Investigating sex and gender differences in dietary intake and the relationship with cardiometabolic diseases

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Investigating sex and gender differences in dietary intake and the relationship with cardiometabolic diseases

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A thesis in fulfilment of the requirements for the degree of a

Doctor of Philosophy

The George Institute for Global Health

Faculty of Medicine, University of New South Wales

December 2021

Thesis title and abstract sheet

Thesis submission for the degree of Doctor of Philosophy

Thesis Title and Abstract | Declarations | Inclusion of Publications Statement | Corrected Thesis and Responses

Thesis Title

Investigating sex and gender differences in dietary intake and the relationship with cardiometabolic diseases

Thesis Abstract

A quarter of adult deaths are attributable to suboptimal diets globally, with cardiovascular (CVD) and metabolic diseases being the leading cause of diet-related deaths. The aim of this thesis was to investigate the relationship of sex and gender with diet and cardiometabolic diseases via a range of geographically diverse studies, through a mixed methods approach.

Three quantitative studies focusing on sex differences were conducted: one looking at biases in relation to self-reported energy intake by a systematic review and meta-analysis; one cross-sectional analysis of dietary behaviours and associations with cardiometabolic risk factors in seven low- and middle-income countries (LMICs); and a prospective analysis of cohort data from the UK looking at dietary intake and associated risks of CVD and premature mortality. Questions arising from these studies were explored through qualitative studies in Fiji: a policy landscape analysis and focus group discussions to understand gender differences in diet knowledge, attitudes and behaviours and gender considerations in policies.

No sex bias in the accuracy of dietary assessment was identified, with similar levels of energy underestimation by women and men. Across the seven LMICs in the cross-sectional analysis, both women and men had poor dietary behaviours, however, women who reported positive (good) salt use behaviour were less likely to have undiagnosed hypertension (not evident for men). Diets of women and men were also poor in the UK cohort, yet an association between specific combinations of macronutrients and a reduced risk of mortality was identified for women and men, and a reduced risk of CVD for men. The policy analysis conducted in Fiji revealed a conflation between "gender" and "reproductive health", and that gender differences in diet-related diseases were not viewed as policy issues. Finally, the focus group discussions identified gender constructs around food, however, upstream determinants of poor diets such as climate change and socioeconomic factors were identified as crucial influences on diet, by women and men.

Collectively, findings identified poor diets for both sexes, with some modest sex differences in associations between diet and disease, which are unlikely due to differences in reporting. Results from the qualitative studies highlight the importance of considering gender in view of other equity factors. These findings will be important in the development of equitable food policy globally.

Originality, copyright, and authenticity statements

Thesis submission for the degree of Doctor of Philosophy

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Publication Details #1

Full Title:	Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis
Authors:	Briar L McKenzie, Daisy H Coyle, Joseph Alvin Santos, Tracy Burrows, Emalie Rosewarne, Sanne A E Peters, Cheryl Carcel, Lindsay M Jaacks, Robyn Norton, Clare E Collins, Mark Woodward, Jacqui Webster
Journal or Book Name:	The American Journal of Clinical Nutrition
Volume/Page Numbers:	Issue 5, Pages 1241–1255
Date Accepted/Published:	10 February 2021
Status:	published
The Candidate's Contribution to the Work:	As the first author of this publication, I contributed significantly (>50%) to this piece of work. I was responsible for conceptualizing the study and designed the initial approach to the study with support from co-authors when requested. I led the data searching and data extraction, with DHC as reviewer 2. I led the data analysis with support from JAS and oversight from MW when needed. I was responsible for writing the first draft of the manuscript, and for coordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This publication is included as Chapter 3 within the thesis.

Publication Details #2

Full Title:	Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: A cross-sectional study of nationally representative surveys in seven low- and middle-income countries
Authors:	Briar L. McKenzie, Joseph Alvin Santos, Pascal Geldsetzer, Justine Davies, Jennifer Manne-Goehler, Mongal Singh Gurung, Lela Sturua, Gladwell Gathecha, Krishna K. Aryal, Lindiwe Tsabedze, Glennis Andall-Brereton, Till Bärnighausen, Rifat Atun, Sebastian Vollmer, Mark Woodward, Lindsay M. Jaacks & Jacqui Webster
Journal or Book Name:	Nutrition Journal
Volume/Page Numbers:	Volume 19, article number 3, pages 1 - 15
Date Accepted/Published:	13 January 2020
Status:	published
The Candidate's Contribution to the Work:	As the first author on this publication, I contributed significantly (>50%) to this piece of work. I conceived the research question and developed the research plan in collaboration with the senior authors (LMJ and JW). I led the statistical analysis, with support when needed from author JAS. I was responsible for writing the first draft of the manuscript, and for coordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This publication is included as Chapter 4 within the thesis.

Publication Details #3

Full Title:	The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank
Authors:	Briar L McKenzie, Katie Harris, Sanne AE Peters, Jacqui Webster, Mark Woodward
Journal or Book Name:	British Journal of Nutrition
Volume/Page Numbers:	Available online (published online ahead of print), pages 1 - 10
Date Accepted/Published:	14 July 2021
Status:	published
The Candidate's Contribution to the Work:	As the first author on this publication, I contributed significantly (>50%) to this piece of work. This piece of work followed on from a publication conducted by MW and SP in 2018, and as such the original research question was posed by MW and SP. I further developed this research question and developed a research plan in consultation with KH. I conducted the statistical analysis in collaboration with KH. I was responsible for writing the first draft of the manuscript, and for coordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This publication is included as Chapter 5 within the thesis.

Publication Details #4

Full Title:	Incorporating a gender lens into nutrition and health-related policies in Fiji: a policy analysis
Authors:	Briar L McKenzie, Gade Waqa, Sarah Mounsey, Claire Johnson, Mark Woodward, Kent Buse, Anne Marie Thow, Rachael McLean, Jacqui Webster
Journal or Book Name:	International Journal for Equity in Health
Volume/Page Numbers:	NA
Date Accepted/Published:	Submitted 10th of November 2021
Status:	submitted
The Candidate's Contribution to the Work:	As the first author on this publication, I contributed significantly (>50%) to this piece of work. I was responsible for developing the research question and developing the research plan in collaboration with senior authors on the paper. I led data extraction from the policy documents, I conducted 15 of the 18 interviews with key informants and led analysis of both the policy content and interview transcripts, with insights from co-authors when appropriate. I was responsible for writing the first draft of the manuscript, and for coordinating and incorporating feedback from co-authors. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This manuscript (submitted for publication) is included as Chapter 6 within the thesis.

Publication Details #5

Full Title:	Perceptions on healthy eating among iTaukei women and men in Viti Levu, Fiji: an intersectional interpretation
Authors:	Briar L McKenzie, Gade Waqa, Ashleigh C Hart, Adi Moala Silatolu, Anna Palagyi, Robyn Norton, Rachael McLean, Jacqui Webster
Journal or Book Name:	Public Health Nutrition
Volume/Page Numbers:	NA
Date Accepted/Published:	Submitted 23rd of November 2021
Status:	submitted
The Candidate's Contribution to the Work:	As the first author on this publication, I contributed significantly (>50%) to this piece of work. I conceptualised the study in consultation with GW and JW. GW led the focus group discussion, and I supported during the sessions. I led the analysis of the focus group transcripts, with ACH acting as the second coder. Themes identified during analysis were discussed with GW and JW. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This manuscript (submitted for publication) is included as Chapter 7 within the thesis.

Publication Details #6

Full Title:	Gender differences in the accuracy of dietary assessment methods to measure energy intake in adults: protocol for a systematic review and meta-analysis
Authors:	Briar L McKenzie, Daisy H Coyle, Tracy Burrows, Emalie Rosewarne, Sanne A E Peters, Cheryl Carcel, Clare E Collins, Robyn Norton, Mark Woodward, Lindsay M Jaacks, Jacqui Webster
Journal or Book Name:	BMJ Open
Volume/Page Numbers:	Volume 10, issue 6, pages 1-4
Date Accepted/Published:	1st June 2020
Status:	published
The Candidate's Contribution to the Work:	As the first author of this publication, I contributed significantly (>50%) to this piece of work. I was responsible for conceptualizing the study, and designed the initial protocol with co-authors (DHC and JW). I drafted the search terms and engagement with Librarians at the University of New South Wales for their review of the search terms. I was responsible for writing the first draft of the manuscript, and for coordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.
Location of the work in the thesis and/or how the work is incorporated in the thesis:	This publication is included as appendix 1 within the thesis.

Candidate's Declaration

I confirm that where I have used a publication in lieu of a chapter, the listed publication(s) above meet(s) the requirements to be included in the thesis. I also declare that I have complied with the Thesis Examination Procedure.

