expended while at rest (Craig et al., 2003).

7.3.5. Metabolic syndrome

The National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III) (Grundy et al., 2005, National Cholesterol Education Program (NCEP) Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III), 2002) definition determined metabolic syndrome within the REACH population. Based on this definition, metabolic syndrome was present where three of the following five criteria were met: waist circumference ≥88 cm for women and ≥102 cm for men; a triglyceride level of ≥1.7 mmol/L; HDL-cholesterol level of <1.03 mmol/L in men or <1.3 mmol/L in women; blood pressure ≥ 130/85 mmHg; fasting blood glucose ≥ 5.6 mmol/L or where medication was taken to control these (Grundy et al., 2005).

7.3.6. Collection of dietary data

An online, validated 109-item FFQ (Mumme et al., 2021) collected frequency and serving size data for foods eaten during the previous month. The FFQ had ten food categories and ten frequency response options ranging from "I never eat this food" to "6 plus times per day". For each participant and for each food item, a daily consumption quantity (g/d) was calculated. Missing values (<1% of all

FFQ items) were imputed using the multiple imputation chained equations method and the *mice* package (van Buuren and Groothuis-Oudshoorn, 2011) with five imputations and 20 iterations (dietary pattern scores from each imputation were checked for robustness i.e., z-scores within 0.1 standard deviation, five imputed data sets were averaged for final dietary data set). Predictors used in the multiple imputation chained equations method were food items, age, sex, education and living situation. Each FFQ food item had a representative food allocated so energy intake could be calculated using the New Zealand FOODfiles 2016 food composition database (New Zealand Institute for Plant & Food Research Ltd and Ministry of Health, 2016). Average daily energy intake was considered implausible if <2100 kJ or >14 700 kJ for women and <3360 kJ or >16 800 kJ for men (Willett, 2012). While data on supplement use was collected it was not included in the data for dietary patterns.

7.3.7. Construction of dietary patterns

The food items from the FFQ were reduced to fifty-seven groups based on similarity of foods and culinary usage (Table 4.1). The Bartlett's test of sphericity measured the presence of relationships within the data (P<0.001) and the Kaiser-Meyer-Olkin (KMO) measured the sampling adequacy (KMO = 0.66). Both demonstrated the dietary dataset was suitable for principal component analysis which reduces the diet components based on their correlations with one another while retaining as much variation within the diet as possible (McCann et al., 2001).

Using R, version 3.6.1 (R Core Team, 2019), the *psych* package (Revelle, 2020) and varimax rotation, the data matrix of food groups (g/d, n 57) was analysed. Three dietary patterns (factors) were retained based on the scree plot, eigenvalue (>1) and interpretability of the factors. Factor loadings measure the relative contribution (correlation) of a food group to a dietary pattern. Positive loadings contribute to a dietary pattern whereas negative loadings have an inverse association to the dietary pattern. Food groups with factor loadings ≥ 0.30 or ≤ -0.30 were considered significant contributors to the pattern for a sample size of 300 (Stevens, 2009). A standardised dietary pattern score was calculated per participant per dietary pattern using the regression method. Labelling of dietary patterns was based on highly correlated food groups and the type of dietary pattern those food groups characterised.

7.3.8. Statistical analysis

Statistical analysis was performed using R Studio (RStudio Team, 2020), R version 3.6.1 (R Core Team, 2019), and *tidyverse* (Wickham et al., 2019). No data were transformed prior to statistical analysis.

Participant data, with a roughly symmetric distribution, were described with mean and standard deviation for continuous data or frequency summary statistics for categorical data. The Welch two-sample t-test or Pearson chi-squared test was used to examine differences between the sexes and between participants with and without metabolic syndrome for characteristic variables. Where categorical variables did not have adequate samples in each category, the Fisher Exact test was applied. BMI and body fat % were categorised as follows: BMI (normal = 18.5-24.9, overweight = 25.0-30.0, obese >30.0 kg/m^2) (World Health Organization, 2000) and body fat % (obese is >25% males, >35% females) (Gallagher et al., 2000).

Logistic regression analysis was used to examine the association between each dietary pattern score (independent variable) and the prevalence of metabolic syndrome (dependent binary variable) while considering key confounding factors: age, sex, physical activity, index of multiple deprivation, and energy intake. With an older population, an Index of Multiple Deprivation was considered a better option to represent socio-economic status than income or education. The REACH population was homogenous in terms of ethnicity and this variable was excluded from further analysis. The first model was unadjusted and contained metabolic syndrome and the dietary pattern scores (Model 0). A second model included the confounding variables: age, sex, physical activity level, index of multiple deprivation, energy intake and other dietary pattern scores (Model 1). Odds ratios and 95% confidence intervals were calculated. Variables in the final regression model were checked for collinearity using the variance inflation factor (Fox and Sanford, 2019). The model showed no multicollinearity as no variables were above 5.0 (ranged 1.0 to 2.6).

To check for effect modifiers, interactions between dietary pattern scores (sex specific tertiles where appropriate) and sex, education, BMI groups, body fat % and energy intake; and between sex and education, BMI, body fat % and energy intake were tested.

7.4. Results

7.4.1. Participant characteristics

The REACH study recruited 371 participants. Figure 8 describes the flow of participants through the study. All participants had plausible energy intakes. Four participants were removed from the analysis due to no dietary data (*n* 3) or no blood data (*n* 1). The characteristics of the remaining 366 participants are presented in Table 7.1. The prevalence of metabolic syndrome was 15% and not different between the sexes (males 14%, females 16% *P*=0.64). Those with metabolic syndrome (*n* 56) had a higher BMI, a higher percentage of body fat, a higher level of deprivation, a lower 'Mediterranean style' dietary pattern score, a lower education (secondary level) and were more

likely to take five or more medications per day than participants without metabolic syndrome (Table 7.). Differences between the sexes in participants with metabolic syndrome were apparent. In those with metabolic syndrome, females (when compared with males) had a higher percentage of body fat (mean (SD) %, females 39 (4), males 28 (3), $P<0.001$), though not a higher BMI (mean (SD) kg/m^2, females 30 (5), males 31 (3), $P=0.55$), were more likely to live alone (females 39%, males 6%, $P=0.02$) and had a lower 'Western' dietary pattern score ($P=0.007$). Overall, 16% (*n* 57) were considered obese by BMI categories (>30 kg/m^2) and 11% (*n* 41) by body fat % categories (≥30% body fat [males] or ≥42% body fat [females]) (Table 7.1).

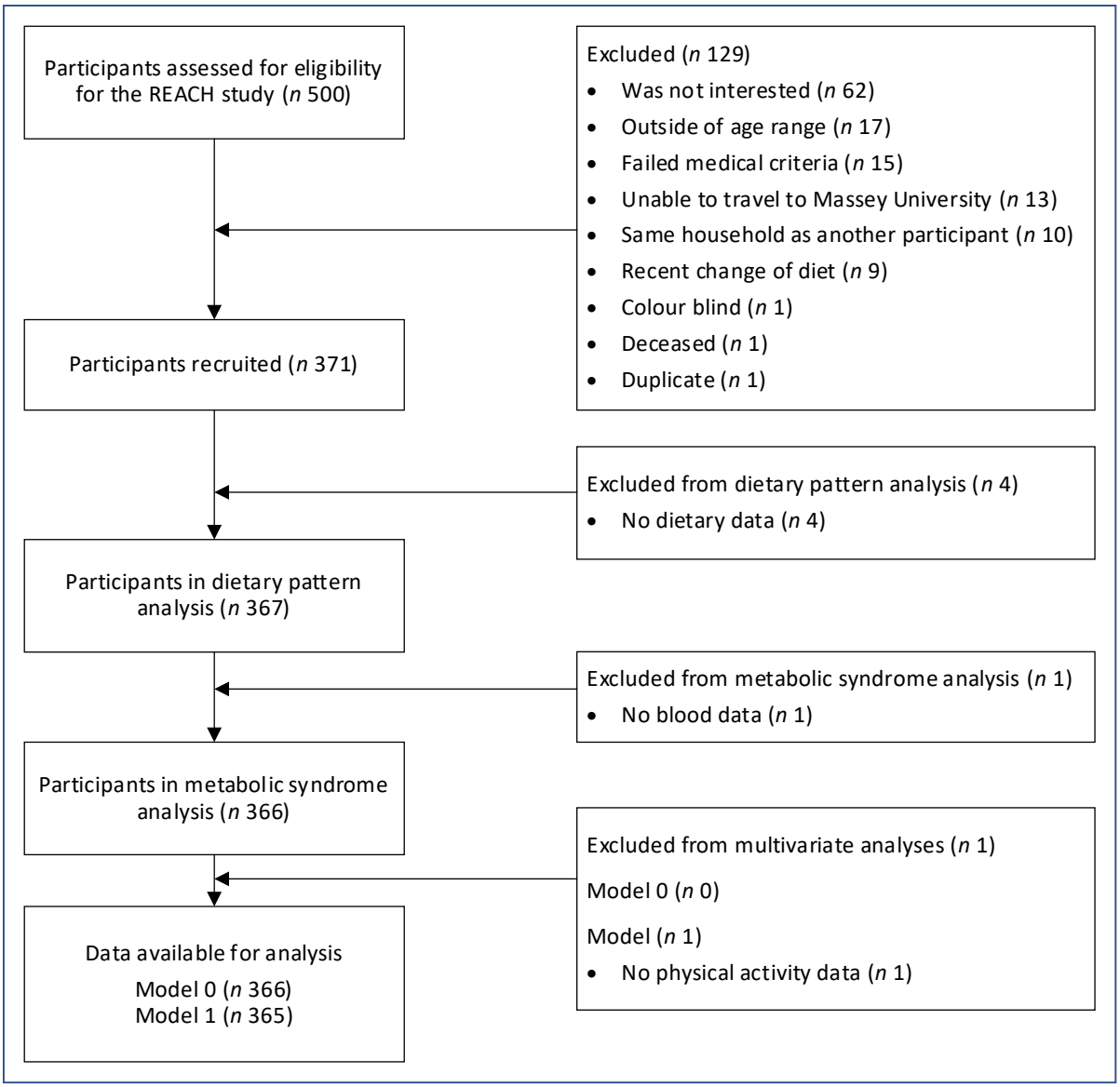

Figure 8: Flow of participants in the dietary patterns and metabolic syndrome study

Table 7.1: Characteristics of participants (*n* 366) with and without metabolic syndrome and their differences

Characteristic	Total	With metabolic syndrome	Without metabolic syndrome	
n (%)	366 (100%)	56 (15%)	310 (85%)	
Age (years) [Δ]	69.7 (2.6)	69.7 (2.6)	69.6 (2.5)	
Sex (% male) †	131 (36%)	18 (32%)	113 (36%)	
BMI (kg/m^2) [Δ]	26.3 (4.5)	30.6 (4.3)	25.5 (4.1)	***
Normal (<25 kg/m^2) [a] †	151 (41%)	2 (4%)	149 (48%)	***
Overweight (25-30 kg/m^2) †	158 (43%)	26 (46%)	132 (43%)	
Obese (>30 kg/m^2) †	57 (16%)	28 (50%)	29 (9%)	***
Body fat % [bΔ]	31.8 (7.5)	35.4 (6.2)	31.2 (7.5)	***
Not obese †	324 (89%)	44 (80%)	280 (90%)	
Obese †	41 (11%)	11 (20%)	30 (10%)	
Education †				
Secondary [c]	83 (23%)	20 (36%)	63 (20%)	*
Post-secondary	147 (40%)	17 (30%)	130 (42%)	
University	136 (37%)	19 (34%)	117 (38%)	
Employed (paid or volunteer) †	179 (49%)	25 (45%)	154 (50%)	
Ethnicity †				
Asian	11 (2%)	2 (4%)	9 (3%)	
European	345 (94%)	50 (89%)	295 (95%)	
Māori/Pacific	10 (3%)	4 (7%)	6 (2%)	
Index of Multiple Deprivation [dΔ] (Exeter et al., 2017)	1982 (949, 3206)	2998 (1834, 3539)	1835 (845, 3046)	***
Living †				
Alone	106 (29%)	16 (29%)	90 (29%)	
With others	260 (71%)	40 (71%)	220 (71%)	
Polypharmacy [e] †	31 (8%)	9 (16%)	22 (7%)	*
Physical activity [f, g] (MET minutes/week) [Δ]	3106 (1680, 5118)	2803 (1422, 3407)	3206 (1848, 5172)	
Smoker †				
Yes (current and 'used to')	77 (21%)	13 (23%)	64 (21%)	
No	289 (79%)	43 (77%)	246 (79%)	
Daily energy intake (MJ) [Δ]	7.6 (2.1)	7.6 (2.4)	7.6 (2.1)	
Dietary pattern score [hΔ]				
Mediterranean style	0.00 (1.00)	-0.27 (0.99)	0.05 (0.99)	*
Western	0.00 (1.00)	0.25 (1.11)	-0.05 (0.97)	
Prudent	0.00 (1.00)	0.06 (1.11)	-0.01 (0.98)	

[a] includes 3 participants (1 male, 2 female) with BMI <18.5 kg/m^2.

[b] one value missing from participant with metabolic syndrome. Obese is body fat % >30% (males) and >42% (females) (Gallagher et al., 2000).

[c] for education, 'no qualification' (n 9) and 'secondary' (n 74) were aggregated, due to small numbers.

[d] low score = least deprived, complete range = 1 to 6181.

Characteristic	Total	With metabolic syndrome	Without metabolic syndrome

[e] 5 or more medicines/d (Masnoon et al., 2017).
[f] one value missing from participant without metabolic syndrome.
[g] MET minutes/week based on 3.3 MET for walking, 4.0 MET for moderate activity and 8.0 MET for vigorous activity.
[h] standardised dietary pattern score based on regression method
[Δ] mean (standard deviation) or median (25^{th}, 75^{th} quartile), differences between those with and without metabolic syndrome calculated using the Welch two-sample t-test (continuous variables).
† n (%) differences between those with and without metabolic syndrome calculated using Pearson chi-squared test or Fisher Exact test (categorical variables).
P-value: *<0.05, **<0.01, ***<0.001

Of the 56 participants with metabolic syndrome, 55 participants were identified based on physical criteria and one participant was identified based on medication to control lipids and a high waist circumference. All five metabolic syndrome criteria were seen in five participants, four criteria in 18 and three criteria in 33 participants. The most prevalent metabolic criterion was high waist circumference (96%), followed by high blood pressure (91%), high triglycerides (74%), low HDL-cholesterol (63%), and high fasting blood glucose (26%).

7.4.2. Dietary patterns

Three dietary patterns were derived from the 109-item FFQ which explained 18% of the variation in dietary intake. Table 5.2 displays the dietary pattern loadings, range of dietary pattern scores, eigenvalues and the variance explained by each dietary pattern.

Dietary pattern 1, named 'Mediterranean style', was characterised by salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs; cheese; tomatoes; and all other fruit. The 'Mediterranean style' dietary pattern scores were associated with higher beta-carotene equivalents, vitamin E and folate intake (all $P<0.001$, all $R^2 \geq 0.26$) (Mumme et al., 2020).