Acknowledgements

Most of this work was conducted at The George Institute for Global Health offices in Newtown, Sydney. I acknowledge the Gadigal People of the Eora Nation as the Traditional Custodians of the land on which this work was done. I pay my respect to Elders past, present and emerging.

Completing this PhD has been a significant personal achievement for me. I am grateful for all the opportunities, all I have learnt, and all the people I have met throughout the process. I also wish to acknowledge the support of a UNSW Scientia Scholarship in completing this PhD, and for the development opportunities that this scholarship made possible in addition to support from The George Institute for Global Health.

Throughout my PhD I have been inspired and supported by my supervisory team – Jacqui Webster, Rachael McLean, Mark Woodward, Robyn Norton and Anushka Patel –you have all been so generous with your time and with your expertise. Thank you all for pushing me (in a good way), and for your roles in teaching me new skills and shaping me as a researcher. Skills that I hope to build on. Jacqui, as my primary supervisor you opened a whole range of doors for me, providing opportunities that I never imagined would have been possible. I certainly did not imagine this outcome when I moved to Sydney for a one-year contract at The George Institute back in 2017. Thank you all for taking a chance on me.

In addition to my supervisory team, I have been lucky to have worked with a range of inspiring researchers. Specifically, Lindsay Jaacks and the Harvard and Göttingen University HPACC teams, Gade Waqa and the team at Fiji National University, and staff and fellow PhD students at The George Institute.

On a personal level, one of the best outcomes of this PhD has been the friendships made. In particular – Daisy Coyle, Maria Shahid, Rosemary Wyber, Emalie Rosewarne, Katie Harris and Jess Gong – I have had the opportunity to work alongside and learn from each of you along with establishing such great friendships. I also want to acknowledge the friendship and support from the WHOCC Salt Reduction team and the Global Women's Health Program.

To my Sydney family (albeit mostly from Aotearoa New Zealand) – Paul Wilton, Brendan Leonard, Margaret McKenzie, and the Bourke St flat (Ruby, Nicole, Mark, Emily, Lizzie, Stew, Liv) – you all made Sydney a very special place for me.

To Mum (Jan), Dad (David), Hamish, and Christie. Words do not provide justice to the level of gratitude that I have for your love and support, now and as always. Thanks for making sure that I do not take myself too seriously, but also for building me up when I needed it.

To Liam, you moved to Sydney for me when I started this PhD, and throughout our relationship you have been a sounding board for my ideas. I will be forever grateful for your unwavering belief in me, for your bolstering, and for your love. To Fergus, thanks for making me laugh and for being my smelly office companion in the last year of relative isolation.

Finally, I wish to acknowledge the study participants. Over 145,000 people across nine different countries have contributed to this PhD through being participants in different studies. I feel privileged to have worked with their data. Ultimately, I hope this research will contribute a piece of the puzzle in ensuring that the diet-related burden of disease is addressed equitably.

Abstract

A quarter of adult deaths are attributable to suboptimal diets globally, with cardiovascular (CVD) and metabolic diseases being the leading cause of diet-related deaths for women and men. There is a growing call for sex and gender considerations in epidemiology to inform more equitable interventions. This call is in line with Sustainable Development Goals three and five, focused on "Good Health and Well-being" and "Gender Equality", respectively. However, minimal research exists on the relationship between sex and gender with dietary intake and behaviours, or if sex and gender differences in diet influence cardiometabolic disease risk. Therefore, the aims of this thesis were to: firstly, identify if there are differences between women and men in dietary intake and/or behaviour and if these are linked to cardiometabolic disease risk factors or outcomes; and secondly, assess how gender considerations are incorporated within nutrition and health- related policies, and whether these policies adequately account for gender differences in dietary intake and the related burden of disease. These aims were addressed via a range of geographically diverse studies with a particular focus on low- and middle-income countries (LMICs), through a mixed methods approach.

Three quantitative studies focusing on sex and gender differences were conducted: one looking at biases in relation to self-reported energy intake by a systematic review and meta-analysis; one cross-sectional analysis of dietary behaviours and associations with cardiometabolic risk factors in seven LMICs; Bhutan, Eswatini, Georgia, Guyana, Kenya, Nepal and St Vincent and the Grenadines; and a prospective analysis of cohort data from the United Kingdom (UK) looking at dietary intake and associated risks of CVD, dementia and premature mortality. Questions arising from these studies were further explored through qualitative studies in Fiji (an upper middle income country): a policy landscape analysis conducted with a gender lens consisting of a review of nutrition and health-related policies and key informant interviews, with reference to the World Health Organization Gender Analysis Framework; and community focus group discussions interpreted using an Intersectionality Framework, to better understand gender

differences in diet knowledge, attitudes and behaviours and gender considerations in related policies.

No sex bias in the accuracy of dietary assessment was identified through the systematic review and meta-analysis, with similar levels of energy intake underestimation by women and men. Across the seven LMICs in the cross-sectional analysis, dietary behaviours were poor for women and men. However, women who reported positive salt use behaviour were less likely to have undiagnosed hypertension, a finding not evident for men. In the UK cohort, diets were also poor for women and men generally. However, a diet characterised by a specific combination of macronutrients (higher in protein but lower in fat and carbohydrate) was associated with a reduced risk of premature mortality for women and men, and a reduced risk of CVD for men specifically. The policy analysis in Fiji revealed a conflation between “gender” and “women’s reproductive health”, and that marked gender differences in diet-related diseases were not viewed as policy issues. Findings from the policy analysis led to four suggested strategic actions for the development of gender-responsive policies in Fiji: 1) framing gender considerations in policies so that they are actionable and more inclusive of a range of gender identities; 2) undertaking advocacy through actor networks to highlight the need for gender-responsive health and nutrition- related policies; 3) ensuring that data collected to monitor policy implementation is disaggregated by sex, and inclusive of gender identities; and 4) promoting equitable participation in nutrition-related issues at both a community and governance level. Given the small sex differences identified in the quantitative studies and, given the relatively low priority that gender considerations were given by policy makers in Fiji, an intersectionality framework was applied to interpret findings from the community focus group discussions. Within this, equity factors such as socioeconomic status and locations of residence, and external factors such as environmental change and the impact of the climate crisis, were identified as issues that interact to influence what people eat, in addition to gender. Both qualitative studies conducted within Fiji highlighted the need to address the upstream determinants of poor diets, to improve health.

Collectively, the findings identified poor diets for both sexes, with some modest sex differences in associations between diet and disease, which are unlikely to be due to differences in reporting. While the sex differences identified were small, the findings do highlight the need to continue to consider the interaction of sex with the diet and cardiometabolic disease relationship, as it is possible that the sex differences could become more pronounced if population diets change. Gender roles and responsibilities are changing around food in Fiji, and gender differences were seen as cultural norms, with people viewing other factors as more important influencers of the diet-related burden of disease. In combination, these findings indicate the need to take a broader equity approach, rather than focussing on gender alone. For example, by applying an intersectionality lens that considers the upstream determinants of health, and how these determinants interact, it is possible to understand the equity factors having the largest impacts on the diet-related burden of cardiometabolic disease. Such an approach is inclusive of sex and gender considerations and will be important to inform future studies, policies, and programs to address the diet-related burden of cardiometabolic diseases globally. Further, development and implementation of equity focused nutrition and health-policies will be essential to achieving the Sustainable Development Goals by 2030.

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Tables are numbered based on the chapter within the thesis and then the number of the table. The table number used within the corresponding chapter manuscript is provided in brackets.

List of figures

Figures are numbered based on the chapter within the thesis and then the number of the figure. The figure number used within the corresponding chapter manuscript is provided in brackets.

List of acronyms

BMI	Body mass index
BP	Blood pressure
CI	Confidence interval
CVD	Cardiovascular diseases
DBP	Diastolic blood pressure
EFR	Estimated food record
FFQ	Food frequency questionnaire
HICs	High-income Countries
HR	Hazard ratio
LMICs	Low- and Middle-income Countries
NCD	Noncommunicable disease
RHRs	Ratio of hazard ratios
SBP	Systolic blood pressure
SE	Standard error
SD	Standard deviation
SHR	Sub-distribution hazard ratio
TEE	Total energy expenditure
TEI	Total energy intake
UK	United Kingdom
WFR	Weighed food record
WHO	World Health Organization

Publications from this thesis

This thesis consists mainly of work that is either published or that has been submitted for publication. The publications have been inserted into the thesis in lieu of chapters, although have been formatted to be in line with the rest of the thesis.

Chapter 3 - **McKenzie BL**, Coyle DH, Santos JA *et al*. Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*. 2021 May;113(5):1241-55.

> A protocol for this systematic review and meta-analysis was published prior to conducting the review. This publication has been included as an appendix to the thesis (appendix 1): **McKenzie BL**, Coyle DH, Burrow T *et al*. Gender differences in the accuracy of dietary assessment methods to measure energy intake in adults: protocol for a systematic review and meta-analysis. *BMJ Open*. 2020 Jun 1;10(6):e035611.