Dietary pattern 2, named 'prudent', was characterised by dried legumes; soy-based foods; fresh and frozen legumes; wholegrains; carrots; and spices. The 'prudent' dietary pattern scores were associated with higher fibre and carbohydrate intake (both $P<0.001$, both $R^2 \geq,0.25$) (Mumme et al., 2020).

Dietary pattern 3, named 'Western', was characterised by processed meats; sauces and condiments; cakes, biscuits, and puddings; meat pies and chips; processed fish; confectionery; vegetable oils;

beer; chocolate; salad dressings; cheese; and sweetened cereal. The 'Western' dietary pattern scores were associated with higher daily energy intake ($P<0.001$, $R^2 = 0.43$) (Mumme et al., 2020).

These dietary patterns have been validated with a subset of the REACH study participants (*n* 294) (Mumme et al., 2021). The dietary pattern loadings obtained from the validation study subset were comparable to the full REACH cohort reported here. Tucker's congruence coefficient (phi) between the loadings of the FFQ derived dietary patterns (REACH validation subset v REACH full cohort) were 0.96, 0.91 and 0.88 for 'Mediterranean style', 'Western' and 'prudent' patterns respectively.

7.4.3. Metabolic syndrome and dietary pattern associations

No interactions between dietary patterns scores and sex, education, BMI groups, body fat %, and energy intake; and between sex and education, BMI, body fat % and energy intake were observed. In the base model (logistic regression analysis, model 0), metabolic syndrome was inversely associated with the 'Mediterranean style' pattern score [OR = 0.71 (95% CI 0.51, 0.96), *P*=0.03], not associated with the 'prudent' pattern [OR = 1.08 (95% CI 0.80, 1.40), *P*=0.59] and positively associated with the 'Western' pattern score [OR = 1.32 (95% CI 1.00, 1.73), *P*=0.05] (Table 7.2).

Model 1 included age, sex, physical activity, multiple deprivation, and energy intake as confounders. The inverse association (Model 0) between the 'Mediterranean style' pattern and metabolic syndrome was attenuated in Model 1 (*P*=0.11). On further examination, this association was attenuated when either the multiple deprivation score or energy intake was added independently into model 1. The 'prudent' dietary pattern was not associated with metabolic syndrome in Model 1. However, the positive association between the 'Western' pattern and metabolic syndrome strengthened [OR = 1.67 (95% CI 1.08, 2.63), *P*=0.02]. Model 1 showed a higher deprivation predicted metabolic syndrome although the association was small [OR = 1.04, (95% CI 1.02, 1.06), *P*<0.001] (Table 7.2).

Table 7.2: Logistic regression model showing associations between dietary patterns and metabolic syndrome

Coefficient	Model 0[a]	Model 1[b]
Mediterranean style	**0.71 (0.51, 0.96)***	0.75 (0.53, 1.06)
Prudent	1.08 (0.80, 1.40)	1.17 (0.83, 1.59)
Western	**1.32 (1.00, 1.73)***	**1.67 (1.08, 2.63)***
Age		1.03 (0.92, 1.16)
Sex		
Male (reference)		
Female		1.91 (0.94, 4.04)
Physical Activity		1.00 (0.98, 1.01)
Multiple deprivation score		**1.04 (1.02, 1.06)*****
Energy intake		0.99 (0.97, 1.01)

[a] *n* 366, unadjusted model containing metabolic syndrome and three dietary pattern scores, odds ratio [OR] (95% confidence interval [CI]).
[b] *n* 365, adjusted for dietary pattern scores, age, sex, physical activity, deprivation, and energy intake; missing data: physical activity score (*n* 1, without metabolic syndrome), OR (95% CI).
P-value: *<0.05, **<0.01, ***<0.001. OR>1 shows an increased risk or OR<1 shows a reduced risk for metabolic syndrome.

7.4.4. Sensitivity analysis

One outlying participant on the 'prudent' pattern had a standardised dietary pattern score of 8.31 ['prudent' score range of -2.49 to 8.31 (Table 5.2)]. This participant consumed significant servings of carrots, peas, canned beans, brown rice, and couscous each day but remained within our energy intake boundaries. A sensitivity analysis recalculated the odds ratio of the association between metabolic syndrome and the dietary patterns after removing this one participant. There were no differences in model 0 and model 1.

7.5. Discussion

A cross-sectional study of healthy, older (65-74 years), community-dwelling adults in Auckland, New Zealand, identified three *a posteriori* dietary patterns and explored their associations with metabolic syndrome. The three valid (Mumme et al., 2021) dietary patterns explained 18% of the variation in the diet of the REACH cohort – 'Mediterranean style', 'prudent', and 'Western'. The 'Mediterranean style' dietary pattern was inversely associated with metabolic syndrome, but the association was no longer significant when confounders (age, sex, index of multiple deprivation, energy intake and physical activity) were added in Model 1. The 'prudent' pattern was not associated with metabolic syndrome in any statistical models. The 'Western' dietary pattern was positively associated with metabolic syndrome, with age, sex, index of multiple deprivation, energy intake, and physical activity

included as possible confounders (Model 1). Having a higher level of deprivation was positively associated with metabolic syndrome.

The 'Mediterranean style' pattern shared similar components with the traditional Mediterranean diet, with foods such as vegetables, avocados, olives, tomatoes, nuts, seeds, oily fish, white fish, shellfish, and berries (Bach-Faig et al., 2011). The 'Mediterranean style' pattern was also similar to 'healthy' dietary patterns, consisting of vegetables, fruit, fish, poultry, and whole grains, identified in recent meta-analyses (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017). Mixed results, in both cross-sectional and cohort studies, are reported when it comes to associations between dietary patterns with these components, and metabolic syndrome (Fabiani et al., 2019, Jayedi et al., 2020a, Rodriguez-Monforte et al., 2017). The current study suggested that an increase of one standard deviation in the 'Mediterranean style' dietary pattern score, decreased the odds of having metabolic syndrome by 29%. However, the effects of multiple deprivation and energy intake independently attenuated the dietary pattern's association in model 1 and it was difficult to separate the interplay between these variables and the 'Mediterranean style' pattern. This weak 'Mediterranean style' dietary pattern finding is still of value as it directs focus to associations between metabolic syndrome, higher deprivation, higher energy intake (diet quantity) and the 'Mediterranean style' pattern (diet quality). Further observational studies should consider these variables.

Interestingly, the 'prudent' dietary pattern had no association with metabolic syndrome, even though it shared components of the 'healthy' dietary patterns covered by meta-analyses e.g., vegetables and whole grains, though it lacked fruits, fish, and poultry (Fabiani et al., 2019, Rodriguez-Monforte et al., 2017). This was surprising considering the high levels of fibre associated with this pattern and the protective effects of fibre on metabolic syndrome (McKeown et al., 2004, Chen et al., 2018). However, this 'prudent' pattern did contain only a limited range of foods (legumes, carrots, whole grains, and spices), and some of these food groups included processed foods such as canned baked beans, refried beans (dried legumes food group) and vegetarian sausages and burgers (soy-based foods food group) which may have blunted the beneficial effects of these food groups on health outcomes.

The 'Western' dietary pattern maintained an association with metabolic syndrome even when multiple deprivation and energy intake were held constant (Model 1). This pattern showed similarities to the 'Western' dietary patterns in other studies (Rodriguez-Monforte et al., 2017, Fabiani et al., 2019) with common components such as processed meats, confectionery, chocolate, puddings, and refined grains. Cross-sectional and cohort studies support a positive association between a dietary pattern with components of unhealthy food groups and metabolic syndrome

(Rodriguez-Monforte et al., 2017, Jayedi et al., 2020a, Fabiani et al., 2019). In this current study, an increase of one standard deviation in the 'Western' dietary pattern score increased the odds of metabolic syndrome by 67%. Of note was the wide confidence interval which is consistent with an association as small as 8% or as large as 163%.

Other studies in older populations have found associations between dietary patterns and metabolic syndrome. In a German population (*n* 853, mean age = 61 years), a 'SELONOP' dietary pattern (containing fruit, vegetables, and antioxidant beverages) was inversely associated with metabolic syndrome [OR = 0.54 (95% CI 0.40, 0.73)] (di Giuseppe et al., 2019). 'Traditional' (containing rice, beans, and oils) (Noel et al., 2009), and 'legumes, beef, processed meat and bouillon' (Barbaresko et al., 2014) dietary patterns were positively associated with metabolic syndrome in Puerto Rican (*n* 1165, mean age ~60 years, [OR = 1.70, (95% CI 1.04, 2.70)]) and German (*n* 905, mean age = 61 years, [OR = 1.71, (95% CI 1.04, 2.79)]) populations, respectively.

The prevalence rate for metabolic syndrome in the current study was 15%. This is in line with an earlier New Zealand study (35-74 years) that reported a prevalence rate of 16% in an "Others" (excludes Māori and Pacific but includes New Zealand European) population (Gentles et al., 2007), although another New Zealand study found the prevalence of metabolic syndrome in Europeans aged 60-79 years to be 22% for males and 31% for females (Simmons and Thompson, 2004). Both studies used the NCEP-ATP III definition. The differences in prevalence between this current study and that of Simmons and Thompson (2004) may be due to markedly different deprivation levels – Simmons and Thompson (2004) based their study in South Auckland which has higher levels of deprivation (School of Population Health, 2018) than North Auckland where the current study was based. This once again highlights the complex interplay between deprivation and metabolic syndrome.

In the current study, the odds of metabolic syndrome increased with deprivation. Holding all other variables constant, for each 100-point increase in deprivation (score range 1 to 6181) the odds of metabolic syndrome increased between 2 and 6%. This is not surprising; deprivation and chronic diseases such as metabolic syndrome are related (Mirmiran et al., 2020) both due to a healthy diet having a higher financial cost (Darmon and Drewnowski, 2015), and because access to primary medical care is reduced when there is a cost barrier (Jatrana and Crampton, 2020) such as in New Zealand where primary health care is subsidised but not fully paid for by the Government. It is important to note that the current study used a multiple deprivation index, an approach that is not commonly used in other studies examining the association between *a posteriori* dietary patterns and metabolic syndrome. Sometimes a socio-economic status indicator (based on combinations of

education, income, occupation, and household assets) have been included in other studies (Deshmukh-Taskar et al., 2009, Hailili et al., 2020, Heidemann et al., 2011). While associations between the dietary patterns and metabolic syndrome were reported in these studies, it is not known how the socio-economic status affected the association other than as a confounding variable. Our deprivation score is based on residential address, but this has limitations within our cohort, as several participants were living with family which may not accurately reflect their true socioeconomic status.

In this current study, age, sex, physical activity, and energy intake were not significant predictors of metabolic syndrome. The narrow age range (10 years) in this study may not have provided sufficient variation to detect an association with metabolic syndrome. The prevalence of metabolic syndrome is steeper in females than males (Pucci et al., 2017). The driver behind this difference is an increase in abdominal obesity and a decrease in HDL-cholesterol levels in females after menopause (Pucci et al., 2017). Even so, there were no sex differences in the prevalence or as a predictor of metabolic syndrome in this current study. Adding energy intake to the model attenuated the association between the 'Mediterranean style' dietary pattern and metabolic syndrome to the point that it was no longer statistically significant. However, the association observed with the 'Western' pattern was retained, and in fact strengthened, suggesting that it resulted from the composition of the foods eaten, beyond just their energy content. Including energy intake as a possible confounder is important, though it is common for energy intake to be excluded from analyses (Rodriguez-Monforte et al., 2017) leaving ambiguity about any true effect of a dietary pattern itself.

Though BMI is recommended as an important confounder due to it being a well-defined risk factor for developing metabolic syndrome (Rodriguez-Monforte et al., 2017), BMI (and body fat %) were excluded as confounders in this study. Both BMI and body fat % were highly correlated with waist circumference which was one (of five) measure used to define metabolic syndrome and considered to be in the causal pathway (Hardy et al., 2021). In this older population, waist circumference was the most prevalent component of metabolic syndrome followed closely by hypertension, as has been reported by others (Barbaresko et al., 2014, Simmons and Thompson, 2004). This can be expected as increasing central obesity and hypertension are both associated with age (Jayedi et al., 2020b, Lloyd-Jones et al., 2000).

This study has several strengths. To our knowledge, this is the first study in an older New Zealand population to explore associations between dietary patterns and metabolic syndrome. A full set of confounders was used in the analyses. Validated tools were used to collect physical activity and

dietary data which produced robust dietary patterns (Mumme et al., 2021) specific to our study population.

However, the findings of this current study also have limitations. First, the New Zealand has population groups with high prevalence of metabolic syndrome – 32% of Māori and 39% of Pacific people (Gentles et al., 2007). Our sampling did not capture these population groups hence our findings are not representative of the New Zealand population overall. In addition, our participants were self-selecting and more likely to be 'health motivated'. This study reports a secondary outcome of the REACH study and an *a priori* power calculation was not calculated for this outcome, therefore our findings may not have statistical power. Despite the FFQ being validated there remains inherent measurement errors associated with assessing dietary intake with any method used. It was also assumed that the current dietary data collected was the usual diet for our participants. Finally, this study is cross-sectional and while known potential confounders were adjusted for, we cannot infer a particular dietary pattern has a causal effect on metabolic syndrome.

7.5.1. Conclusion

In an older New Zealand population group of primarily European adults, the 'Western' dietary pattern, explaining 6% of the variation in the diet, was positively associated with metabolic syndrome. Also, of importance, was the observed positive association between higher deprivation and metabolic syndrome. However, these results cannot be applied to the New Zealand population in general. Further observational studies in a larger representative sample of the New Zealand older population, including Māori and Pacific people, and those with higher deprivation may identify further associations with a dietary pattern with healthy or unhealthy food groups. The current study provides further support for a Western dietary pattern being a risk factor for metabolic syndrome in older people, an understudied population group. Future research on metabolic syndrome should consider deprivation as a confounder.

7.6. References

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Chapter Eight: Discussion

This chapter concludes the thesis. The outline and main results of the thesis are summarised. The impact of this research and results are discussed and areas for further research are suggested.

The main aim of this thesis was to explore associations between the dietary patterns and cognitive function and metabolic syndrome in older adults living in New Zealand. To achieve this aim, a valid FFQ was required to obtain consistent and robust dietary patterns using principal component analysis. With a subset of the REACH cohort, the REACH FFQ and their derived dietary patterns were examined for reproducibility (against a second administration of the same FFQ) and for relative validity (against a four-day food record). From this validation study, the REACH FFQ and its derived dietary patterns had acceptable reproducibility and relative validity. Thus, the REACH FFQ was suitable to derive dietary patterns to examine associations with cognitive function and metabolic syndrome in older adults

With confidence, three dietary patterns, 'Mediterranean style', 'Western', and 'prudent', were derived from the full REACH dietary data set explaining 18% of the variation within the diet. The 'Mediterranean style' dietary pattern consisted of salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs; cheese; tomatoes; and all other fruit. This dietary pattern was associated with higher intakes of beta-carotene, folate, and vitamin E. The 'Western' dietary pattern consisted of processed meat; sauces and condiments; cakes, biscuits, and puddings; meat pies and chips; processed fish; confectionery; vegetable oils; beer; chocolate; salad dressings; cheese; and sweetened cereal. This dietary pattern was associated with higher energy intake. The 'prudent' dietary pattern consisted of dried legumes; soy-based foods; fresh and frozen legumes; whole grains; carrots; and spices. The 'prudent' dietary pattern was associated with higher intakes of carbohydrates and fibre. The loadings from the three dietary patterns were comparable with the validation study dietary patterns.

The REACH cohort consisted of 367 healthy, community-dwelling adults aged between 65 and 74 years from the Auckland region. The cohort was primarily European, educated, and food secure. Further analysis provided insights regarding the socio-demographics of the participants in the study. Being female correlated with living alone and a higher episodic memory score but a lower education level and lower energy and alcohol beverage intake than males. Participants with metabolic syndrome had a higher BMI, body fat %, and level of deprivation, a lower 'Mediterranean style'

dietary pattern score and were more likely to take five or more medications per day than participants without metabolic syndrome.

The 'Mediterranean style' dietary pattern was associated with being female, having a university education, and being physically active. The 'Western' dietary pattern was associated with being male, having a secondary education (males only), living with others, and a higher alcohol beverage intake. The 'prudent' dietary pattern was associated with being physically active and a low alcohol beverage intake.

Despite this well-designed and conducted study, the REACH dietary patterns were not associated with either global cognition; attention and vigilance; executive function; episodic memory; working memory; or spatial memory domains. Instead, the cognitive domains showed associations with age, education, sex and the *APOE* -ε4 allele suggesting these factors influence cognitive function more than current dietary patterns. Few studies examining dietary patterns and cognitive function have reported null findings and there is a possibility that other null findings have not been reported (Allès et al., 2012). Studies with null findings are still part of the research process. It is important to report them as this information may limit further resources being applied to similar hypotheses (Campbell et al., 2020). Instead, research in this area can either move forward by focussing on important determinants of cognitive health in older people e.g., earlier life dietary patterns and education, or further confirm, with robust methods, that dietary patterns in older adults are or are not associated with cognitive function at 65 to 74 years. Whichever way, dietary effects on cognition remain complex and effects may vary due to social, cultural, or geographic perspectives such as cooking methods, sharing meals, mindful eating, and lifestyle values (Chen et al., 2018).

While there were no associations observed between the dietary patterns and cognitive function, a positive association between the 'Western' dietary pattern and metabolic syndrome emerged. This finding adds to the moderate body of evidence where dietary patterns containing food groups considered unhealthy increase the odds of metabolic syndrome (Jayedi et al., 2020). This finding suggests reducing the prominent food groups in the 'Western' dietary pattern by one standard deviation may reduce the odds of metabolic syndrome by 40%. There was also an inverse association between metabolic syndrome and the 'Mediterranean style' dietary pattern which was attenuated when deprivation or energy intake was added to the model.

A higher multiple deprivation score was positively associated with metabolic syndrome. Targeting metabolic syndrome by a move away from a 'Western' dietary pattern has many challenges including an environment of abundant and easily accessible unhealthy foods (Mackay et al., 2021). Nevertheless, knowledge of the socio-demographic and lifestyle factors associated with the

'Western' dietary pattern can assist public health interventions by targeting males, those with a secondary education (males only), those living with others, or with a higher alcohol beverage intake. In addition, less healthy food groups in the 'Western' pattern (processed meats; sauces and condiments; and cakes, biscuits and puddings) can be targeted for reformulation to reduce saturated fat, sugar and sodium content (Steele et al., 2020, Mackay et al., 2021). Also, the display of Health Star Ratings on food packages can be mandated which may guide consumers towards healthier choices (Mackay et al., 2021).

In addition, this study has provided an important descriptive statistic for the European population living in Auckland aged between 65 and 74 years, being the prevalence of metabolic syndrome at 15%. Reducing the prevalence of metabolic syndrome has a substantial effect on reducing the risk of type 2 diabetes mellitus and cardiovascular disease and may also reduce the risk of vascular dementia and cognitive decline (Ford et al., 2008, Atti et al., 2019, Gami et al., 2007, Mottillo et al., 2010, Siervo et al., 2014). With so many gains, less adherence to a 'Western' dietary pattern has substantial financial benefits to society and will have a positive impact on mortality.

8.1. Strengths and limitations

Despite the limitations of a cross-sectional study design i.e., causality cannot be inferred, this thesis has many strengths. The primary strength being the use of valid and reliable tools adding credibility and robustness to the study's results. Though an FFQ is limited by self-reporting, the valid REACH FFQ is suitable to collect dietary data and derive dietary patterns to examine relationships between these patterns and health outcomes in the older New Zealand population. Protocols were followed for collecting anthropometry data, measuring blood pressure, and collecting and testing blood samples. Physical activity data was collected using a validated questionnaire. Body fat % was accurately measured using Dual-emission X-ray Absorptiometry (DeXA). A proven battery of cognitive tests, sensitive to nutrition effects, were used to assess the cognitive function of the REACH participants in a facility controlled for environmental factors. Additionally, using the software platform, Computerised Mental Performance Assessment System (COMPASS-Northumbria University, Newcastle upon Tyne, UK) removed any administration bias. Furthermore, the data collected allowed for an array of confounders including the *APOE*-ε4 genotype to be included in the analysis. A second strength of this thesis was the *a priori* power calculation to ensure the sample size was adequate to detect any associations between dietary patterns and cognitive function.

Recruiting a well-rounded, representative sample of the population is challenging (Harada et al., 2013) and this thesis included a self-selected sample thus was not representative of the New Zealand older population. The sample was largely European which increased the internal validity of

the results as the dietary patterns were less influenced by ethnic eating styles. However, other ethnic groups within New Zealand were not well represented in this sample. This was a major limitation of the study. One such group is Māori, the tangata whenua of New Zealand. Māori have disproportionately negative health and well-being outcomes, therefore it is crucial to involve Māori in health research to limit the risk of increasing health disparities and to progress research for improving health outcomes (Māori Health Committee, 2010, National Health Medical Research Council, 2003). In future, this limitation could be avoided by partnering with research associates who have access to other population groups and the knowledge to ensure research methods are appropriate for those participating groups. Furthermore, the European population studied was not representative of the New Zealand European population. The REACH population had a higher level of university education (37% v 13%) and a higher level of food secure households (96% v 59%) compared with the New Zealand population (University of Otago and Ministry of Health, 2011, Stats NZ, 2021). Regardless, the study had good acceptance by the participants who were interested in the study progress and results.

It is difficult to say if the results would have been different with a more representative New Zealand population. Firstly, there may have been ethnic differences between the dietary patterns based on the findings of Beck et al (2018). Secondly, although the level of education was high, the cognitive scores showed variability with the MoCA scores ranging from 12 to 30 (Table 6.2) so it is likely a null finding may still appear. Thirdly, a broader range of index of multiple deprivation scores may show stronger associations with the dietary patterns, metabolic syndrome and possibly cognition. Finally, greater ethnic variability is likely to increase the prevalence of metabolic syndrome, strengthening any metabolic syndrome result through increased power and possibly identifying an association between metabolic syndrome and another dietary pattern.

Even though the FFQ showed good reproducibility and acceptable relative validity for measuring food group intake, it may still be limited by measurement error such as underreporting or omitting intakes of food groups due to sex, BMI or social desirability. In this study the dietary patterns relied on the ranking of the food group intakes rather than the absolute intake thereby minimising some reporting errors from the FFQ. However, errors may still exist through poor recall and limitations of food composition databases when estimating energy intake.

A narrow age band (65-74 years) was chosen to minimise age dependency of risk factors (Legdeur et al., 2018) and to diminish the effects of age on cognitive function. However, decline in cognitive status starts well before the sixth decade (Salthouse, 2009) and later years may not be an effective starting point for interventions if decline is already underway (Salthouse, 2019). Therefore, collecting

dietary and cognitive function data in mid-life may be more effective as a baseline for capturing changes in cognition status.

8.2. Future directions and concluding items

Following this thesis, there is much scope for further research from methodology to developing tools for a public health intervention. For example,

1. This thesis provides baseline data and an opportunity to collect longitudinal data to explore changes in dietary patterns, cognition status, metabolic syndrome status and other health outcomes.
2. Exploring the relationship between the whole diet and health outcomes requires robust dietary patterns. Clear methodologies are available to examine reproducibility and relative validity of the derived dietary patterns, but this is limited by subjective methods used to determine similarity between the dietary patterns. Therefore, further research to clarify a comparison method is required to provide further guidance to researchers.
3. There have been many studies exploring dietary patterns and cognitive function in recent years. There is heterogeneity within the methods used in these studies and a new systematic review may be required to highlight the inconsistencies and suggest dependable methods.
4. Only the food group intake from the FFQ was examined for reproducibility and relative validity but not the nutrient intakes identified from the FFQ and 4-day food record, therefore, a further validation study may provide further use and purpose for the REACH FFQ in older adults.
5. The REACH dietary patterns are specific to the demographics of an older educated European adult living in New Zealand, already a well-studied group. The knowledge gained from this study does not contribute towards reducing the healthy inequities of other New Zealand populations. Therefore, identifying dietary patterns (and their associations) in other ethnicities may assist with improving health outcomes and inequalities.
6. Further research is warranted, in a case-control design (to oversample people with metabolic syndrome), to explore associations between dietary patterns and metabolic syndrome in other New Zealand populations e.g., Māori and Pacific populations.
7. Even though dietary patterns were not associated with cognitive function, through metabolomics, a further study could examine the metabolome to look for blood biomarkers which may be associated with cognitive function, metabolic syndrome, the dietary patterns, or the nutrients associated with each dietary pattern.

8. Nutrient data can help explain mechanisms for health outcomes. Nutrient patterns derived from the nutrients of the REACH FFQ can create a different picture and be used to explore associations between nutrient patterns and health outcomes.
9. Dietary patterns using reduced rank regression provides further understanding of dietary intake and may be more closely associated with health outcomes. Using an inflammation blood marker or another biomarker (e.g., from metabolomic analysis), further dietary patterns may be identified, and health outcome associations explored.
10. There are many *a priori* indices which could be applied to the REACH dietary data and associations to health outcomes can be explored. Relevant indices would include the Mediterranean Diet Index, DASH, the World Cancer Research Fund index.

To conclude, with regards to deriving and validating dietary patterns, further research to develop adequate guidelines to support best practice may improve the quality of evidence. Furthermore, consistent methodology e.g., cognitive testing and food grouping, will improve heterogeneity and is likely to produce more conclusive and comparable results in studies examining associations between dietary patterns and health outcomes. This thesis was novel by examining dietary patterns in the older adult living in New Zealand and their associations with cognitive function and metabolic syndrome. Current evidence was reinforced where a dietary pattern with unhealthy food groups is likely to result in less favourable health outcomes e.g., metabolic syndrome. Action is required to transition older people following the 'Western' dietary patterns toward healthier food options or improving food quality through reformulation. Healthy ageing is beneficial at all levels. From maintaining independence and quality of life in later years, reducing the burden of care from families to savings in healthcare and residential care costs. However, consistent dietary pattern methodology is required to reach the next steps.

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Appendices

9.1. Statement of Contribution for each manuscript or publication

9.1.1. Chapter three

DRC 16

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Karen Mumme
Name/title of Primary Supervisor:	Associate Professor Kathryn Beck
In which chapter is the manuscript /published work:	Chapter Three

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Mumme, K., von Hurst, P. R., Conlon, C. A., Jones, B., Haskell-Ramsay, C. F., Stonehouse, W., Heath, A.-L. M., Coad, J. & Beck, K. L. 2019. Study protocol: Associations between dietary patterns, cognitive function and metabolic syndrome in older adults – a cross-sectional study. BMC Public Health. 19. 535. DOI: 10.1186/s12889-019-6900-4

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Karen Mumme Digitally signed by Karen Mumme Date: 2021.07.12 16:57:21 +12'00'
Date:	
Primary Supervisor's Signature:	Kathryn Beck Digitally signed by Kathryn Beck DN: cn=Kathryn Beck, c=NZ, o=Massey University, email=k.l.beck@massey.ac.nz Date: 2021.07.22 08:56:26 +12'00'
Date:	

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

GRS Version 5 – 13 December 2019
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9.1.2. Chapter four

Now published - DOI: 10.1016/j.jand.2021.05.022

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STATEMENT OF CONTRIBUTION
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We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Karen Mumme
Name/title of Primary Supervisor:	Associate Professor Kathryn Beck
In which chapter is the manuscript /published work:	Chapter Four

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Mumme K, Conlon C, von Hurst PR, Jones B, de Seymour J, Health A-L, Stonehouse W, Coad J, Haskell-Ramsay C, Beck KL, (in press) Relative validity and reproducibility of a food frequency questionnaire for assessing dietary patterns and food group intake in older New Zealand adults: The REACH studv. J Acad Nutr Diet.

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Karen Mumme Digitally signed by Karen Mumme Date: 2021.07.12 16:57:51 +12'00'
Date:	
Primary Supervisor's Signature:	Kathryn Beck Digitally signed by Kathryn Beck DN: cn=Kathryn Beck, o=NZ, o=Massey University, email=k.l.beck@massey.ac.nz Date: 2021.07.22 09:02:59 +12'00'
Date:	

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9.1.3. Chapter five

DRC 16

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Karen Mumme
Name/title of Primary Supervisor:	Associate Professor Kathryn Beck
In which chapter is the manuscript /published work:	Chapter Five

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Mumme, K., Conlon, C., von Hurst, P., Jones, B., Stonehouse, W., Heath, A.-L. M., Coad, J., Haskell-Ramsay, C., de Seymour, J. & Beck, K. 2020. Dietary patterns, their nutrients, and associations with socio-demographic and lifestyle factors in older New Zealand adults. Nutrients, 12 (11). 3425. DOI: 10.3390/nu12113425

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

Karen searched the literature, analysed and interpreted the data, drafted, wrote,and submitted the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Karen Mumme Digitally signed by Karen Mumme Date: 2021.07.12 16:59:01 +12'00'
Date:	
Primary Supervisor's Signature:	Kathryn Beck Digitally signed by Kathryn Beck DN: cn=Kathryn Beck, c=NZ, o=Massey University, email=k.l.beck@massey.ac.nz Date: 2021.07.22 09:01:09 +12'00'
Date:	

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9.1.4. Chapter six

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We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Karen Mumme
Name/title of Primary Supervisor:	Associate Professor Kathryn Beck
In which chapter is the manuscript /published work:	Chapter Six

Please select one of the following three options:

○ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

◉ The manuscript is currently under review for publication – please indicate:

- The name of the journal:

European Journal of Nutrition

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00
- Describe the contribution that the candidate has made to the manuscript/published work:

Dietary patterns and cognitive function in older New Zealand adults: the REACH study
Candidate conducted research, analysed data and performed statistical analysis, wrote paper, had primary responsibility for final content

○ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Karen Mumme Digitally signed by Karen Mumme Date: 2021.07.12 17:02:26 +12'00'
Date:	
Primary Supervisor's Signature:	Kathryn Beck Digitally signed by Kathryn Beck DN: cn=Kathryn Beck, o=NZ, o=Massey University, email=k.l.beck@massey.ac.nz Date: 2021.07.22 08:56:55 +12'00'
Date:	

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9.1.5. Chapter seven

DRC 16

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Karen Mumme
Name/title of Primary Supervisor:	Associate Professor Kathryn Beck
In which chapter is the manuscript /published work:	Chapter Seven

Please select one of the following three options:

○ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

◉ The manuscript is currently under review for publication – please indicate:

- The name of the journal:

British Journal of Nutrition

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00

- Describe the contribution that the candidate has made to the manuscript/published work:

Associations between dietary patterns and metabolic syndrome in older New Zealand adults: the REACH study
Candidate conducted research, analysed data and performed statistical analysis, wrote paper, had primary responsibility for final content

○ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Karen Mumme Digitally signed by Karen Mumme Date: 2021.07.12 17:01:15 +12'00'
Date:	
Primary Supervisor's Signature:	Kathryn Beck Digitally signed by Kathryn Beck DN: cn=Kathryn Beck, c=NZ, o=Massey University, email=k.i.beck@massey.ac.nz Date: 2021.07.22 08:59:34 +12'00'
Date:	

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9.2. Recruitment documents

This section contains the information sheet, poster and screening form used during the recruitment of REACH participants. These forms were not created by the PhD candidate but have been included in the Appendix to ensure complete documentation of the recruitment process for the REACH study.