Chapter 4 - **McKenzie BL**, Santos JA, Geldsetzer P *et al*. Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: a cross-sectional study of nationally representative surveys in seven low- and middle-income countries. *Nutrition Journal*. 2020 Jan;19(1):1-5.

Chapter 5 - **McKenzie BL**, Harris K, Peters SA *et al*. The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank. *British Journal of Nutrition*. 2021 Jul 14:1-24.

Chapter 6 – **McKenzie BL**, Waqa G, Mounsey S *et al*. Incorporating a gender lens into nutrition and health-related policies in Fiji: a policy analysis. Submitted to *International Journal for Equity in Health*, Nov 2021.

Chapter 7 – **McKenzie BL**, Waqa G, Hart AC *et al.* Perceptions on healthy eating among iTaukei women and men in Viti Levu, Fiji: an intersectional interpretation**.** Submitted to *Public Health Nutrition*, Nov 2021.

Other outcomes arising from this thesis

Conference presentations

International conferences:

- **McKenzie BL**, Harris K, Peters SA *et al.* The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank. *International Society of Behavioral Nutrition and Physical Activity Annual Meeting*. 8th – 10th of June 2021. Recorded oral presentation (virtual conference).
- **McKenzie BL**, Coyle DH, Santos JA *et al*. Gender differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review. *International Society of Behavioral Nutrition and Physical Activity Annual Meeting*. 20th of June 2020. Recorded oral presentation (virtual conference).
- **McKenzie BL**, Santos JA, Geldsetzer P *et al*. Sex differences in dietary behaviours and cardio-metabolic disease in seven low-and-middle-income countries. *World Public Health Nutrition Congress*. May 2020. Poster presentation (virtual conference).
- **McKenzie BL**, Santos JA, Ravuvu A *et al.* Gender differences in diet and cardio-metabolic diseases in Pacific Island countries. *Pacific Islands Health Research Symposium*. Fiji, Suva. 29th of August 2019. Oral presentation.
- **McKenzie BL**, Santos JA, Geldsetzer P *et al*. Sex differences in dietary behaviours and their relationship to hypertension, in seven low-to-middle income countries. *International Society of Behavioral Nutrition and Physical Activity Annual Meeting*. Czech Republic, Prague. 4 – 7th June 2019. Poster presentation.

- **McKenzie BL**, Santos JA, Peters SA *et al.* Sex differences in diet and cardio-metabolic diseases in Pacific Island countries. *Nutrition Society of New Zealand Annual Meeting*. New Zealand, Auckland. 28 – 30th November 2018. Oral presentation.

Institute specific presentations:

- **McKenzie BL**, Harris K, Peters SA *et al.* The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank. *The George Institute, Lunchtime Seminar Series.*14th of July 2021. Oral presentation (virtual).
- **McKenzie BL**. Investigating gender differences in dietary intake and behaviours and their relationship with cardio-metabolic diseases. *The George Institute, Lunchtime Seminar Series*. Sydney, Australia. 27th November 2019. Oral presentation.
- **McKenzie BL**, Santos JA, Geldsetzer P *et al*. Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: A cross-sectional study of nationally representative surveys in seven low- and middle-income countries. *Harvard TH Chan School of Public Health, Nutrition Research Seminar.* USA, Cambridge. 4th November 2019. Oral presentation.
- **McKenzie BL**. Gender differences in dietary intake and cardiovascular outcomes. *Oxford University, work in progress meeting.* UK, Oxford. 13th of June 2018.

Publications not included in this thesis

During the course of my PhD I have contributed to 13 other publications, mainly focused on diet-related disease risk, the implementation of food policies, investigations on cardiovascular disease management and outcomes, or the incorporation of sex and gender considerations in health research.

- Webster J, Santos JA… **McKenzie BL** *et al*. Implementing Effective Salt Reduction Programs and Policies in Low- and Middle-Income Countries: Learning from retrospective policy analysis in Argentina, Mongolia, South Africa and Vietnam. *Public Health Nutrition*. 2021 Aug.

- Santos JA, **McKenzie B**, Rosewarne E *et* al. Strengthening Knowledge to Practice on Effective Salt Reduction Interventions in Low-and Middle-Income Countries. *Current Nutrition Reports*. 2021 Jul 5:1-5.
- Shahid M, Waqa G, Pillay A… **McKenzie B** *et al*. Packaged food supply in Fiji: Nutrient levels, compliance with sodium targets and adherence to labelling regulations. *Public Health Nutrition.* 2021 May 19:1-1.
- **McKenzie BL**, Jaacks LM. Nutritional research is moving to a whole-diet approach, time for food policy. *BMC medicine*. 2021 Apr;19(1):1-3.
- Rosewarne E, Chislett WK, **McKenzie B** *et al*. Stakeholder perspectives on the effectiveness of the Victorian Salt Reduction Partnership: a qualitative study. BMC nutrition. 2021 Apr;7(1):1-21.
- Peiris D, Ghosh A… **McKenzie B** *et al*. Cardiovascular disease risk profile and management practices in 45 low-income and middle-income countries: A cross-sectional study of nationally representative individual-level survey data. *PLoS medicine*. 2021 Mar 4;18(3):e1003485.
- Wainer Z, Carcel C… **McKenzie B** *et al*. Sex and gender in health research: updating policy to reflect evidence – an Australian call to action. *Medical Journal of Australia*. 2020 Feb;212(2):57-62.
- Thout SR, Santos JA, **McKenzie B** *et al*. The Science of Salt: Updating the evidence on global estimates of salt intake. *The Journal of Clinical Hypertension*. 2019 April 29: 1-12.
- Frank SM, Webster J, **McKenzie B** *et al*. Consumption of fruits and vegetables among individuals 15 years and older in 28 low and middle-income countries. *The Journal of Nutrition*. 2019 Jun: 149(7): 1252-1259.
- Santos JA, Christoforou A, Trieu K, **McKenzie BL** *et al*. Iodine fortification of foods and condiments, other than salt, for preventing iodine deficiency disorders (Review). *Cochrane Database Syst Rev*. 2019 Feb 12;2:CD010734.

- **McKenzie B**, Trieu K, Grimes CA *et al*. Understanding Barriers and Enablers to State Action on Salt: Analysis of Stakeholder Perceptions of the VicHealth Salt Reduction Partnership. *Nutrients*. 2019 Jan 11(1).
- Santos JA, **McKenzie B** *et al*. Contribution of fat, sugar and salt to diets in the Pacific Islands - A systematic review. *Public Health Nutrition*. 2019 Jan 7:1-14
- Sparks E, Farrand C… **McKenzie B** *et al*. Sodium Levels of Processed Meat in Australia: Supermarket Survey Data from 2010 to 2017. *Nutrients*. 2018 Nov;10(11):1686.

Published reports

- **McKenzie B[1]**, Hunnisett C[1], Abbott H, Baldock A, Feeny E, Rosewarne E, Webster J, Waqa GD. Sustainable Food Security in the Pacific. Sydney, Australia: The George Institute for Global Health; 2021. ([1] *joint first authorship*)
- Rosewarne E[1], Hunnisett C[1], Abbott H, Baldock A, Bennett-Brook K, Coombes J, Corby C, Feeny E, Leslie G, McCausland R, **McKenzie B**, Webster J and Spencer W. A community in action. How Walgett is redefining food systems. Sydney, Australia: The George Institute for Global Health; 2021
- Rosewarne E[1], Hunnisett C[1], Abbott H, Baldock A, Bennett-Brook K, Coombes J, Corby C, Leslie G, McCausland R, **McKenzie B**, Spencer W, Feeny E[2], Webster J[2]. Whose paradigm counts? An Australia-Pacific perspective on unheard voices in food and water systems. Sydney, Australia: The George Institute for Global Health; 2021.
- Community of Practice. Centre for Food Policy Research Brief. Understanding Lived Experience of Food Environments to Inform Policy: An Overview of Research Methods. February 2021. https://researchcentres.city.ac.uk/__data/assets/pdf_file/0004/595318/Understanding-Lived-Experience-FINAL-v4.pdf

Online articles

- **McKenzie B**. Does diet affect the biggest killers of men and women differently? 21st of July 2021. https://www.georgeinstitute.org/news/does-diet-affect-the-biggest-killers-of-men-and-women-differently
- **McKenzie B**. How good are men and women at telling us what they eat and why does it matter? 15th February 2021. https://www.georgeinstitute.org/news/how-good-are-men-and-women-at-telling-us-what-they-eat-and-why-does-it-matter
- **McKenzie B.** Urgent action on diet needed to stem rising tide of chronic disease in less developed nations. 14th of January 2020. https://www.georgeinstitute.org/media-releases/urgent-action-on-diet-needed-to-stem-rising-tide-of-chronic-disease-in-less
- **McKenzie B.** Nutrition Week - Scientia PhD student Briar McKenzie is examining differences in dietary intake for women and men. 18th of October 2019. https://www.georgeinstitute.org/profiles/nutrition-week-scientia-phd-student-briar-mckenzie-is-examining-differences-in-dietary

Grants and awards

- **ZonMw Gender in Health Research Fellow.** The Netherlands Organisation for Health Research and Development (ZonMw), and the departments of Epidemiology and Internal Medicine of ErasmusMC, University Medical Center Rotterdam (*virtual/remote participation*), May – August 2021.
- **Valuable Treasures Award.** The George Institute for Global Health. Awarded for role as student representative for TGI research students, June 2019 -July 2020.
- **Travel scholarship.** Nutrition Society of New Zealand Annual Meeting, December 2018.
- **Scientia PhD Scholarship**. A four-year scholarship awarded through the University of New South Wales. Awarded 2017, for 2018 - January 2022.