9.2.1. Recruitment poster

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

The REACH Study

(Researching Eating Activity and Cognitive Health)

Are you 65-74 years of age?

The School of Sport, Exercise & Nutrition at Massey University is undertaking a study investigating dietary patterns and associations with cognitive function and other health outcomes associated with aging.

All participants will receive

- **$50 on completion of the study** (In the form of a voucher)
- **FREE breakfast**
- **FREE body composition, blood lipid, blood glucose and blood pressure assessments.**

Can you help?

If you can, you will be required to:

- Complete a short screening questionnaire
- Visit the Massey University Human Nutrition Research Unit in Albany to:
  - Answer questionnaires about physical activity and nutrition
  - Complete tests measuring cognitive function, grip strength & body composition
  - Provide a small blood sample
  - Complete questions about your food intake at home

For more information please get in touch:

www.massey.ac.nz/reachstudy

email: reachstudy@massey.ac.nz

Phone: (09) 213 6859

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 17/69. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 90999 85094, email humanethicsoutha@massey.ac.nz.

9.2.2. Screening questionnaire

Participants were screened prior to being invited to join the REACH study (not prepared by PhD candidate)

The REACH Study – Researching Eating Activity and Cognitive Health

Screening Questionnaire

Thank you for your interest in our research project. To ensure that you meet the inclusion criteria of the study, we would appreciate if you could answer the questions below. If you have any queries or concerns about the form, please contact Owen Mugridge or Cassie Slade during working hours on 09 414 0800 ext 43650 (Owen) or 09 414 0800 ext 43859 (Cassie) or send an email to reachstudy@massey.ac.nz.

When you have completed this form, please use the enclosed postage-paid envelope to return it to Owen Mugridge, School of Sport Exercise and Nutrition, Massey University, Albany, Auckland or email the form to reachstudy@massey.ac.nz. Alternatively, one of our researchers can take you through this questionnaire over the phone.

Name: _____

Gender (Please tick):

Female □

Male □

Gender Diverse □

Date of birth (date/month/year): _____

Telephone number(s): _____

Email address: _____

Postal address:

Number and street name _____

Suburb _____

Postcode _____

Medical Practitioner/Practice:

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

Yes □ No □

Are you living independently? (ie. do not require assistance with daily activities or 24/7 skilled nursing).

Yes □ No □

Are you proficient in English?

Yes □ No □

Have you ever been diagnosed with any of the following:

Indicate √ yes **X** no

Stroke	
Traumatic head / brain injury	
Dementia	
Mild cognitive impairment	
Other neurological condition	
Psychiatric condition	
Colour blindness	

If yes, please provide more details:

_____

Are you currently suffering from any other illness not listed above that could affect your brain function? (Please provide details)

_____

_____

Are you taking any form of medication, including traditional or homeopathic medicine?
Yes □ No □

Please specify the condition, the medication and the dosage in the table provided.

Condition	Medication	Dosage & Frequency

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

Yes □ No□

If yes, what are the name, brand and dosage of the supplements you are taking?

Supplement	Brand	Dosage & Frequency

Is there anything that has occurred in the past year or two that has impacted on your dietary intake or cognitive function? (eg. Death or illness of a partner, caring for family members)

_____

_____

_____

How has this impacted on your dietary intake / cognitive function?

_____

_____

_____

Thank you for your time, we will contact you shortly.

Te Kunenga ki Pūrehuroa

Massey University – School of Sport, Exercise and Nutrition, College of Health
Private Bag 102904, North Shore, Auckland 0745, New Zealand **T** +64 9 213 6653 **www.massey.ac.nz**

9.2.3. Information Sheet

Participants received a study information sheet when expressing their interest in the study (not prepared by PhD candidate)

The REACH Study – Researching Eating Activity and Cognitive Health

INFORMATION SHEET

Researchers Introduction

We would like to invite you to take part in the REACH (Researching Eating Activity and Cognitive Health) Study. The purpose of the study is to identify dietary patterns in older adults and explore their association with cognitive function. We will also look at other health outcomes associated with aging, including novel metabolic biomarkers, genetics, and factors influencing mobility. This study is being conducted by a group of researchers from Massey University and the University of Otago, New Zealand and overseas (who are listed at the end of the information sheet).

Please read this Information Sheet carefully before deciding whether or not to participate.

The lead researchers for this study are Dr Kathryn Beck and Owen Mugridge.

Dr Kathryn Beck
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Phone: (09) 414 0800 x 43650

Project Description and Invitation

The New Zealand population is ageing, with 21% of the population expected to be over 65 years by 2031. Optimising cognitive function for as long as possible is critical for successful ageing. Diet and lifestyle are important factors to prevent cognitive decline. However, to date most research has focused on single nutrients (eg. omega 3) and foods (eg. fish). This has several limitations as people do not consume foods and nutrients in isolation but as combinations of foods and nutrients resulting in dietary patterns. 'Dietary patterns' (a relatively new approach to assessing dietary intake) capture the overall complexity of the diet. Overseas research has linked dietary patterns to health outcomes including cognitive function. However, very little research has considered dietary patterns in the context of genetics, and other lifestyle factors (eg. physical activity). This study aims to identify dietary patterns in older adults living in New Zealand and explore their association with cognitive function and other health outcomes associated with aging.

Participant Identification and Recruitment

Who are we looking for?

We are looking for 360 male and female volunteers to participate in this study. To take part in this study you should:

- Be between 65-74 years of age
- Be living independently (not requiring assistance with daily activities or 24/7 skilled nursing)
- Be proficient in English
- Not have had a diagnosis of dementia.

- Not have or have had any of the following conditions which may cause impairments in cognitive function: stroke, traumatic head/brain injury, have a neurological or psychiatric condition.
- Not be colour blind.
- Not be taking medication which may influence cognitive function.

Due to the type of study this is we can only include one person from any household. However, you are welcome to bring a family member or support person with you.

Project Procedures

What is going to happen?

The total time involved in this study is approximately 4.5 hours. If you decide to take part in this study after you have read and had time to consider the information contained in this information sheet, you will be asked to complete a screening questionnaire to ensure that you meet the criteria to take part in the study. If you meet the inclusion criteria you will be invited to take part in the study. A researcher will then make an appointment with you to visit the Human Nutrition Research Unit at Massey University in Albany at a time early in the morning before you have had breakfast. You should not eat or drink anything (other than water) from 10pm the previous evening. At this appointment you will first be asked to sign a consent form for participating in the study and you will have the opportunity to ask any questions about the study.

We will reimburse you for your travel costs and give you a free breakfast. During this visit we will ask you to:

- Complete a health and demographic questionnaire.
- Have height, weight, waist and hip circumference measured.
- Have percentage body fat measured using Dual X-Ray Absorptiometry (DXA).
- Have your blood pressure and grip strength measured.
- Have an ultrasound scan of your knee(s) to look for signs of osteoarthritis
- Provide a small blood sample will be taken by a qualified phlebotomist (about 20ml which is equivalent to 4 teaspoons) for the measurement of glucose, HDL and LDL cholesterol, triglycerides, HbA_1C, single nucleotide polymorphisms (SNPs), metabolites and nutrients specific to dietary intake (such as vitamin C, β-carotene and folate), inflammatory markers (such as C-RP, TNF-α, IL-6, IL-1) and cartilage oligomeric matrix protein and C-telopeptide, both markers of arthritis in your blood. We will also measure the ApoE ε4 genotype. As ApoE ε4 is a gene which may affect cognitive function it is important to consider ApoE ε4 when investigating the relationship between dietary patterns and cognitive function.
- Complete a series of cognitive tasks on paper and on the computer (the Computerised Mental Performance Assessment System (COMPASS)). COMPASS includes a range of tests which measure different areas of brain function such as attention and memory. We will train you on how to use the computer to complete the tasks.
- Complete questionnaires to assess your dietary intake and physical activity levels
- Complete a short questionnaire – The KOOS or “Knee Injury and Osteoarthritis Outcome Survey” to assess any symptoms of osteoarthritis in your knees.

This visit will take about 3 hours in total. Following this appointment, we will ask you to record everything you eat and drink on a form while at home for a period of four days. We will also send you a questionnaire / link with some more questions regarding your dietary intake 4-8 weeks following your appointment (approximately 1.5 hours required at home).

What are the benefits and risks of taking part in this study?

You will receive feedback on your individual blood (glucose, HDL cholesterol, LDL cholesterol, triglycerides, HbA_1C), blood pressure and body composition results. Blood results outside the normal range will be reviewed by a vocationally registered general practitioner (GP) under the NZ Medical Council, who will advise if you need to visit your GP. The DXA body composition scan also provides minimal information on your bone mineral density. If this scan indicates the need for further investigation of your bone health, we will inform you of this and recommend you consult your GP. We encourage you to share these results with your General Practitioner, whether or not any abnormalities are detected. If you elect to receive the results of your tests, and you seek life or health insurance you or your GP can be asked to disclose them by the insurer. Failure to disclose them could invalidate any insurance policy issued where disclosure has not been made.

We will be measuring the genetic factors (SNPs) and the metabolome from a blood sample. SNPs are a DNA sequence variation occurring commonly within a population. The metabolome is a set of compounds found in your blood including amino acids, fatty acids, nucleic acids, hormones, enzymes, amines, vitamins, organic acids, short peptides, and sugars, as well as environmental contaminants, food additives, toxins, and drug metabolites. As these results are non-diagnostic they will not be made available to participants. One genetic factor we will be measuring is known as the ApoE ε4 allelic variant. Carriers of the ApoE ε4 allelic variant (25% of the population) are at substantially increased risk of Alzheimer's Disease. However, inheriting an ApoE ε4 allele does not mean a person will develop Alzheimer's disease. Therefore, results of the ApoE genotype test will be anonymised and not given to participants. None of the cognitive tasks are diagnostic so results of these will not be provided to participants.

The principal benefit of taking part in this study is a contribution to obtaining an in-depth understanding of the dietary patterns of adult New Zealanders (beyond an isolated food and nutrient approach) and advancing our knowledge of their associations with cognitive function and health outcomes associated with ageing. This is the first important step on a pathway to developing recommendations for adult New Zealanders to maintain cognitive function and health as long as possible. You will receive a brief report summarising the main findings of the project via mail or email. After completing the study, you will receive a link to the Ministry of Health Food and Nutrition Guidelines for Healthy Older Adults. You will be reimbursed for travel costs with a $50 voucher following your visit.

Some people may have a fear of having a blood sample taken or experience discomfort when the blood samples are taken. Occasionally a slight bruising will result. The bruising usually disappears within a day or two. Blood samples will be taken by a trained phlebotomist. There may be social or cultural discomfort from having a blood sample, grip strength or body composition measurements taken, however, privacy will be ensured, you will be treated with respect. The height measurement involves standing upright, and the researcher bringing a head plate gently onto the top of your head and compressing the hair if necessary. We will explain all measurements and ask for your permission prior to undertaking these measurements. You may also be accompanied by a support person if required. Every effort will be made to ensure your comfort and respect your participation.

We will use the Hologic DXA machine to estimate body fat percentage. The DXA has X-ray beams at 2 different energies. This dose is very low and unlikely to cause harm. The total effective dose of radiation to which you will be exposed to is 10 microsieverts (μSv), which is much lower than the range normally used in medical diagnostics. To place in perspective, the amount of radiation you are exposed to during a flight to the United Kingdom return is 100 μSv and from a dental Xray 50 μSv. The room is private and you can enter the DXA room in complete privacy. We will provide you with a gown to wear during this measurement.

Data Management

The data will be used only for the purposes of this project and no individual will be identified. Only the investigators and administrators of the study will have access to personal information and this will be kept secure and strictly confidential. Participants will be identified only by a study identification number.

Results of this project may be published or presented at conferences or seminars. No individual will be able to be identified.

At the end of this study the list of participants and their study identification number will be disposed of. Any raw data on which the results of the project depend will be retained in secure storage for 10 years, after which it will be destroyed.

The ApoE4 genotype results will be stored separately and only Dr Kathryn Beck and Owen Mugridge will have access to these records.

Who is funding the research?

This research is funded by a New Zealand Health Research Council Emerging Researcher Grant.

Participant's Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded.

Project Contacts

If you have any further questions or concerns about the project, either now or in the future, please contact either Kathryn Beck or Owen Mugridge.

Dr Kathryn Beck	Owen Mugridge
School of Sport Exercise and Nutrition, College of Health, Massey University	School of Sport Exercise and Nutrition, College of Health, Massey University
Email: reachstudy@massey.ac.nz	Email: reachstudy@massey.ac.nz
Phone (09) 414 0800 ext 43662	Phone: (09) 414 0800 ext 43650

The other members of the research team are Dr Pamela von Hurst and Dr Cathryn Conlon (School of Sport Exercise and Nutrition, Massey University), Dr Jane Coad (School of Food and Nutrition, Massey University), Dr Beatrix Jones (Institute of Natural and Fundamental Sciences, Massey University), Dr Anne-Louise Heath (Department of Human Nutrition, University of Otago), Dr Welma Stonehouse (CSIRO, Australia) and Dr Crystal Haskell-Ramsay (University of Northumbria, United Kingdom).

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 17/69. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 9099 x 85094, email humanethicsoutha@massey.ac.nz.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Thank you for considering participating in this study!

The REACH Study Research Team

9.2.4. Informed Consent form

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COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

The REACH Study – Researching Eating Activity and Cognitive Health

PARTICIPANT CONSENT FORM - INDIVIDUAL

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: _____ **Date:** _____

Full Name - printed _____

Te Kunenga ki Pūrehuroa

Massey University – School of Sport, Exercise and Nutrition, College of Health
Private Bag 102904, North Shore, Auckland 0745, New Zealand T +64 9 213 6653 www.massey.ac.nz

9.3. Participant Newsletters

REACH newsletters were prepared by candidate. The full REACH results were not always available at the time of writing the newsletters so there may be some differences between the thesis and the newsletters.

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August 17, 2018

The REACH Study

Researching Eating Activity and Cognitive Health

In this issue:

- Study update
- Meet Dr Beck
- The REACH timeline
- Food diaries
- Countries of birth
- Ask Owen
- Feedback

Study update

Thanks so much for participating in the REACH study. We have really enjoyed meeting all of you.

We need 360 participants to take part and we are nearly half way there - 75% of our participants are women. Recruitment is still open. We will be running study days for the rest of the year so please forward this email to others who may be interested.

Most of you would have received feedback on body composition, blood results and blood pressure. Our latest participants will receive their results shortly.

Meet Dr Kathryn Beck

You may have meet Dr Beck during your Dexa scan. Dr Beck is the principal scientist on this study and received an Emerging Researcher Grant ($246,508) from the Health Research Council of New Zealand to undertake this 3 year project.

Here is Kathryn's view point on the study

"I'm fascinated with how we can use food to improve our health, well-being and performance. Traditionally, nutrition research has focussed on individual foods and nutrients, however this has several limitations as people don't eat foods and nutrients in isolation – they eat combinations of foods as meals or snacks to form an overall dietary pattern.

The REACH study will use a dietary pattern approach to investigate associations between dietary intake and cognitive function. A dietary pattern approach reflects the complexity of the diet and how foods are eaten in combination

I'm really looking forward to sharing our results with you as we move forward"

Dr Beck's grip strength is 28 kilograms

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The REACH Study

Researching Eating Activity and Cognitive Health

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August 17, 2018

The REACH timeline

Food diaries

A big thank you for your efforts in the 4-day food diary. As you can appreciate these take time to process. A well detailed food diary gives the best information for dietary intake right down to the last B vitamin. You can never give too much detai0. Here is the address to our Food Diary Video on the study day— http:// massey.ac.nz/foodrecordinstructions. Remember to include any supplements or medication in your diary.

Ask Owen

Q: Will we receive our cognitive test results?
A: The cognitive testing was not a diagnostic test and results will not be sent provided to participants. Please see your doctor if you have concerns

Q: What do you test in the blood?
A: The blood contains a myriad of information and we look at:

- ☑ Fasted blood sugar levels at a point in time. HbA1C provides a picture of blood sugar levels over the last couple of months
- ☑ Lipid profile i.e. total cholesterol, triglycerides, HDL-cholesterol, LDL-cholesterol
- ☑ The above is tested in the lab on the study day. A GP reviews these results before forwarding to you.
- ☑ ApoE ε4, is a genetic factor carried by 25% of the population. Carriers have an increased risk of developing Alzheimer's disease.
- ☑ Markers of arthritis to see how they compare with your knee ultrasound
- ☑ The above two tests are done by an outside laboratory and are not available to participants.

Some feedback about the study days

"I found the exercise quite fun"

-570088

"I enjoyed the day, but was quite tired after it"

-570129

"what a fascinating study – it is interesting to be a small part of it"

-570193

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The REACH Study

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August 17, 2018

Where do you come from?

The majority of our participants are born in New Zealand but others are from different places around the globe.

Thank you for visiting us at Massey University, Albany.
Remember we are looking for more participants—particularly males.
Call Cassie on (09) 414 0800 ext 43859 or forward details onto people who may be interested

Cassie Kathryn. Nicola Pam
Harriet Owen Karen

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August 17, 2018

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November 16, 2018

The REACH Study

Researching Eating Activity and Cognitive Health

In this issue:

- Study update
- Meet Cassie
- The REACH timeline
- Food diaries
- Ask Owen
- A few stats

Study update

Approaching 300, and it's been fantastic to meet everyone. If you can think of anyone, friends or family that meet our criteria, please share our details.

We are particularly looking for male participants, but not just them, we're looking far and wide. If each completed volunteer found one more willing participant we'll be done in no time!

Recruitment is still open. We will be running study days until 20 December, starting up again from 9 January.

Follow us on Facebook = REACH study

Meet Cassie Slade

Cassie is the Research Assistant on the REACH Study. Her role includes recruiting and screening of participants and helping to run the study testing days. She is currently finishing her Masters in Human Nutrition and is due to start her PhD next year, researching Nutrition and Osteoarthritis.

You will have met Cassie at the ultrasound machine—scanning your knees

Cassie's view on the study ...

"Working on the REACH study is fantastic. I work with a great team and a fascinating topic. My background is in psychology and nutrition and this study allows me to research in both those fields. Being so hands on has given me the opportunity to learn from more experienced researchers, giving me a great foundation for when I start my own PhD research next year.

I love coming to work but testing days are my favourite as I really enjoy getting to know our lovely participants over the course of the morning. Meeting such a varied and interesting group of people, means no two days are the same, making it great fun and never boring. I feel very lucky and privileged to be involved in such a great piece of research."

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The REACH Study

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November 16, 2018

Food diaries

A big thanks for returning the food diaries, we might contact you if we need some further clarification.

About food diaries ...

"It made me aware of 'mindless' eating, of nibbling and has been a good wake-up call"

"I've seen just what a boring and repetitive diet I have"

We are working our way through the big stack of your food diaries

Ask Owen

Q: Do we have to come for a second visit?
A: No, just one morning visit to Massey University is all we require. We will ask that you complete another Food Frequency Questionnaire one month after your visit. This can be done either online via your computer or we can send you a paper copy to complete.

Q: What does the DeXA scan do?

☑ A: DeXA stands for dual-energy X-ray absorptiometry. The scan is used to estimate body fat percentage—this is one of the measurements sent to you along with the blood results. To obtain this measurement the DeXA will scan your whole body and as a bonus the bone mineral density is also measured. This is not a diagnostic measurement but more indicative. We will advise you if your bone mineral density levels appear low for follow up by your general practitioner.

☑ The DeXA uses X-ray beams of two different energies. One of these beams is absorbed by soft tissue and the other is absorbed by bone. The dose of X-ray is extremely low (10 µSv) which is less than the amount of radiation exposed to from a dental X-ray or flight to United Kingdom.

The REACH timeline

2018 Apr	Start recruitment
Aug	
Nov	Recruiting
2019 Feb	Complete recruitment
May	Start analysis
Aug	
Nov	Complete analysis
2020 Feb	Study results feedback to participants

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The REACH Study

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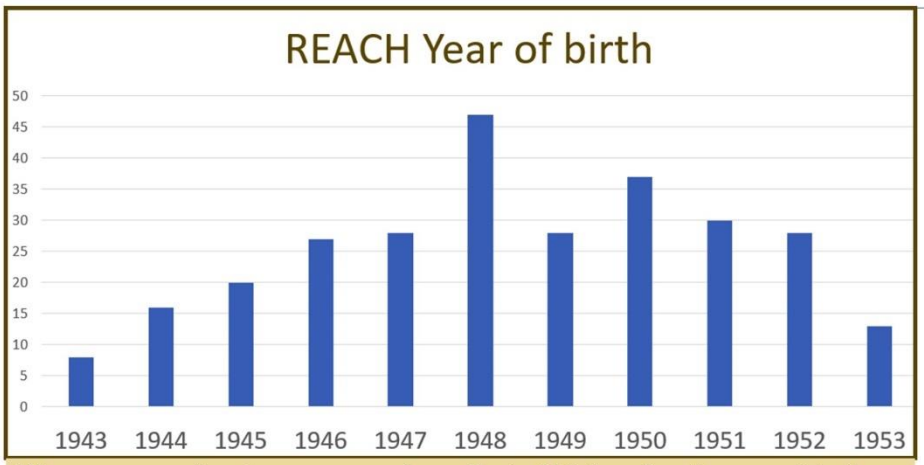
Researching Eating Activity and Cognitive Health

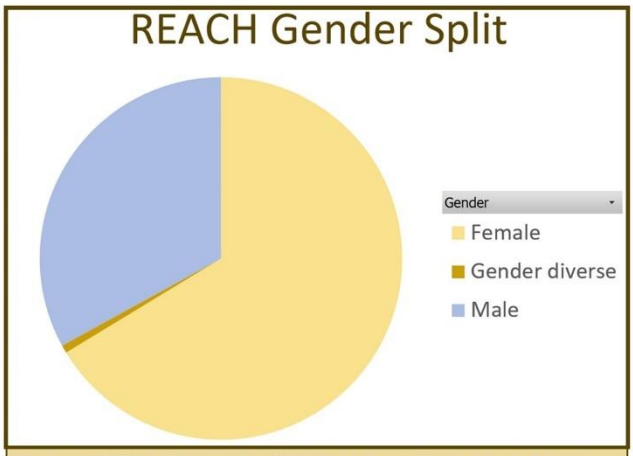
November 16, 2018



We were expecting to see more of an effect of births after the war—it is there but not very obvious

Thank you ...

for visiting us at Massey University, Albany. Remember we are looking for more participants—particularly males. Call Cassie on (09) 213 6859 or forward details onto people who may be interested



Most (66%) of our participants are female - please pass on the study details to males who might be keen to take part

Cassie Karen Owen
Kathryn. Pam
Nicola
Harriet

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May 16, 2019

The REACH Study

Researching Eating, Activity and Cognitive Health

In this issue:

- Study update
- Meet Owen
- Ask Owen
- The REACH timeline
- Food diaries

Study update

We have taken our last blood sample, served the last breakfast and completed the final cognitive test. The REACH recruitment and data collection is complete—371 people have taken part—a huge thank you to you all.

Recruitment is now finished

Our first paper has been published giving background to the REACH study along with our methodology. The paper can be read at https://rdcu.be/bBcE0

The next phase of the trial involves processing the data. We have a large amount — bloods to analyse, cognitive tests to grade, food frequency questionnaires, 4-day food diaries to process and physical activity questionnaires to score.

Follow us on Facebook = REACH study

Owen is sampling some English culinary gems while travelling in Europe last year

Meet Owen Mugridge

I am the project coordinator of the REACH Study. Although my favourite bit is over (meeting all the volunteers), there's still some interesting aspects to come.

My day-to-day job involves project management tasks on many different projects, working with babies, children, pre-diabetics, athletes, and many more! It's a very varied role and I relish the challenges that pop up every day.

My role also includes organising nutrition symposia and workshops in order to disseminate our research project findings to health professionals in the field so they can apply it to their practice – a very rewarding and important part of scientific research.

We hope to present the REACH Study results to this audience in 2020 but also host the REACH volunteers at a get together later in the year once all the data has been analysed. We'll be in touch!

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The REACH Study

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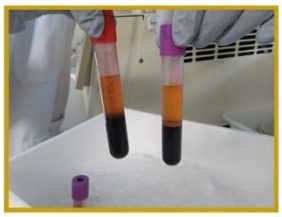
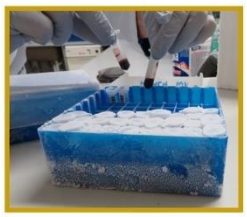
Researching Eating, Activity and Cognitive Health

May 16, 2019

Ask Owen

Q: What happens to our blood?
A: Three tubes of blood were taken by our phlebotomist—2 lavender-top and one red-top. Whole blood from one lavender-top was used to measure blood sugars and cholesterol profiles. The second lavender-top tube sat on ice while the red-top tube coagulated at room temperature for 30 minutes. These two tubes were centrifuged to separate the plasma (lavender-top) and serum (red-top) which is stored in smaller tubes in a −80° C freezer for further tests.


Q: What can the blood tell us?
A: The blood can tell us many things. We have measured blood sugars and cholesterol levels but there are other small molecules in the blood which we are interested in.

With technological advances and metabolomics (the study of low molecular weight compounds) we are able to identify the B-vitamin molecules in the blood. By comparing the dietary intake of B-vitamins with the level of B-vitamins in the blood we can get an idea of changes in the absorption and use of B-vitamins.

As well as targeting specific molecules (B-vitamins) in the blood we are also doing an untargeted approach—a bit like fishing—put out the net and see what we catch. We will be looking to see if we can find any molecules whose levels are related to scores on the cognitive tests. We can then use those molecules to help us understand what biochemical pathways are related to cognitive function and plan more research.

The REACH timeline

2018 Apr	Start recruitment
Aug	
Nov	Recruiting
2019 Feb	Complete recruitment
Apr	Start analysis
Aug	
Nov	Complete analysis
2020 Feb	Study results feedback to participants

http://massey.ac.nz/reachstudy

COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

The REACH Study

Researching Eating, Activity and Cognitive Health

May 12, 2020

In this issue:
- Study update
- Meet Anne
- Dietary patterns
- More on the knee ultrasound ...

Study update

Thanks to your generosity the REACH study has a large data set. Progress is steady with the data analysis and we are starting to tie up a few loose ends but there is still a bit more to do. In this newsletter we can tell you about dietary patterns, let you know why your knee underwent ultrasound and you can meet Anne, currently trapped in France.

Meet Anne

Bonjour! My name is Anne Hiol. I originally come from Cameroon, but have lived and studied in France for many years. I completed my MSc in Food Science and Human Nutrition at the University of Nantes (France) where I undertook a 5-month internship at Massey University investigating the dietary intake of 50 adults from in the REACH study.

My key responsibilities in the REACH study included processing blood, undertaking anthropometric measures and entering food diaries. During this time, I was pleased to meet enthusiastic people, share some stories and practice my English. At many levels, it was demanding but at the end of each day it was satisfying. Also, I had the opportunity to discover a country with rolling green hills, majestic mountains, breath-taking fjords and an amazing diversity of landscape from one island to the next.

At the end of my internship, I was heartbroken to leave the REACH team. Three months later I decided to come back to New Zealand for my PhD '*Investigating protein intake, body composition and muscle strength in older adults*'. Working with the REACH team facilitated my growth and development as a researcher. As part of this, I had an abstract accepted for a presentation at the international conference on Frailty and Sarcopenia research. This took place in Toulouse, France from the 11–13th March 20. Due to the quickly-evolving COVID-19 situation, I have not been able to return to NZ. I am in quarantine with my family in France and continue studying on my PhD. Hopefully the world returns to normal (whatever that will look like!) soon.

...

Publications to date ... (click the link)

Study protocol: associations between dietary patterns, cognitive function and metabolic syndrome in older adults – a cross-sectional study

The REACH Study

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Researching Eating, Activity and Cognitive Health

May 12, 2020

One REACH study aim is to identify the dietary patterns of our participants

Q: What are dietary patterns?
A: We are interested in your eating patterns—how you combine foods to create the whole diet. Patterns of the diet portray your eating behaviours. The patterns are revealed using a statistical process and the data from the Food Frequency Questionnaire. How the foods correlate and relate to each other is key to this process.

Correlations we found show you drink milk with tea and coffee and if you eat nuts/seeds then you are likely to have dried fruit in your pantry or people who enjoy pizzas and pies were less likely to eat bran cereal or berry fruits.