Chapter 1. Introduction

1.1 Chapter overview

The need for a focus on, and inclusion of, sex and gender considerations in nutrition and cardiometabolic disease research is described within this chapter. This includes establishing terminology used throughout the thesis, describing what is known about sex and gender differences in cardiometabolic disease risk, and in dietary intake and behaviours. Gaps in the literature addressed by this thesis are highlighted, inclusive of reasoning for the need to focus on lower resource settings such as low-and middle- income countries (LMICs). This chapter concludes with the thesis aims and specific research questions that are addressed.

1.2 Definitions and terminology

1.2.1 Sex and gender

The terms sex and gender are often used interchangeably in research [1, 2]. While the terms can be interrelated, they do refer to different concepts. Both sex and gender considerations are included within this thesis. The definitions that have guided use of related terms were sourced from the World Health Organization [1] and the Australian Bureau of Statistics Standard for Sex, Gender, Variations of Sex Characteristics and Sexual Orientation Variables [2].

Sex is used in reference to biological characteristics, such as chromosomes, hormone profile and reproductive organs [1, 2]. Based on these characteristics, sex is usually classified as female or male. Some people are born with variations of sex characteristics, which covers a wide spectrum of variations to genetic, hormonal, or physical characteristics usually used to classify people as female or male [2]. Further, a person's self-reported sex may differ from their sex recorded at birth and may change during their life [2].

Gender is a social construct, and therefore can differ by society, place, and time [1]. Gender encompasses social and cultural factors related to norms, behaviours, roles and responsibilities of women, men and non-binary people [1]. Gender identity then encompasses how people experience their world and how they express themselves. As with sex and gender, someone's self-reported gender identity can change over time [2].

The use of sex and gender terminology has been guided by these definitions. However, where discussing study results (as is done within this chapter), the terms used reflect those included within the studies being discussed.

1.2.2 Cardiometabolic diseases

A range of diseases can come within the "cardiometabolic disease" definition. In general, cardiometabolic disease is a term that is inclusive of cardiovascular disease, stroke, type 2 diabetes mellitus (diabetes) and chronic renal failure [3]. In this thesis the focus is on cardiometabolic non-communicable diseases (NCDs): cardiovascular disease, stroke, and diabetes [4], unless otherwise specified.

1.3 Overview of the global burden of cardiometabolic diseases

Globally, the leading causes of death are ischaemic heart disease and stroke [3]. Ischaemic heart disease and stroke are predicted to be the leading contributors towards adult mortality for the foreseeable future [5]. Cardiometabolic diseases and risk factors are key contributors to the global disease burden [3]. Cardiometabolic diseases account for the leading causes of premature death and disability for women and men [3]. While this burden is substantial across sexes, men are more likely to die from cardiometabolic diseases at a younger age than women [3, 6, 7]. However, women are more likely to live longer with poorer health due to disease related comorbidities [3]. The burden of cardiometabolic diseases is also known to differ by socioeconomic status, with a higher burden of disease for people living at higher levels of socioeconomic disadvantage [8, 9]. Further, there is some evidence of poorer outcomes following events for people living at high socioeconomic disadvantage compared to those living at lower levels of disadvantage [10].

Established risk factors for cardiometabolic diseases are age, sex, smoking, dyslipidaemia, hypertension, and hyperglycaemia [11]. The highly preventable burden of cardiometabolic diseases is linked with increasing prevalence of metabolic risk factors. Specifically, high body-mass index (BMI), high fasting plasma glucose, high systolic blood pressure, kidney dysfunction and high LDL cholesterol have increased in prevalence on average by 1.37% per year between 1990 and 2019, with average increases of 1.46% per year between 2010 and 2019, globally [3]. The prevalence of metabolic risk factors varies across regions with different sociodemographic indices and differs by sex [3]. Diet is a key contributor to metabolic risk factors [3, 12]. It is therefore a key contributor to cardiometabolic disease, particularly cardiovascular disease (CVD) and diabetes [12].

1.3.1 Cardiometabolic disease burden in low-and-middle income countries

Of all cardiometabolic disease deaths, approximately 80% occur in LMICs [13]. The burden of cardiometabolic disease is increasing at a higher rate in LMICs than it is in high income countries (HIC) [4, 14], particularly for women in LMICs compared to women in HICs. For example, across 15 LMICs with death registration data, age-standardised death rates for NCDs (mainly formed by cardiometabolic diseases) were 86% higher for women, and 54% higher for men in LMICs than women and men in HICs [14]. There are also marked differences in the burden of cardiometabolic risk factors in LMICs compared to HICs. For example, 67% of people living with obesity [15, 16] live in countries classified as an LMIC. LMIC countries within the Pacific Islands experience some of the highest levels of non-communicable disease and related premature mortality (defined as dying before 70 years of age) globally [17]. As an example, in Fiji, 42% of women and 22% of men live with obesity, approximately a third of women and men live with hypertension, and 15% of women and men have impaired fasting glycaemia [18]. Further, 8.3% of men and 6.7% of women aged between 40 and 64 years are estimated to be at a very high risk of having a CVD event or CVD caused death within a 10-year period [19].

In a review that aimed to understand the rise of cardiometabolic diseases in LMICs [4], authors discussed the increasingly “toxic and obesogenic” environments that people who are raised in LMICs are exposed to [4]. Both under-nutrition and over-nutrition are prevalent in LMICs [20].

Chronic childhood undernutrition resulting in stunting is known to have lasting metabolic effects, and history of childhood stunting is known to relate to the prevalence of overweight and obesity in adulthood, along with the development of cardiometabolic diseases at younger ages [4, 21]. While prevention is better than cure in all settings, a focus on preventing disease is increasingly important in low resource settings, like LMICs.

1.3.2 Sex and gender differences in cardiometabolic disease risk factors and management

In recent decades there have been steady decreases in incidence rates for CVD events in HICs. However, there is evidence that the rate of this decline is slowing, and for women plateauing or increasing [22, 23].

A study conducted by Kim JK et al [23] in the US investigated CVD risk over a 20-year period (1990-2010) finding a "growing similarity" in CVD risk profiles between women and men. While men had steady decreases in the prevalence of risk factors across the 20 years, increases were seen for women, and at the mid-point of this study, which was 2000, women aged 60 or older had a higher risk of CVD than men aged 60 or older. Sex differences have also been investigated in the prevalence, treatment, and control of cardiovascular risk factors [24, 25]. In a UK cohort, the prevalence of CVD risk factors; smoking, hypertension, overweight and dyslipidaemia, were more common in men than in women in 2017. While treatment and control of risk factors were similar for women and men for most risk factors, women were less likely than men to have treated and controlled dyslipidaemia [24]. Comparatively, in a US cohort BMI increased more so in women than in men between 2001 and 2016, while total cholesterol decreased more in men than in women during the same period of time [25]. While improvements were identified in the treatment and control of CVD risk factors for women and men, there were still sex differences in the degree of control, with better control of hypertension and diabetes for women in comparison to men, yet worse control of dyslipidaemia for women compared to men [25].

Additionally, there is evidence that diabetes is a stronger risk factor for stroke and coronary heart disease in women compared to men. Two large meta-analyses by Peters SAE et al [26, 27] found that women with diabetes have a 27% [27] and 44% [26] higher relative risk for stroke and coronary heart disease, respectively, than men with diabetes. The authors hypothesised that this is due to "*a combination of both a greater deterioration in cardiovascular risk factor levels and a chronically elevated cardiovascular risk profile in the prediabetic state, driven by greater levels of adiposity in women compared with men*" [26]. This hypothesis is supported by studies showing men tend to develop diabetes at a lower BMI compared to women [28-30].