The REACH timeline

2018 Apr	Start recruitment
Aug	Recruiting
Nov	Recruiting
2019 Feb	Complete recruitment
May	Start analysis
Aug	Continue analysis
Nov	Continue analysis
2020 Feb	Continue analysis
May	Complete analysis
Sep	Study results feedback to participants

We found three dietary patterns. The big food contributors to each pattern are shown below. While we cannot give your individual result you can probably guess which pattern best reflects your diet

*Dietary Pattern **1***

- *Vegetables*
- *Fruit*
- *Nuts/seeds*
- *Fish/shellfish*
- *Olives/avocados*
- *Water*
- *Soy/legumes*
- *Spices*
- *Milk*

*Dietary Pattern **2***

- *Soy/legumes*
- *Wholegrains*
- *Biscuits, cakes and pastries*
- *Refined grain*
- *Confectionery*
- *Vegetable oils*
- *Takeaways*
- *Processed fish*
- *Diet drinks*

*Dietary Pattern **3***

- *Processed meats*
- *Cheese*
- *Sauces/dressings/ spreads*
- *Red wine*
- *Beer*
- *Tea/coffee*
- *Milk*
- *Takeaways*

...

The REACH Study

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Researching Eating, Activity and Cognitive Health

May 12, 2020

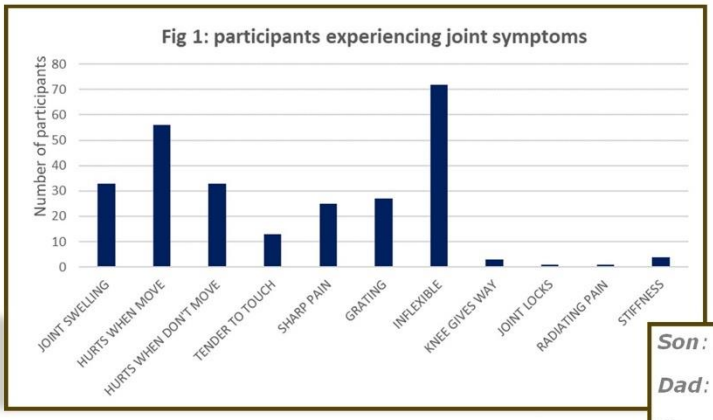
More on the knee ultrasounds …

Cassie featured in our 2nd newsletter. Here, Cassie updates us on her osteo-arthritis pilot study

You may remember my area of interest is osteoarthritis (OA) and the impact of lifestyle factors on this disease. OA is a leading cause of disability in older adults in New Zealand and an exciting area to study right now. I feel fortunate to have you, our fantastic group from the REACH cohort, who have allowed me to pursue a PhD tackling this worthwhile topic. It is lovely for me to share some of my work and give you an insight into what is in the pipeline as I progress through my PhD.

Using data from the knee questionnaire, I identified a subset of individuals who suffered more markedly from joint issues. These 95 participants completed another questionnaire to understand an individual's behaviours and attitudes concerning joint issues and OA. Here's a snapshot of selected results...

All the individuals questioned experienced one or more joint symptoms, 87% felt joint pain and 79% said joint issues impacted their lifestyle. Only half of these individuals had a diagnosis of OA. Figure 1 shows joint symptoms experienced by participants vary widely. This variation and prevalence in joint symptoms supports the importance of studying joint issues and OA, looking at ways we can diagnose earlier and treat symptoms earlier to gain the best possible outcomes.



The next phase of my PhD will scrutinise the ultrasound knee pictures to validate their ability to diagnose OA. I will investigate the knee cartilage thickness and compare with known blood biomarkers of cartilage damage and the original knee questionnaires completed at the time of the ultrasound scan.

***Son**: Dad... how many kidneys do I have?*

***Dad**: Two. You have two, son.*

***Son**: Nope... I have four. *point to belly* Two kidneys here... *points to legs* ...and two kid knees here!*

Thank you ...

for being part of the REACH study—an important step in understanding dietary patterns in the older New Zealand adult and associations with health outcomes.

Nicola Clare Kathryn. Karen Pam
Harriet
Cassie
...

The REACH Study

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Researching Eating, Activity and Cognitive Health

May 16, 2019

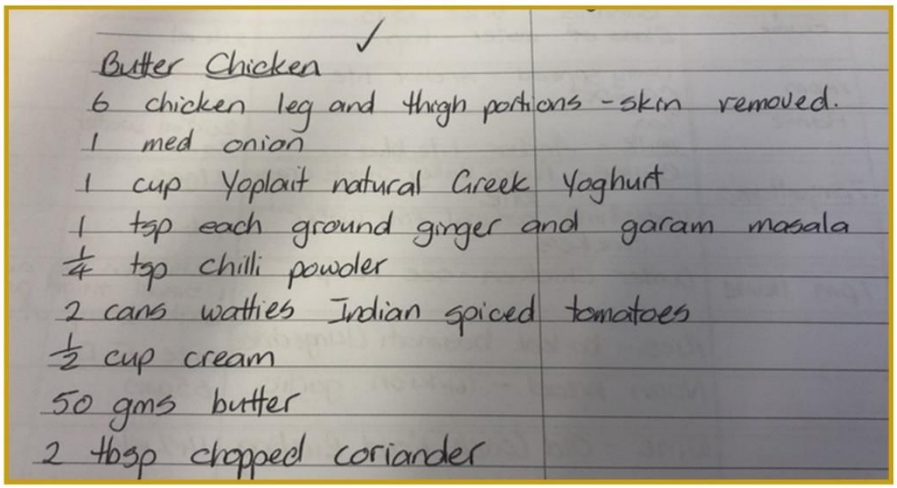
Food diaries

A big thanks for all the food diaries. A food diary can take 2—3 hours to enter into our Foodworks programme which converts what you eat into into a profile of the nutrients you are consuming. We have nearly processed half of the REACH food diaries.

We have even tried some of the recipes included in the food diaries. Cherise, who has entered many of the food diaries, made this Butter Chicken

Cherise recalls:

"Someone was describing a drink but it looked like vast quantities of spices were consumed. It had "yuk!!" written next to it. I clarified with the participant that it was, in fact, a drink and they had omitted the fluid content. However, they said "the drink was still not pleasant"



Thank you ...

for being part of the REACH study—an important step in understanding dietary patterns in the older New Zealand adult

Nicola Quen Cassie Pam Kathryn. Karen Harriet

http://massey.ac.nz/reachstudy

9.4. Data collection documents

This section contains questionnaires, forms and documents used during data collection. Many of these forms were not created by the PhD candidate but have been included in the Appendix to ensure complete documentation of the data collection process for the REACH study.

9.4.1. Questionnaires

9.4.1.1. Health and Demographics questionnaire

The REACH Study – Researching Eating Activity and Cognitive Health

Please complete the following form. All the information you give us is in confidence and will be used only for the purposes of this study. If you need any help to complete the form please ask one of the research team.

What is your gender (please tick)?

☐ Male
☐ Female
☐ Gender diverse

What is your date of birth (day/month/year)?

_____

Which ethnic group(s) do you belong to? Tick whichever applies to you (you may tick more than one box)

☐ European
☐ Māori
☐ Pacific Peoples
☐ Chinese
☐ Indian
☐ Middle Eastern/Latin American/African
☐ Other Ethnicity *Please state which other ethnicity or ethnicities you belong to*

_____

Which country were you born in?

☐ New Zealand
☐ Australia
☐ England
☐ China (People's Republic of)
☐ South Africa
☐ Samoa
☐ Cook Islands
☐ Other *Please state which country* _____

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

Month (eg. February) _____

Year (eg. 2000) _____

What is your first language? _____

What is your current living arrangement?

☐ Living alone

☐ Living with others

If living with others, how many others do you live with and what is their relationship to you (eg. Husband, wife, partner, son, daughter, grandson, granddaughter, flatmate, boarder, etc)

_____

_____

Which of the following best describes they type of residence that you currently live in? (please tick one box)

☐ House or townhouse – detached or 'stand alone'

☐ House, townhouse unit or apartment joined to one or more other houses, townhouses, units or apartments

☐ Unit, villa or apartment in retirement village

☐ Moveable dwelling (eg. Caravan, motorhome, boat, tent)

☐ Rest home or continuing care hospital

☐ Other, please describe

_____

_____

In terms of the ownership arrangements your primary residence is? (please tick one box)

☐ Owned by yourself and/or spouse/partner with a mortgage

☐ Owned by yourself and/or spouse/partner without a mortgage

☐ Owned by family/whānau

☐ Owned by a family/whānau trust

☐ Private rental

☐ State, council or kaumātua housing

☐ None of the above

☐ License to occupy

☐ Other, please specify

_____

_____

Are you?

☐ Married / cohabiting / civil union / de facto

☐ Divorced / separated

☐ Widowed

☐ Single

☐ Other, please describe

_____

What is your highest educational level (choose one)?

☐ No qualifications

☐ Primary school

☐ Secondary school

☐ Post-secondary certificate, diploma, or trade diploma

☐ University degree

Which of the following best describes your current work situation? (please tick as many as apply)

☐ Paid employment

Occupation and number of hours of paid employment per week?

_____

How long have you worked for your current employer?

_____

☐ Volunteer work

Position and number of volunteer hours per week?

_____

☐ Fully retired

☐ Semi-retired

☐ Other (eg. caregiver, studying, homemaker), please describe

_____

If retired, at what age did you retire?

_____

During your working life, what was your main occupation?

☐ Labourer (eg. Cleaner, food packer, farm worker)

☐ Machinery operator/driver (eg. Machine operator, store person)

☐ Sales worker (eg. Insurance agent, sales assistant, cashier)

☐ Community or personal service worker (eg. Teacher aide, armed forces, hospitality worker, care)

☐ Technician/trades worker (eg. Engineer, carpenter, hairdresser)

☐ Professional (eg. Accountant, doctor, nurse, teacher)

☐ Manager (eg. General manager, farm manager)

☐ Other *(Please Specify)* _____

What would be the total income, that your household got *from all sources*, before tax or anything was taken out of it, in the last 12 months? (Please tick one box)

☐ Loss

☐ Zero

☐ $1 - $10,000

☐ $10,001 - $20,000

☐ $20,001 - $30,000

☐ $30,001 - $40,000

☐ $40,001 - $50,000

☐ $50,001 - $60,000

☐ $60,001 - $70,000

☐ $70,001 - $100,000

☐ $100,001 - $150,000

☐ $150,001 - $200,000

☐ $201,000 or more

☐ Don’t know

☐ Prefer not to answer

The following questions are about your material standard of living – the things that money can buy. Your material standard of living does NOT include your capacity to enjoy life. You should NOT take your health into account.

Generally, how would you rate your material standard of living? (Please tick one box)

☐ High
☐ Fairly high
☐ Medium
☐ Fairly low
☐ Low

Generally, how satisfied are you with your current material standard of living? (Please tick one box)

☐ Very satisfied
☐ Satisfied
☐ Neither satisfied or dissatisfied
☐ Dissatisfied
☐ Very dissatisfied

How well does your total income meet your everyday needs for such things as accommodation, food, clothing and other necessities? (Please tick one box)

☐ Not enough
☐ Just enough
☐ Enough
☐ More than enough

Do you smoke cigarettes or a pipe?

☐ Yes

☐ No

☐ Former smoker

If yes, approximately how many cigarettes per day: _____

Do you drink alcohol?

☐ Yes

☐ No

☐ I used to drink alcohol, but no longer drink alcohol

If yes, how often do you usually drink alcohol?

☐ Monthly

☐ Weekly

☐ Daily

How many standard drinks of alcohol do you usually drink in the timeframe selected above?

A standard drink is 1 can of beer (330ml), 1 glass of wine (100ml), 1 Ready to Drink (RTDs), 1 shot/nip of spirits (30ml)

_____

On any one drinking occasion, what is the maximum number of standard drinks you would have?

A standard drink is 1 can of beer (330ml), 1 glass of wine (100ml), 1 Ready to Drink (RTDs), 1 shot/nip of spirits (30ml)

_____

How many alcohol free days do you usually have per week?

☐ 1 day
☐ 2 days
☐ 3 days
☐ 4 days
☐ 5 days
☐ 6 days
☐ 7 days

_____

Have you been diagnosed by a medical practitioner with rheumatoid arthritis?

☐ Yes

☐ No

Have you been diagnosed by a medical practitioner with osteoarthritis?

☐ Yes

☐ No

If yes, which joint has been diagnosed with arthritis?

_____

Are you currently taking medication for your osteoarthritis, or have you received injections as treatment for your osteoarthritis? If yes, please describe.

_____

_____

Have you ever had or been diagnosed with any of the following?

☐ Stroke

☐ Traumatic head or brain injury

☐ Dementia

☐ Mild cognitive impairment

☐ Other neurological condition

☐ Depression

☐ Anxiety

☐ Other mental illness

☐ Any other acute or chronic condition which might affect your brain function

If yes to any of the above, please describe (diagnosis, year diagnosed)

_____

_____

_____

Do you have any family history of dementia or cognitive impairment?

☐ Yes

☐ No

If yes, please describe

_____

_____

Have you ever had or been diagnosed with any of the following?

☐ Cancer

☐ Heart trouble (e.g. angina, heart attack, heart failure)

☐ High cholesterol

☐ High blood pressure or hypertension

☐ Gut disorder that interferes with digestion and absorption of your food

☐ Gastric reflux

☐ Diabetes or persistent sugar in the urine

☐ Endocrine disease (hormone trouble)

☐ Thyroid disease (e.g. goiter)

☐ Kidney problems

☐ Liver problems (e.g. active/chronic hepatitis, cirrhosis)

☐ Respiratory condition (e.g. bronchitis, asthma, COPD)

☐ Active or chronic gout

☐ Disorder of the neck or back (e.g. lumbago, sciatica, chronic back or neck pain, vertebrae or disc problems)

☐ Sleep disorder

☐ Disability

☐ Osteoporosis

☐ Peripheral vascular disease

☐ Any other acute or chronic conditions not listed above

If yes to any of the above, please describe (diagnosis, year diagnosed)

_____

_____

_____

_____

Are you currently taking any medication prescribed by a medical practitioner?

☐ Yes

☐ No

If yes, please state what medication you are taking, the dosage and why

_____

_____

_____

_____

Are you taking any other medication or substances (e.g. over the counter, homeopathic, drugs other than alcohol, tobacco or prescription medication)?

☐ Yes

☐ No

If yes, please state what medication/substances you are taking, the dosage and why

_____

_____

_____

_____

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

☐ Yes

☐ No

If yes, what is the name, brand and dosage of the supplements you are taking?

_____

_____

_____

_____

How would you rate your quality of life (please tick one box)?

☐ Very good

☐ Good

☐ Neither good nor poor

☐ Poor

☐ Very poor

In general, would you say your health is:

☐ Excellent

☐ Very good

☐ Good

☐ Fair

☐ Poor

Can you see ordinary newsprint (with glasses or contact lenses if you usually wear them)? (Please tick one box)

Easily	With difficulty	Not at all
☐	☐	☐

Can you hear a conversation with one other person (even when wearing hearing aids)? (Please tick one box)

Easily	With difficulty	Not at all
☐	☐	☐

How would you describe the health of your teeth and mouth? (Please tick one box)

Excellent	Very good	Good	Fair	Poor
☐	☐	☐	☐	☐

Can you bite and chew on hard foods such as a firm apple? (Please tick one box)

Yes, without difficulty	Yes, with difficulty	No
☐	☐	☐

Do you have any mobility restrictions (eg. hip/knee replacement, ongoing pain, loss of driver's license) which impact on your daily life?