Age is a key mediating factor for CVD risk in women. Compared with age-matched men, CVD events occur approximately 5-10 years later for women [6, 31]. It has been thought that this delay in events is due to a protective relationship between oestrogen and CVD risk, such that when oestrogen levels decrease as women age, the risk of CVD increases [32]. However, further research has shown that the association between oestrogens (specifically oestradiol) and risk of myocardial infarction is confounded by age and other classical cardiovascular risk factors (such as high blood pressure, smoking status, high cholesterol, high systolic blood pressure, diabetes, high body mass index (BMI) and socioeconomic status) [33]. Given the aging population, there is a need to look at preventable measures for CVD risk for women and men.

1.4 The burden of poor diets and the relationship of poor diets with cardiometabolic disease

Globally, poor diets were associated with 5.6 million deaths in 2019 [3]. For women, dietary risks were ranked as the second highest contributor to deaths (with high systolic blood pressure ranking first) and was the third highest contributor to deaths for men (with tobacco smoking and high systolic blood pressure ranking first and second, respectively) [3].

The burden of disease due to poor diets is reflected by the World Health Organization's Global NCD Targets [34]. These targets should be met by 2025:

- A 30% relative reduction in mean population intake of salt (sodium chloride) intake

- A 25% relative reduction in the prevalence of raised blood pressure or contain the prevalence of raised blood pressure, according to national circumstances
- Halt the rise in diabetes and obesity

In relation to the first two targets, there is a large body of high quality evidence showing an increased risk of elevated blood pressure with increasing salt intake [35, 36]. As high blood pressure is a leading risk factor for cardiovascular disease, reducing blood pressure at a population level is vital and therefore population salt reduction is a global health priority. For overweight, obesity and type 2 diabetes mellitus, diets that are high in energy, saturated fat and total fat, and low in fibre (commonly found in fruit, vegetables and wholegrains) increase risks [37, 38]. Additionally there is some evidence that a high intake of sugar sweetened beverages (high in "free" sugars) increases the risks of becoming overweight/obese and diabetic [39, 40]. Dietary interventions typically either focus on addressing specific WHO targets, or aim to address poor diets more holistically by aiming to change dietary habits and dietary patterns. However, evidence of effectiveness of dietary interventions considering the interaction of sex or gender are limited.

1.4.1 The burden of poor diets in low-and-middle income countries

Globally, there has been evidence of a "nutrition transition", which was developed into a five-stage model by Barry Popkin in 1993 [41]. Within this nutrition transition, and Popkin's five-stage model, the fourth "degenerative disease" stage is characterised by poor diets contributing to the burden of obesity and related diseases, like cardiometabolic diseases. While it can be argued that most of the world is within the fourth nutrition transition stage, where this is most apparent is in LMICs. A clear example of this is in LMICs within the Pacific Island region, where a transition from diets composed of traditional and locally sourced foods (largely plant and seafood based) to more "Western" diets, characterised by foods high in saturated fats, salt and sugar, has been evidenced in parallel with the increasing burden of cardiometabolic risk [42-44]. The impacts of the nutrition transition are evident in Fiji, where salt intake is estimated at twice the recommended levels from the WHO (10.3g a day in adults compared to the recommendations of less than five grams a day) [45], and where there is an extensive supply of unhealthy processed foods high in salt and sugar [46]. LMICs within the Pacific region, including Fiji, are particularly vulnerable to the environmental impacts of climate change, adding stress to their food systems particularly the production of foods locally, increasing the reliance on processed and imported foods [47, 48].

1.5 Sex and gender differences in the diet-related disease burden

There are some sex differences in nutrient requirements. Biologically, men require more energy, and therefore protein, carbohydrate, and fat, than women, due to their generally larger size and body composition being higher in muscle [49]. During a woman's life cycle, there are periods of increased nutrient need, including increased need for iron during reproductive years, due to blood loss from menstruation, and increased energy and specific micronutrient needs if pregnant or lactating [49]. However, it is unclear whether dietary patterns differ between women and men to address these needs, and if this relates to any differences in health outcomes. Bennett E et al [50] assessed women-to-men mean differences in nutrient intake and odds ratios for non-adherence to dietary recommendations, using the UK Biobank data. This four-year longitudinal study of 210,106 people (52.5% women, aged 40-69 years at baseline) used a 24-hour dietary recall questionnaire to estimate intake. They found that, when standardised for body weight, women's energy consumption was higher than in men, and women were 10% more likely to consume more energy than recommended, compared to men. For specific nutrients, sugar showed the largest difference, contributing 24.5% and 22.5% to total energy intake in women and men, respectively.

While there are biological (sex) reasons for differences in dietary requirements between women and men, there are also likely gender related reasons for differences in dietary intake and diet-related behaviours. Food and eating practices are strongly linked to culture (shared norms, values, traditions, and customs of a group). In some cultures, there are gender related stereotypes and expectations related to social constructs and perceptions of "femininity" and “masculinity” [51]. For example, traits such as being caring or nurturing are often defined as feminine traits, and therefore food preparation and looking after the nutrition of family groups can be defined as “women’s responsibility”. Gender stereotypes have been the target for marketing campaigns. For example, the food industry has been shown to have purposely marketed certain products to women, men, girls, and boys [52].

There is evidence of gender differences in relation to health promoting behaviours [53, 54]. Studies have demonstrated that women in western populations tend to self-report more health promoting behaviours than men [53, 54]. For example, in a systematic review of salt related knowledge, attitudes and behaviour, women were more likely than men to report positive behaviours, however the authors were not able to quantify the difference in behaviour due to the range of questionnaires used across studies [54]. It is also known that reporting health promoting behaviours does not always translate into better health outcomes [55, 56]. More research is needed to understand if differences in reporting of health promoting dietary behaviours in women and men translate to differences in cardiometabolic outcomes.

1.5.1 Sex and gender differences identified in dietary interventions and compliance

Differences in how women and men adhere to and respond to changes in diets are further areas of interest. The Mediterranean dietary pattern (characterised by higher intakes of vegetables, fruits, nuts, seeds, legumes, wholegrains, fish, seafood and extra virgin olive oil, with lower intakes of red meat) has been identified as protective for cardiovascular disease [57, 58]. Studies based in Canada [59-61] have investigated a Mediterranean dietary intervention against an isogenic diet (a diet that has the same total energy value as the intervention diet, but comprised of different types of food) for four weeks [59, 60] or a 12 week nutritional program to increase compliance to a Mediterranean diet [61]. In both cases a food frequency questionnaire was used and a “MedScore” calculated (a score based on compliance to a Mediterranean style dietary pattern). In the four-week dietary intervention they found no sex differences in MedScore from baseline to follow-up [59]. However, for cardiometabolic outcomes, benefits were seen in cholesterol ratios (TC:HDL) and systolic blood pressure for men, but not women [60], albeit women had a healthier cardiometabolic profile at baseline. Following the nutrition program, men reported larger decreases in red and processed meat and increases in fruit intake compared to women, men also showed greater improvements in cholesterol. However, it was noted that, at baseline, women's diets were closer to the Mediterranean pattern than men [61].

In the PREDIMED study - a large study that was designed as a randomised control trial to evaluate the effects of a Mediterranean diet on incident CVD - there was no evidence of an interaction by sex for the protective relationship of the study diets compared to the control diet [62]. However, there were evident differences in compliance to the study diets with men more likely to have higher compliance if they had a family history of CVD and women more likely to have a higher compliance if married. Yet for both women and men, compliance was highest among those with poorer baseline diets [63].

A study by Raparelli et al [64] aimed to better understand reasons for low compliance to a Mediterranean style diet. Both sex-related and gender-related reasons for low compliance were investigated among 366 adults with ischemic heart disease in Italy , finding that male personality traits and perceived stress (both classified as "gender-related reasons") were associated with low compliance to a Mediterranean style diet regardless of sex, age or comorbidities [64].

These studies suggest that there may be gender related differences in either baseline dietary intake or compliance to dietary interventions.

1.5.2 Diet assessment methods, and the potential for a gender bias in reporting

Getting an accurate picture of a person's habitual diet is difficult, as measures routinely used rely on self-report and therefore are subject to a range of biases [65, 66]. There are retrospective measures, that ask participants to report foods and beverages consumed in the past, over a selected period. For example, 24-hour diet recalls require a person to recall what they consumed in the previous 24-hours, the accuracy of this method is enhanced by conducting several "passes" where an interviewer or an automated system (self-administered) will ask multiple rounds of questions on what foods and drinks are consumed and the quantity [67]. While this method can provide in-depth information on consumption, what someone eats can vary from day to day, and so one 24-hour diet recall is not a good measure of habitual intake [66]. Another example of retrospective recall is a food frequency questionnaire (FFQs) [68, 69]. FFQs require a person to report the frequency at which they consume certain food items with defined portion sizes from a predefined list, over a set period. The time covered can vary from the past week, month, or year. FFQs provide an estimate of food intake, which allows for the ranking of individuals based on their past intake [68, 69]. However, the ability of an FFQ to appropriately rank individuals is dependent on how closely the predefined list of foods reflects diets of the population surveyed [68]. Prospective methods include weighed food records or estimated food records [66]. These methods require participants to record what they eat, and how much they eat, over three to seven days, for weighed food records each item of food is weighed before eating [66]. These methods can induce a high respondent burden, particularly over longer data collection periods. As described, each method has different strengths and weaknesses which can influence the estimate of habitual intake [67]. Further, estimating nutrient intake data from the diet assessment requires the use of food composition databases. Food composition databases used should be context specific, based on recent laboratory analysis of foods available within the country studied [70]. This is not always possible, especially in low resource settings [70]. Previous studies and systematic reviews have hypothesised gender biases in the self-report of dietary intake, reporting that women may be more likely to underestimate what they eat, either consciously or sub- consciously [67, 71]. However, the extent of this bias was not quantified.