☐ Yes

☐ No

If yes, please describe.

_____

_____

_____

_____

Comparing yourself now to when you were 20 years old, would you say you have lost or gained weight? If so, by how much

☐ Lost 10kg or more (22lb or 1st 8lb)
☐ Lost up to 10kg (22lb or 1st 8lb)
☐ No change (0)
☐ Gained up to 5kg (11lb)
☐ Gained up to 10kg (11-22lb or 11lb-1st 8lb)
☐ Gained up to 15kg (22-33lb or 1st 8lb – 2st 5lb)
☐ Gained 15kg or more (33lb or 2st 5lb)
☐ Don't know

Has what you eat changed in the past 10 years?

☐ Yes

☐ No

If yes, please describe (eg. I eat less because my appetite is lower; I eat more vegetables).

_____

_____

_____

_____

Has your level of physical activity changed in the past 10 years?

☐ Yes

☐ No

If yes, please describe.

_____

_____

_____

_____

Compared with 10 years ago, has your intake of the following foods increased, decreased or stayed the same (tick the box which is most accurate – either eat more, eat less or eat the same)

	Eat more	Eat the same	Eat less
Fruit			
Vegetables			
Breads, cereals & grains			
Milk, yoghurt, cheese			
Oily fish and seafood (eg. salmon, tuna, mackerel, herring)			
All fish and seafood			
Red meat & poultry			

How often are you excessively sleepy during the day?

Never Rarely Frequently Often

How often do you feel that you lack companionship? (please circle)

Hardly ever Some of the time Often

How often do you feel left out? (please circle)

Hardly ever Some of the time Often

How often do you feel isolated from others? (please circle)

Hardly ever Some of the time Often

Please select the response which best describes your situation

I/We can afford to eat properly

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

Food runs out in my/our household due to lack of money

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

I/we eat less because of lack of money

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

The variety of foods I am (we are) able to eat is limited by a lack of money

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

I/we rely on others to provide food and/or money for food, for my/our household, when I/we don't have enough money

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

I/we make use of special food grants or food banks when I/we do not have enough money for food

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

I feel stressed because of not having enough money for food

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

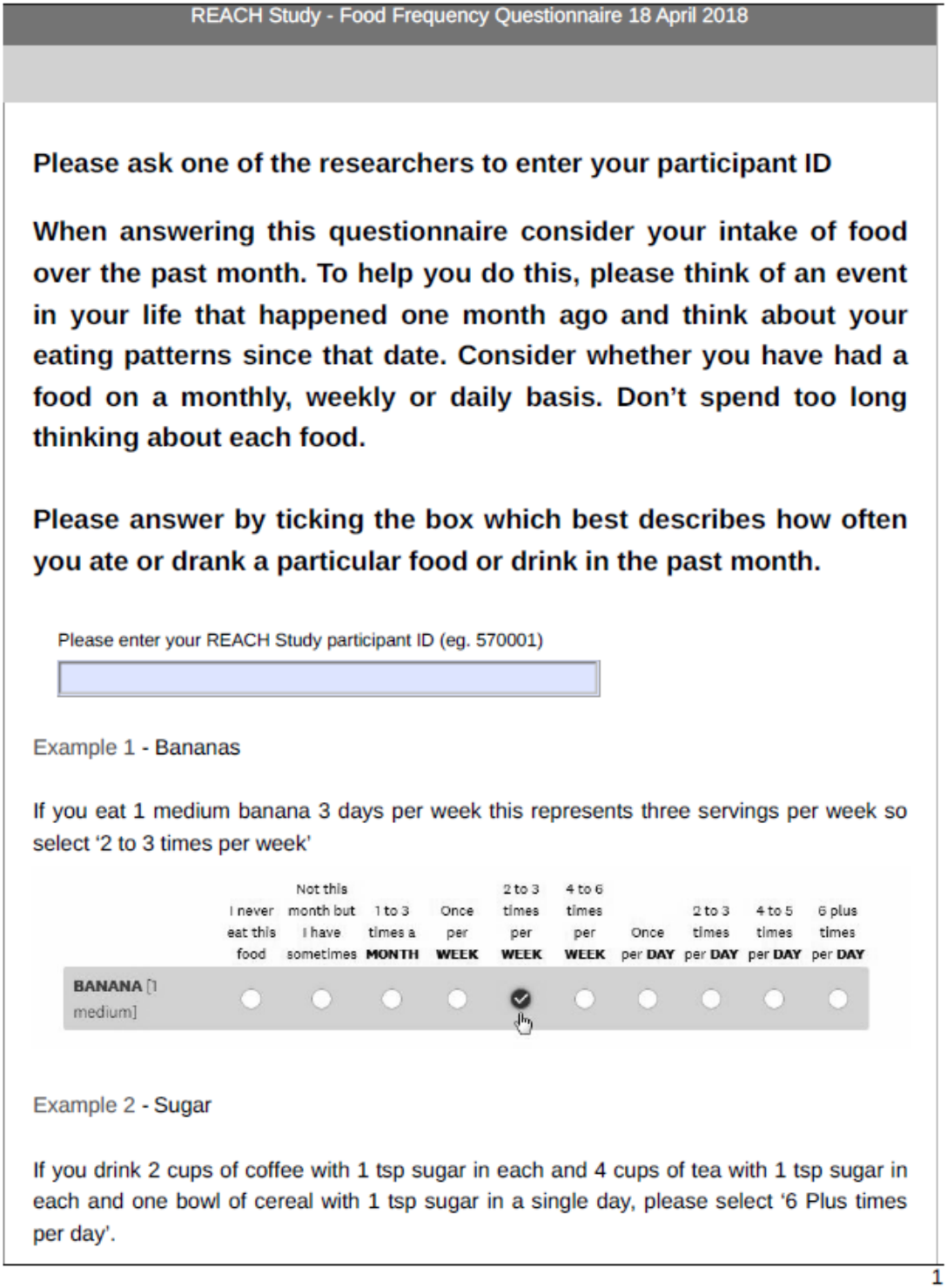
I feel stressed because I can't provide the food I want for social occasions

☐ Always / often
☐ Sometimes
☐ Rarely / never
☐ Don't know

9.4.1.2. Dietary data

The dietary data was collected online using Survey Monkey. The 4-day food record was collected using pen and paper.

109-item food frequency questionnaire



REACH Study - Food Frequency Questionnaire 18 April 2018

Please ask one of the researchers to enter your participant ID

When answering this questionnaire consider your intake of food over the past month. To help you do this, please think of an event in your life that happened one month ago and think about your eating patterns since that date. Consider whether you have had a food on a monthly, weekly or daily basis. Don't spend too long thinking about each food.

Please answer by ticking the box which best describes how often you ate or drank a particular food or drink in the past month.

Please enter your REACH Study participant ID (eg. 570001)

Example 1 - Bananas

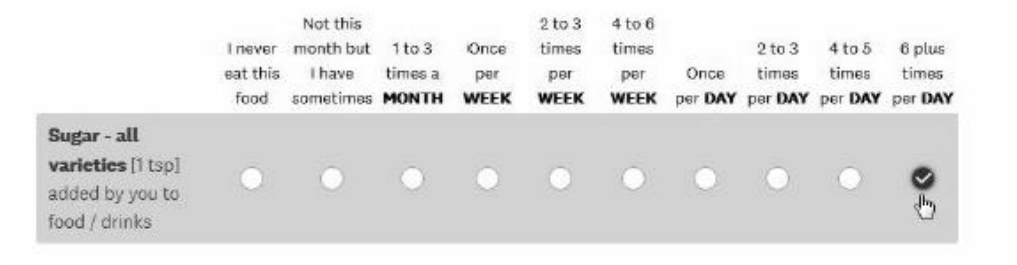
If you eat 1 medium banana 3 days per week this represents three servings per week so select '2 to 3 times per week'

	I never eat this food	Not this month but I have sometimes	1 to 3 times a MONTH	Once per WEEK	2 to 3 times per WEEK	4 to 6 times per WEEK	Once per DAY	2 to 3 times per DAY	4 to 5 times per DAY	6 plus times per DAY
BANANA [1 medium]	○	○	○	○	✓	○	○	○	○	○

Example 2 - Sugar

If you drink 2 cups of coffee with 1 tsp sugar in each and 4 cups of tea with 1 tsp sugar in each and one bowl of cereal with 1 tsp sugar in a single day, please select '6 Plus times per day'.

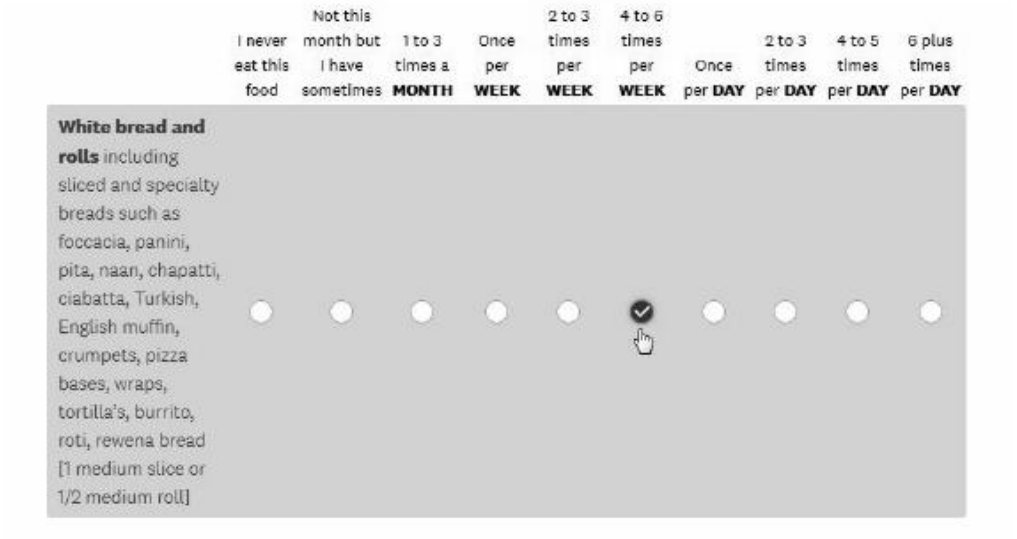
1



	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Sugar - all varieties [1 tsp] added by you to food / drinks	○	○	○	○	○	○	○	○	○	●

Example 3 - White bread and rolls

If eating 2 medium slices of bread two times per week this represents four servings per week so select "4 to 6 times per week".



	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
White bread and rolls including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin, crumpets, pizza bases, wraps, tortilla's, burrito, roti, rewena bread [1 medium slice or 1/2 medium roll]	○	○	○	○	○	●	○	○	○	○

2

REACH Study - Food Frequency Questionnaire 18 April 2018

The questionnaire starts here.

FRUIT

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Apples, pears, nashi pears [1 medium]	○	○	○	○	○	○	○	○	○	○
Banana [1 medium]	○	○	○	○	○	○	○	○	○	○
Citrus fruits e.g. orange, tangelo, tangerine, mandarin, grapefruit, lemon, lime [1 medium or 2 small]	○	○	○	○	○	○	○	○	○	○
Stone fruit e.g. apricots, nectarines, peaches, plums, lychees [1 medium or 2 small]	○	○	○	○	○	○	○	○	○	○
Avocado [1/4 avocado]	○	○	○	○	○	○	○	○	○	○
Olives [4 olives]	○	○	○	○	○	○	○	○	○	○
Strawberries, blackberries, cherries, blueberries, boysenberries, loganberries, cranberries, gooseberries, raspberries (fresh, frozen, canned) [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Dried fruit e.g. sultanas, raisins, currants, figs, apricots, prunes, dates [2 Tbsp]	○	○	○	○	○	○	○	○	○	○
All other fruit e.g. feijoa, persimmon, tamarillo, kiwifruit, grapes, mango, melon, watermelon, pawpaw, papaya, pineapple, rhubarb [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○

REACH Study - Food Frequency Questionnaire 18 April 2018

VEGETABLES

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Potato e.g. boiled, mashed, baked, jacket, instant, roasted [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Hot potato chips, French fries, wedges [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Kumara, taro, green banana, cassava e.g. boiled, mashed, baked, roasted [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Carrots [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Other root vegetables e.g. yams, parsnip, swedes, beetroot, turnips [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Peas, green [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Green beans, broad beans, runner beans [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Broccoli, cauliflower, brussel sprouts, cabbage (all varieties) [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Salad vegetables e.g. lettuce, cucumber, celery, sprouts [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Green leafy vegetables e.g. spinach, silver beet, swiss chard, watercress, puha, Whitloof, chicory, kale, chard, collards, Chinese kale, Bok Choy, taro leaves (palusami) [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Tomatoes (all varieties) [1 medium or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
All other vegetables e.g. corn, pumpkin, mushrooms, capsicum, peppers, courgette, zucchini, gerkins, marrow, squash, asparagus, radish, eggplant, artichoke [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Onions, leeks, garlic [1 Tbsp]	○	○	○	○	○	○	○	○	○	○

4

REACH Study - Food Frequency Questionnaire 18 April 2018

MEAT and CHICKEN

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Beef, lamb, hogget, mutton, pork, veal e.g. roast, steak, fried, chops, schnitzel, silverside, casserole, stew, stir fry, curry, BBQ, hamburger meat, mince dishes, frozen dinners [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Chicken, turkey or duck e.g. roast, steak, fried, steamed, BBQ, casserole, stew, stir fry, curry, mince dishes, frozen dinners [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Liver, kidney, other offal (including pate) [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Sausages, frankfurters, cheerios, hot dogs [1 medium sausage]	○	○	○	○	○	○	○	○	○	○
Ham, bacon, luncheon sausage, salami, pastrami, other processed meat [2 medium slices]	○	○	○	○	○	○	○	○	○	○
Corn beef (canned), boil up, pork bones, lamb flaps, povi masima [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Meat pies, sausage rolls [1 meat pie or 2 sausage rolls]	○	○	○	○	○	○	○	○	○	○

5

REACH Study - Food Frequency Questionnaire 18 April 2018

FISH and SEAFOOD

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Fish fried in batter (from fish & chips shop) [1 piece of palm size fish]	○	○	○	○	○	○	○	○	○	○
Albacore tuna, salmon, sardines, herring, kahawai, swordfish, carp, dogfish, gemfish, Alfonsino, rudderfish, anchovies [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Mackerel, snapper, oreo, barracouta, trevally, dory, trout, eel [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Tuna (canned), hoki, gurnard, hake, kingfish, cod, tarakihi, groper, flounder [Palm size or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Crumbed fish e.g. patties, cakes, fingers, nuggets [1 patty/cake or 2 fingers/nuggets]	○	○	○	○	○	○	○	○	○	○
Green mussels, squid [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Shellfish e.g. cockles, kina, oysters, paua, scallops, shrimp/prawn, pipi, roe [1/2 cup]	○	○	○	○	○	○	○	○	○	○