There are objective methods available for some specific diet components. For example, doubly labelled water experiments provide a measure of energy expenditure, which in weight stable conditions will be equivalent to energy intake. However, doubly labelled water experiments are expensive and have a high respondent burden, and therefore are not commonly used [66]. A range of diet biomarker indexes have been developed to aid understanding of diet disease relationships [72]. Song et al [72] conducted a systematic review to see if sex is taken into account in the development of the indexes. The majority (29/54) did not consider sex in index development, and only 7 (13%) studies produced a diet-biomarker-related index for men and women separately.

1.6 Policy implications

1.6.1 Gender responsive policy making, and frameworks for analysis

There is a growing recognition of the need to incorporate sex and gender considerations in medical research [73, 74]. Sex differences identified in cardiovascular disease risk and treatment have been key to recognising that health policies have been largely blind to sex differences [75]. Given almost 50% of the world's population is comprised of women and almost 50% of men, sex is a crucial population demographic. There is also an established need to incorporate gender considerations (including gender identities, gender roles and gender responsibilities) in health policy, as an accountability system for progress towards gender equity [76].

Evaluating the inclusion of sex and gender in policies and programs is aided by using gender analysis frameworks. There are many gender analysis frameworks, for example: the Harvard Analytical Framework (also known as the "Gender Roles Framework") [77], which assesses the relationship of gender with access and control of resources; Moser Gender Planning Framework [78] which assesses gender relationships and the influence on access and control of resources along with investigating reasons and processes that lead to gender differences in the access and control of those resources; Gender Analysis Matrix [79], that acts as a tool to facilitate participation within communities to define and analyse gender related issues within the participants' community; Women's Empowerment Framework [80], a framework that focuses on four dimensions of women's empowerment (resource access, self-awareness of rights, mobilize their rights, and control their environment to a level equal to men); Social Relations Approach [81], which focuses on gender inequalities within institutions and assess structural and systemic causes of gender inequality based on the idea that gender relations are part of social relations; and the World Health Organization Gender Analysis Tool [82], which aids the assessment of policies or programs in terms of gender-responsiveness through 23 criteria on sex and gender inclusion and considerations within the policy or program being assessed. Each framework has different strengths and weaknesses, and often are used in combination to assess different gender considerations [83]. They also often promote the categorisation of policies as gender-blind (do not acknowledge gender as a factor), gender-sensitive (recognise gender norms, however no actions are proposed to address any inequities), gender-specific (recognise gender norms and normally target specific groups like women of reproductive age) or gender-transformative and responsive (focus on addressing the underlying causes of gender inequity) [83]. Assessment of policy, programs, or community relations, using gender analysis frameworks, can therefore highlight areas of priority to address in order to improve gender equality.

1.6.2 Sex and gender considerations in food policy

Gender-responsive food and nutrition policy would establish both a political acknowledgement of the need to consider gender and an accountability system for the advancement towards equitable food systems [84]. However, a review of global food system organizations showed that commitment to gender equity is somewhat limited, with "gender" related objectives often focused on women of reproductive age and/or women who are pregnant or breastfeeding [84]. There are issues with this limited conceptualisation of gender considerations in food and nutrition policy; it views women only in terms of reproductive capabilities without broader lifecycle considerations, it perpetuates the idea that women are responsible for the nutritional health of their families, and it disregards roles of, or implications for, people of other gender identities. There is also a need for a broader gender equity focus within food and nutrition policies given the need for progress towards the United Nations Sustainable Development Goals three "Good Health and Well-being" and five "Gender Equality" [85].

As established in this introduction, there are sex and gender differences in cardiometabolic disease risk, there are also likely sex and gender differences in dietary intake and behaviour that may influence cardiometabolic disease burden in a sex specific and/or gendered way, a focus area for this thesis. A further consideration for this thesis is how sex and gender are considered in food and nutrition related policy. While reviews have been conducted of sex and gender considerations in food system organization policy, the focus in this thesis will be on country/government specific policy, focusing on a case-study in a country that has pronounced sex and gender differences in the prevalence of cardiometabolic disease risk factors.

1.7 Conclusion

The substantial global burden of cardiometabolic disease is largely preventable, particularly through improving diets. Few studies have investigated dietary intake with cardiometabolic risk factors or outcomes in a sex disaggregated or gender sensitive manner. While there is some evidence that women are more likely to report health promoting behaviour, the link between self-reported intake, actual intake, and health outcomes is lacking. There is also an evidence gap around how sex and gender related factors are considered in country specific food and nutrition policy. These evidence gaps are addressed in the present thesis, using data from both HICs and LMICs, but with a particular focus of the implications of these data for LMICs.

1.8 Thesis aims and research questions

This thesis aims to:

1. Identify if there are differences between women and men in dietary intake and/or behaviour and if these are linked to cardiometabolic disease risk factors or outcomes

2. Assess how gender considerations are incorporated within nutrition and health- related policies, and whether these policies adequately account for gender differences in dietary intake and the related burden of disease

To address the above aims, the following questions are explored:

a) Are there sex differences in the self-report of dietary intake?
b) Do sex differences exist in dietary intake or behaviours and are there associations with cardiometabolic disease outcomes?
c) How are gender considerations included in nutrition and health- related policies?

d) Are there gendered perceptions and roles in relation to diet and food provision?

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Chapter 2. Methodological approach

This chapter provides a brief overview to the methods used within this thesis, to address the thesis aims. As this thesis was conducted by publication, with publications used in lieu of chapters, specific methodology for each chapter is provided in depth within each publication.

2.1 Methods overview

This thesis focuses on exploring sex and gender equity factors in both nutrition and cardiometabolic disease. This thesis was approached through a sex and gender equity lens, putting a focus on analysing the relationship between diet and cardiometabolic disease by sex and gender factors to identify if there are inequities in the diet related burden of cardiometabolic disease by sex and/or gender. This lens was also applied to assess nutrition and health- related policies, for the inclusion of sex and gender considerations[1-3].

A mixed methods approach was used to address the thesis aims and corresponding research questions, as set out in **table 2.1**.

The first thesis aim was addressed by three quantitative studies, consisting of: a systematic review and meta-analysis of sex differences in the accuracy of dietary assessment methods; a cross-sectional analysis of nationally representative surveys across seven LMICs assessing the relationship of dietary behaviours with cardiovascular risk factors; and a prospective analysis of the UK Biobank cohort data looking at associations between dietary intake and disease outcomes. The specific diet methodology and approaches to quantitative analysis used to address this aim are described in detail within chapters 3, 4 and 5.

To address the second research aim, in-depth qualitative data were needed, and to do this it was deemed appropriate to focus on one country. As established in the Introduction (chapter 1), Pacific Island countries experience some of the highest prevalence's of cardiometabolic diseases globally, with many countries within the region experiencing a nutrition transition [4-6]. As such, Fiji was chosen to focus on. Fiji is one of the larger Pacific Island Nations with a population of approximately 900,000 people [7]. As with other countries in the region, there is a high prevalence of cardiometabolic disease in Fiji, with differences in prevalence by sex [8, 9]. Fiji was also chosen given collaborations with researchers at Fiji National University and given an existing program of work being conducted by The George Institute for Global Health in collaboration with Fiji National University [10]. This program of work focuses on strengthening and scaling up food policy interventions in Fiji, meaning the work conducted in this thesis could feed into the recommendations and support for policy strengthening. For chapter 6, a policy landscape analysis was conducted, consisting of a desk-based analysis of nutrition and health related policies in Fiji with assessment against the World Health Organization Gender Analysis Tool [11] and key stakeholder interviews to understand perceptions on barriers and enablers to including gender considerations within policies. Both an inductive and deductive thematic analysis was conducted to assess stakeholder perceptions [12]. Findings from the stakeholder interviews were triangulated with findings from the desk-based policy review [12]. For chapter 7, focus group discussions were held with community members in Fiji to understand perceptions on health and healthy eating and the role that an individual's gender has within this. Themes from focus group discussions were analysed using an inductive thematic analysis, with main findings mapped to an Intersectionality framework [13, 14]. Further information on the qualitative approach, process of data analysis and data triangulation is supplied in chapters 6 and 7.