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EGG, NUTS, SOY and LEGUMES

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Eggs – boiled, poached, raw [1 egg]	○	○	○	○	○	○	○	○	○	○
Eggs - fried, scrambled, egg based dishes including quiche, soufflés, frittatas, omelets [1 egg]	○	○	○	○	○	○	○	○	○	○
Nuts e.g. peanuts, mixed nuts, macadamias, pecan, hazelnuts, brazil nuts, walnuts, cashews, pistachios, almonds [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Seeds e.g. pumpkin seeds, sunflower seeds, pinenuts, sesame seeds, tahini [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Nut butters or spreads e.g. peanut butter, almond butter, pesto [1 tsp]	○	○	○	○	○	○	○	○	○	○
Tofu, soybeans, tempeh [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Beans (canned or dried) e.g. black beans, butter beans, haricot beans, kidney beans, cannellini beans, refried beans, baked beans, chilli beans [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Peas and lentils e.g. chickpeas, hummus, falafels, split peas, cow peas, dahl [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Vegetarian sausages / meat, vegetarian burger patty, textured vegetable protein [1 sausage or 1 patty]	○	○	○	○	○	○	○	○	○	○

REACH Study - Food Frequency Questionnaire 18 April 2018

CEREALS and GRAINS

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Bran based cereals, muesli, porridges – e.g. rolled oats, oat bran, oat meal, All Bran, Sultana bran [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Weetbix, cornflakes or rice bubbles [2 weetbix or 1/2 cup]	○	○	○	○	○	○	○	○	○	○
Sweetened cereals e.g. Nutrigrain, Fruit Loops, Honey Puffs, Frosties, Milo cereal, CocoPops [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Other breakfast cereals e.g. Special K, Light and tasty [1/2 cup]	○	○	○	○	○	○	○	○	○	○
White rice [1/2 cup cooked]	○	○	○	○	○	○	○	○	○	○
Brown rice [1/2 cup cooked]	○	○	○	○	○	○	○	○	○	○
White pasta, noodles e.g. spaghetti, canned spaghetti, vermicelli, egg noodles, rice noodles, instant noodles [1/2 cup cooked]	○	○	○	○	○	○	○	○	○	○
Whole meal pasta, noodles [1/2 cup cooked]	○	○	○	○	○	○	○	○	○	○

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*

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Couscous, polenta, congee, Bulgur wheat, quinoa e.g. tabbouleh [1/2 cup cooked]	○	○	○	○	○	○	○	○	○	○
Pancakes, waffles, sweet buns, scones, sweet muffins, fruit bread, croissants, doughnuts, brioche [1 serve]	○	○	○	○	○	○	○	○	○	○
White bread and rolls including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin, crumpets, pizza bases, wraps, tortilla's, burrito, roti, rewena bread [1 medium slice or 1/2 medium roll]	○	○	○	○	○	○	○	○	○	○
Whole meal or wheat meal bread and rolls including sliced and specialty breads [1 medium slice or 1/2 medium roll]	○	○	○	○	○	○	○	○	○	○
Whole grain or multi grain bread and rolls including sliced and specialty breads [1 medium slice or 1/2 medium roll]	○	○	○	○	○	○	○	○	○	○
Crackers e.g. crisp bread, water crackers, rice cakes, cream crackers, Cruskits, Mealmates, vitawheat [2 medium crackers]	○	○	○	○	○	○	○	○	○	○

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REACH Study - Food Frequency Questionnaire 18 April 2018

DAIRY PRODUCTS and ALTERNATIVES

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Cheese e.g. Cheddar, Colby, Edam, Tasty, blue vein, camembert, parmesan, gouda, feta, mozzarella, brie, processed [2 slices]	○	○	○	○	○	○	○	○	○	○
Cottage cheese, ricotta cheese [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Cream, sour cream, cream cheese, cheese spreads [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Cow's milk including milk as a drink, milk added to drinks (e.g. milky coffees), milk added to cereal [1 cup]	○	○	○	○	○	○	○	○	○	○
Soy milk, coconut milk, rice milk, almond milk [1 cup]	○	○	○	○	○	○	○	○	○	○
Smoothies, milk shakes (made from milk, yoghurt, ice cream), **milk shakes, flavoured milk** [1 cup]	○	○	○	○	○	○	○	○	○	○
Milk based puddings e.g. rice pudding, custard, semolina, instant puddings, dairy food [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Yoghurt [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Ice cream [1/2 cup]	○	○	○	○	○	○	○	○	○	○

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REACH Study - Food Frequency Questionnaire 18 April 2018

NON-ALCOHOLIC DRINKS

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Hot chocolate, drinking chocolate, Cocoa, Ovaltine, Nesquik, Milo [1 cup]	○	○	○	○	○	○	○	○	○	○
Coffee (all varieties) [1 cup]	○	○	○	○	○	○	○	○	○	○
Tea [1 cup]	○	○	○	○	○	○	○	○	○	○
Herbal tea, fruit tea [1 cup]	○	○	○	○	○	○	○	○	○	○
Low calorie cordials [1 glass]	○	○	○	○	○	○	○	○	○	○
Cordials including syrups, powders e.g. Raro [1 glass]	○	○	○	○	○	○	○	○	○	○
Fruit and vegetable juices (all varieties) [1 glass]	○	○	○	○	○	○	○	○	○	○
Sports drinks e.g. Powerade [1 glass]	○	○	○	○	○	○	○	○	○	○
Energy drinks e.g. Red Bull, V [1 glass]	○	○	○	○	○	○	○	○	○	○
Diet soft/fizzy drinks e.g. Sprite Zero, Diet Coke, Coke Zero [1 glass]	○	○	○	○	○	○	○	○	○	○
Soft/fizzy drinks e.g. Sprite, Coke [1 glass]	○	○	○	○	○	○	○	○	○	○
Water including tap, bottled or sparkling water [1 glass]	○	○	○	○	○	○	○	○	○	○

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REACH Study - Food Frequency Questionnaire 18 April 2018

ALCOHOL

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Beer, lager, cider (all varieties) [1 can or bottle]	○	○	○	○	○	○	○	○	○	○
Red wine [1 small glass]	○	○	○	○	○	○	○	○	○	○
White wine [1 small glass]	○	○	○	○	○	○	○	○	○	○
Port, sherry, liquors [1 small glass]	○	○	○	○	○	○	○	○	○	○
Spirits e.g. gin, brandy, whiskey, vodka [1 shot or 30ml]	○	○	○	○	○	○	○	○	○	○
Ready to drink alcoholic beverages [1 bottle or can]	○	○	○	○	○	○	○	○	○	○

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REACH Study - Food Frequency Questionnaire 18 April 2018

MISCELLANEOUS FOODS and SNACKS

* In the past month I have had this food

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Cakes, slices, pastries [1 medium serve]	○	○	○	○	○	○	○	○	○	○
Non-milk based puddings e.g. pavlova, sweet pastries, fruit pies, trifle [1 medium serve]	○	○	○	○	○	○	○	○	○	○
Biscuits, plain [2 biscuits]	○	○	○	○	○	○	○	○	○	○
Biscuits, chocolate or cream filled [2 biscuits]	○	○	○	○	○	○	○	○	○	○
Butter, ghee [1 tsp]	○	○	○	○	○	○	○	○	○	○
Margarine [1 tsp]	○	○	○	○	○	○	○	○	○	○
Vegetable oils [1 tsp]	○	○	○	○	○	○	○	○	○	○
Sugar (all varieties) added by you to food / drinks [1 tsp]	○	○	○	○	○	○	○	○	○	○
Jam, marmalade, honey, syrups, sweet spreads or preserves [1 tsp]	○	○	○	○	○	○	○	○	○	○
Marmite, vegemite [1 tsp]	○	○	○	○	○	○	○	○	○	○
Coconut cream [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Coconut oil [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Creamy dressings e.g. mayonnaise, tartar, thousand island, ranch dressing [1 Tbsp]	○	○	○	○	○	○	○	○	○	○

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*

	I never eat this food	Not this month but I have sometimes	1 to 3 times a **MONTH**	Once per **WEEK**	2 to 3 times per **WEEK**	4 to 6 times per **WEEK**	Once per **DAY**	2 to 3 times per **DAY**	4 to 5 times per **DAY**	6 plus times per **DAY**
Light dressings e.g. French and Italian dressing, balsamic vinegar [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
White sauce, cheese sauce, gravies [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Tomato sauce, barbeque sauce, sweet chilli sauce [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Pickles, chutney, mustard [1 Tbsp]	○	○	○	○	○	○	○	○	○	○
Spices e.g. turmeric, ginger, cinnamon [1 tsp]	○	○	○	○	○	○	○	○	○	○
Soup, homemade or canned [1 cup]	○	○	○	○	○	○	○	○	○	○
Muesli or cereal bar (all varieties) [1 bar]	○	○	○	○	○	○	○	○	○	○
Potato crisps [1/2 cup]	○	○	○	○	○	○	○	○	○	○
Sweets, lollies [5-6 lollies]	○	○	○	○	○	○	○	○	○	○
Chocolate (all other varieties) [4 squares]	○	○	○	○	○	○	○	○	○	○

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REACH Study - Food Frequency Questionnaire 18 April 2018

* Are there any other foods which you have eaten in the past month?

- Yes
- No

If yes, please state the food, the serving size and the frequency of consumption

Food (A)

Serving size (Food A)

Frequency of comsumption (Food A)

Food (B)

Serving size (Food B)

Frequency of comsumption (Food B)

Food (C)

Serving size (Food C)

Frequency of comsumption (Food C)

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4-day food record

Participant ID

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

The REACH (Researching Eating Activity and Cognitive Health) Study

4 Day Food Record

Thank you very much for taking part in the REACH Study. We are extremely grateful for your time, effort and commitment!

If you have any questions, please contact Owen Mugridge on (09)2136650; or email reachstudy@massey.ac.nz

All information in this diary will be treated with the strictest confidence. No one outside the study will have access to this.

What to do?

- Record all that you eat and drink on the following dates.

_____

_____

_____

_____

_____

- If possible record food at the time of eating or just after – try to avoid doing it from memory at the end of the day.
- Include all meals, snacks, and drinks, even tap water.
- Include anything you have added to foods such as sauces, gravies, spreads, dressings, etc.
- Write down any information that might indicate size or weight of the food to identify the portion size eaten.
- Use a new line for each food and drink. You can use more than one line for a food or drink. See the examples given.
- Include any supplements (brand name, type, number taken, etc)
- Use as many pages of the booklet as you need.

Describing Food and Drink

- Provide as much detail as possible about the type of food eaten. For example **brand names and varieties / types** of food.

General description	Food record description
Breakfast example – cereal, milk, sugar	1 cup Sanitarium Natural Muesli 1 cup Pam's whole milk 1 tsp Chelsea white sugar
Coffee	1 tsp Gregg's instant coffee 1 x 200ml cup of water 2 Tbsp Meadow fresh light green milk
Pasta	1 cup San Remo whole grain pasta spirals (boiled)
Pie	Big Ben Classic Mince and Cheese Pie (170g)

- Give details of all the **cooking methods** used. For example, fried, grilled, baked, poached, boiled…

General description	Food record description
2 eggs	2 size 7 eggs fried in 2tsp canola oil 2 size 6 eggs (soft boiled)
Fish	100g salmon (no skin) poached in 1 cup of water for 10 minutes

- When using foods that are cooked (eg. pasta, rice, meat, vegetables, etc), please record the **cooked portion** of food.

General description	Food record description
Rice	1 cup cooked Jasmine rice (cooked on stove top)
Meat	90g lean T-bone steak (fat and bone removed)
Vegetables	½ cup cooked mixed vegetables (Wattie's peas, corn, carrots)

- Please specify the **actual amount of food eaten** (eg. for leftovers, foods where there is waste)

General description	Food record description
Apple	1 x 120g Granny Smith Apple (peeled, core not eaten – core equated to ¼ of the apple)
Fried chicken drumstick	100g chicken drumstick (100g includes skin and bone); fried in 3 Tbsp Fern leaf semi-soft butter

- **Record recipes** of home prepared dishes where possible and the proportion of the dish you ate. There are blank pages for you to add recipes or additional information.

Recording the amounts of food you eat

It is important to also record the quantity of each food and drink consumed. This can be done in several ways.

- By using household measures – for example, cups, teaspoons and tablespoons. Eg. 1 cup frozen peas, 1 heaped teaspoon of sugar.

- By weight marked on the packages – eg. a 425g tin of baked beans, a 32g cereal bar, 600ml Coke

- Weighing the food – this is an ideal way to get an accurate idea of the quantity of food eaten, in particular for foods such as meat, fruits, vegetables and cheese.

- For bread – describe the size of the slices of bread (eg. sandwich, medium, toast) – also include brand and variety.

- Using comparisons – eg. Meat equal to the size of a pack of cards, a scoop of ice cream equal to the size of a hen's egg.

- Use the food record instructions provided to help describe portion sizes.

General description	Food record description
Cheese	1 heaped tablespoon of grated cheese 1 slice cheese (8.5 x 2.5 x 2mm) 1 cube cheese, match box size Grated cheese, size 10B

- If you go out for meals, describe the food eaten in as much detail as possible.

- ***Please eat as normally as possible - don't adjust what you would normally eat just because you are keeping a food record and be honest! Your food record will be identified with a number rather than your name.***

Example day

Time and place food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed (units, measures, weight)**
Example 7:55am At home	Sanitarium weetbix	2 weetbix
" "	Anchor Blue Top milk	150ml
" "	Chelsea white sugar	2 heaped teaspoons
" "	Orange juice (Citrus Tree with added calcium – nutrition label attached)	1 glass (275 ml)
10.00am In car	Raw Apple (gala)	Ate all of apple except the core, whole apple was 125g (core was ¼ of whole apple)
12.00pm At home	Home made pizza (recipe attached)	1 slice (similar size to 1 slice of sandwich bread, 2 Tbsp tomato paste, 4 olives, 2 rashers bacon (fat removed), 1 Tbsp chopped spring onion, 3 Tbsp mozzarella cheese)
1.00pm At work	Water	500ml plain tap water
3.00pm At work	Biscuits	6 x chocolate covered Girl Guide biscuits (standard size)
6.00pm At home	Lasagne	½ cup cooked mince, 1 cup cooked Budget lasagne shaped pasta , ½ cup Wattie's creamy mushroom and herb pasta sauce, ½ cup mixed vegetables (Pam's carrots, peas and corn), 4 Tbsp grated Edam cheese
6.30pm At home	Banana cake with chocolate icing (homemade, recipe attached)	1/8 of a cake (22cm diameter, 8 cm high), 2 Tbsp chocolate icing
" "	Tip Top Cookies and Cream ice cream	1 cup (250g)
7.30pm At home	Coffee	1 tsp Gregg's instant coffee 1 x 300ml cup of water 2 Tbsp Meadow fresh blue top milk 2 tsp sugar

Date_____ DAY 1

Time and place food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Recipes (Day 1)