2.2 Terminology use within chapters

The definitions for terms of sex, gender and cardiometabolic disease are established in section **1.2 Definitions and terminology**. The quantitative chapters (3 through to 5) have focused on sex differences. This is because existing data were used for analyses in each chapter, and sex was the defined characteristic within these data sources. These chapters focused on comparisons between binary women/female and men/male groupings. Conversely, in the qualitative chapters (6 and 7), data were collected during the PhD with information on participant gender requested. The qualitative chapters also had a strong focus on gender related roles and responsibilities around food and health. As such these chapters use the term gender. More specifics on the use of terms are included within each chapter.

Table 2.1 Thesis structure and methods used, in line with research aims

Thesis chapter	Aim addressed	Research question addressed	Methods used	Title of chapter and publication status
Chapter 1	Thesis introduction - establishing the need to investigate sex differences and gender considerations in the relationship between diet and cardiometabolic disease.			Introduction -*Unpublished work*
Chapter 2	Thesis methods - a summary of approach taken, with in-depth description of methodology explained within Chapters 3 through to 7.			Methods - *Unpublished work*
Chapter 3	Identify if there are differences between women and men in dietary intake and/or behaviour and if these are linked to cardiometabolic disease risk factors or outcomes	Are there sex differences in the self-report of dietary intake?	Systematic review and meta-analysis	Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis – *Published*
Chapter 4		Do sex differences exist in dietary intake or behaviours and are there associations with cardiometabolic disease outcomes?	Cross-sectional analysis of dietary behaviours and cardiometabolic risk factors in LMICs	Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: a cross-sectional study of nationally representative surveys in seven low- and middle-income countries – *Published*
Chapter 5			Prospective analysis of UK cohort data	The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank - *Published*
Chapter 6	Assess how gender considerations are incorporated within nutrition and health- related policies, and whether these policies adequately account for gender differences in dietary intake and the related burden of disease	How are gender considerations included in nutrition and health related policies?	Fiji case study 1 – Policy landscape analysis	Incorporating a gender lens into nutrition and health-related policies in Fiji: a policy analysis – *Submitted for publication*
Chapter 7		Are there gendered perceptions and roles in relation to diet/food provision?	Fiji case study 2 - Qualitative analysis of focus group discussions with community members in Fiji	Perceptions on healthy eating among iTaukei women and men in Viti Levu, Fiji: an intersectional interpretation – *Submitted for publication*
Chapter 8	Thesis discussion and conclusions – a summary of thesis findings, and proposed implications of findings.			Discussion -*Unpublished work*

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Chapter 3. Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis

3.1 Chapter overview

This chapter provides a systematic review and meta-analysis of the accuracy of dietary assessment methods, with a focus on investigating differences by sex. This chapter forms an important first step to the thesis, as it provides the basis for understanding if any differences in reported dietary intake, or differences identified in diet disease relationships, are due to a sex bias in reporting. This chapter consists of a published manuscript, *"Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis."*

The review included studies that had used a method of dietary intake assessment to estimate total energy intake and collected energy expenditure via doubly labelled water methods. Doubly labelled water is an objective measure of energy expenditure and, in weight stable conditions, energy expenditure is equivalent to energy intake. Both energy intake, and energy expenditure measures had to be available disaggregated by women/female and men/male categories for the studies to be included. Across 32 included studies, there was no evidence of a sex bias in the accuracy of reporting energy intake. Both females and males were equally likely to underestimate their energy intake by a substantial amount, across commonly used diet assessment methods. While this underestimation should be considered when assessing diet-disease relationships, the results do not imply that analyses investigating sex differences in the diet-disease relationship may be affected by a systematic sex bias in reporting of energy intake. As such, the findings in this chapter were valuable for chapters 4 and 5, where self-reported diet information is used to investigate sex differences between diet and cardiometabolic risk factors and outcomes.

A protocol for this chapter was published in BMJ Open and is supplied as an appendix to this thesis (Appendix 1). In the protocol, it was established that gender differences in energy intake reporting would be investigated albeit search terms related to both sex and gender were included. When the review was conducted most of the included studies included results by sex, and all included binary (women/female, men/male) categories. The change in terminology from the protocol to the published manuscript is explained in more depth in the discussion section of this chapter.

3.2 Publication details

McKenzie BL, Coyle DH, Santos JA, Burrows T, Rosewarne E, Peters SA, Carcel C, Jaacks LM, Norton R, Collins CE, Woodward M, Webster J. Investigating sex differences in the accuracy of dietary assessment methods to measure energy intake in adults: a systematic review and meta-analysis. *The American journal of clinical nutrition*. 2021 May;113(5):1241-55.

3.2.1 Author contributions

As the first author of this publication, I contributed significantly to this piece of work. I was responsible for conceptualising the study and designed the initial approach to the study with co-authors. I led the data searching and data extraction, with DHC as reviewer 2. I led the data analysis with support from JAS and oversight from MW when needed. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows (and as published): BLM, DHC, MW, JW: designed the research; BLM, DHC: conducted the research; TB, CEC: provided expert content knowledge on energy intake and energy expenditure methods; BLM, JAS: performed the statistical analysis; BLM: wrote the paper; JW: had primary responsibility for final content; all authors: contributed to the manuscript; and all authors: read and approved the final written manuscript.

3.3 Manuscript

Abstract

Background: To inform the interpretation of dietary data in the context of sex differences in diet-disease relationships, it is important to understand whether there are any sex differences in accuracy of dietary reporting.

Objective: To quantify sex differences in self-reported total energy intake (TEI) compared to a reference measure of total energy expenditure (TEE).

Design: Six electronic databases were systematically searched for published original research articles between 1980 and April 2020. Studies were included if they were conducted in adult populations with measures for both females and males of self-reported TEI, and TEE from doubly-labelled water. Studies were screened and quality assessed independently by two authors. Random-effects meta-analyses were conducted to pool the mean difference between TEI and TEE for, and between, females and males, by method of dietary assessment.

Results: From 1,313 identified studies 31 met the inclusion criteria. The studies collectively included information on 4,518 individuals (54% females). Dietary assessment methods included 24-hour recalls (n=12, two with supplemental photos of food items consumed), estimated food records (EFR, n=11), food frequency questionnaires (FFQ, n=10), weighed food records (WFR, n=5), and diet histories (n=2). Meta-analyses identified underestimation of TEI by females and males, ranging from -1,318 kJ/day (95% CI: -1,967, -669) for FFQ to -2,650 kJ/day (95% CI: -3,492, -1,807) for 24-hr recalls for females, and from -1,764 kJ/day (95% CI: -2,285, -1,242) for FFQ to -3,438 kJ/day (95% CI: -5,382, -1,494) for WFR for males. There was no difference in the level of underestimation by sex, except when using EFR where males underestimated energy intake more than females (by 590 kJ/day, 95% CI 35, 1,146).

Conclusion: Substantial underestimation of TEI across a range of dietary assessment methods was identified, similar by sex. These underestimations should be considered when assessing TEI and interpreting diet-disease relationships.

1. Background

A quarter of all deaths globally are attributable to poor diets, and the burden of diet-related non-communicable disease is increasing [1]. In order to assess and monitor population diet quality and to subsequently deliver targeted and effective dietary interventions, it is vital to collect reliable and accurate dietary data. Retrospective methods such as 24-hour diet recalls, food frequency questionnaires (FFQ) and diet histories, and prospective methods such as weighed or estimated food records, are commonly used to assess dietary intake [2, 3]. These methods differ in terms of the type of information collected and the reference time period. For example, 24-hour recalls assess recent intake of all foods and drinks consumed the previous day, and by comparison FFQ and diet histories assess intake over a longer period, which influences group level estimates of habitual intake [3, 4]. For prospective methods, food consumed is recorded over several days (typically three to seven) with portion sizes either estimated using household measures such as cups, spoons and a ruler, or by weighing each item using scales [3].All of these methods rely on self-report and on the accuracy of nutrient databases to provide information on dietary intake at an individual and/or group level. As such, dietary assessment is subject to error and bias [5] and validity is commonly questioned [2].

Objective reference measures for some components of dietary intake exist, with doubly labelled water being the reference measure for total energy expenditure (TEE), which is equivalent to total energy intake (TEI) in relatively weight stable individuals [2, 6]. Doubly labelled water analyses are conducted by providing participants with water labelled with stable hydrogen and oxygen isotopes to drink, at a dose often determined by an individual's body weight. The isotopes are then most often recovered in the participant's collected urine and analysed over a seven to 14-day period. Calculations based on the excreted isotopes can be used to estimate TEE, which strongly correlates with TEI [2, 3]. While this provides an objective measure of TEI, the process is costly for researchers and burdensome on participants and research laboratories conducting the analysis, and therefore tends to be used infrequently.

Previous studies and reviews have used the comparison between measured TEE and reported TEI to identify factors that potentially influence the accuracy of self-reported TEI. A review published in 2001 by Hill and Davies [4] identified dietary restraint, low socioeconomic status and sex (female), as characteristics associated with under-estimating dietary intake. More recently, Burrows et al [7] conducted a systematic review of the accuracy of self-reported dietary assessment methods which identified that females were more likely to mis-report TEI in comparison to males for some dietary assessment methods. In both cases the extent of this mis-reporting was not quantified. While multiple factors likely interact to impact the accuracy of self-reported TEI (for example socioeconomic status with gender identity, sex and the presence of dietary restraint), there is literature that suggests females are more likely to report health promoting behaviour [8, 9], and as such the hypothesis for the present review was that female subjects would underestimate energy intake to a greater extent than male subjects.

In order to interpret dietary data, and to use dietary data to analyse associations with disease outcomes, we need to understand the magnitude and direction of mis-reporting by females and males and evaluate whether systematic mis-reporting differs by sex. The aim of the current study was to conduct a systematic review and meta-analysis comparing TEI assessed using self-reported dietary assessment methods with measured TEE for females and males separately, and to quantify the difference in TEI estimation accuracy between sexes.

2. Methods

The protocol for this study was registered with PROSPERO [10] and has been published [11].

2.1 Search Strategy

A systematic literature review was conducted of articles published between January 1980 and April 2020. The following electronic databases were searched: MEDLINE, Scopus, Web of Science, EMBASE, CINAHL and Cochrane Central Register of Controlled Trials. A combination of key words (diet*, nutrition, self, survey, diet*survey, diet*questionnaire, diet*recall, diet*record, food recall and doubly labelled water) and subject headings (diet, eating, energy intake, nutrition assessment, dietary intake, diet assessment, energy expenditure, surveys and questionnaires, self-report and diet surveys) were used in each database, specific examples of these are shown in the published protocol [11].

2.2 Selection of Studies

Studies were included based on the following criteria: original research studies published in peer-reviewed journals, conducted in free-living/un-hospitalised adults (18 years or older), included a measure of self-reported TEI and a measure of TEE via doubly labelled water, disaggregated by sex, and with the full-text available in English. We excluded studies conducted in single sex populations, populations where significant weight change was likely (e.g. studies conducted in elite athletes, weight loss trials, or in people with a medical condition where weight change is a common side effect of the disease or treatment), where the population was unlikely to be eating in their usual manner (e.g. controlled feeding studies) and studies conducted in animals. As the focus was on methods using self-reported TEI we excluded studies that used food photos, images or video methods without quantifying through a self-reported TEI method. We excluded reviews, but searched reference lists for relevant studies.

The screening and identification of studies included in the review is depicted in **figure 1**. Studies identified in the electronic database search were uploaded into *Covidence* for data management. Two authors (BLM and DHC) independently screened the title and abstracts for potential eligibility. Full texts of the potentially eligible studies were then retrieved and independently assessed by the two authors against the inclusion and exclusion criteria. Any disagreements at either assessment stage were discussed with a third author (ER), and with the larger authorship team, as needed. Reasons for exclusion at the full text stage were coded as: studies that were conducted in one sex (and therefore comparison between sexes was not possible), studies that had an unacceptable study design (for example review articles, commentaries or secondary analyses of study data already included in the review), studies that did not disaggregate data on TEI and TEE for females and males, duplicates, studies with an unacceptable patient population (for example elite athlete, hospitalised or pregnant populations, as set out in our exclusion criteria), unacceptable comparator (studies that did not use DLW to estimate TEE or did not use a self-report dietary assessment method to estimate TEI), studies where the full text was not available through the online databases or through request through university libraries, studies with an abstract only (for example abstracts published from conference presentations without evidence of a full text being available), studies conducted in populations aged less than 18 years and studies that were not available in English.

2.3 Data Extraction and Conversions

All data were extracted independently by two authors (BLM and DHC), then cross checked. Any disagreements in data extraction were resolved by discussion. The characteristics of the study data extracted included: year the study was published, year the study was conducted, location, number of participants, age and education level of participants, ethnicity, body mass index (BMI; mean, or percentage of participants in each BMI category), and any presence of chronic disease. Data were also extracted regarding the type of dietary intake assessment method, the dosage and duration of doubly labelled water testing and any adjustments made for participant weight changes. Studies were grouped by dietary intake assessment method.

The outcomes of interest for the current review were mean TEI and TEE for females and males. These values, along with their measure of variability (standard deviation or confidence intervals for the mean values), were extracted. For the meta-analysis, a mean measure of TEI and TEE (with corresponding standard deviations) in kilojoules per day, and disaggregated by sex, were required. Additionally, correlation coefficients between TEI and TEE for females and males respectively, were needed in order to calculate the standard deviation for the difference between TEI and TEE [12]. The following steps were taken to achieve this:

- Most studies provided the mean TEI as an average of the measures conducted (for example, as an average of three 24-hour diet recalls). Two studies [13, 14] presented the mean TEI per dietary assessment measure, rather than as an average of the total measures. Therefore, the measure with the largest sample size was used if the sample sizes differed between measurements. If the sample sizes for each measure were the same, then the first measure was used. We decided to take this approach as equations to calculate the average of group measures are based on the premise that the populations of each group are independent, which was not the case in our included studies [12].

- Most studies provided correlation coefficients for total energy intake with energy expenditure by sex. For studies that provided a correlation coefficient for the whole population (not disaggregated by sex), we used the same correlation coefficient for females and males. For studies that did not provide correlation coefficients (n 6 studies), the mean of the correlations for the other studies that used the same dietary assessment methods was used [12].
- Studies reported mean total energy intake in either kilojoules per day, or kilocalories per day, with standard deviations. We converted kilocalories per day to kilojoules per day by multiplying by 4.184 [3].

2.4 Assessment of Quality

The quality of the included studies was assessed using the Quality Criteria Checklist in *The Academy of Nutrition and Dietetics evidence analysis manual: steps in the academy evidence analysis process* [15]. This checklist includes ten study quality criteria: clarity of the research question, selection of participants, comparability of study groups, methods of handling withdrawals, blinding of intervention and measurements, descriptions of the intervention, description of outcomes, appropriateness of statistical analyses, discussion of biases and limitations and the likely influence of study funding or sponsorship. The criteria on blinding were considered "not applicable" to this review, given that blinding of the variables of interest would not have been feasible. Therefore, study quality was assessed overall as positive, neutral or negative based on nine quality criteria. If the study was marked positive for six or more criteria inclusive of the criteria on selection of study participants, comparability of study groups, explanation of procedures and description of outcomes then it was marked as of positive quality overall. Studies assessed as neutral overall met at least five of the nine quality criteria and negative studies met four or less. The study quality was assessed independently by two authors (BLM and DHC) with any disagreements discussed and resolved with a third author (ER).

2.5 Analysis

A narrative synthesis, summarising key results from the included studies in relation to the research question, was conducted.

For the studies with the available data, the mean difference between TEI and TEE was calculated separately for females and males. The standard deviation for the mean difference was calculated, along with the standard error for the difference [12]. In order to quantify sex differences, the difference in the mean differences (difference between TEI and TEE among males minus difference between TEI and TEE among females) was calculated for each study. The standard error for the difference in the mean difference was then calculated (see the **supplementary methods** for details on the equations used). Pooled mean differences with 95% confidence intervals were calculated using random effects meta-analysis models and the DerSimonian and Laird inverse-variance method.

Given the findings of previous studies [7], we hypothesised that the agreement between TEI and TEE would vary based on the type of dietary assessment method used (i.e. multiple pass 24-hour diet recalls, weighed food records, estimated food records and FFQ). Separate meta-analyses were conducted for each dietary assessment method, where there were two or more studies that used comparable methods. Sensitivity analyses were conducted by including studies that reported geometric means (converted for meta-analysis to raw means and standard deviations [16]), inclusion of studies that were assessed as of "positive" quality only, and inclusion of the different mean measures of total energy intake for two studies [13, 14].

Heterogeneity was assessed using Cochran's Q-test and the I^2 statistic. Sub-group analyses were conducted to explore possible sources of heterogeneity. This was only possible for the studies using 24-hour diet recall surveys and estimated food records, given the small numbers of studies that used other dietary assessment methods. Subgroups were pre-defined [11], however, given the data available in the included studies, the subgroups investigated from the pre-defined list were limited to the following: study country's income status (high income vs. lower-upper middle income, based on The World Bank classifications [17]), sample size (above vs. below the median sample size across the studies), duration of doubly labelled water collection (above vs. below the median), BMI (investigated as categories "normal, overweight, obese" corresponding to a study mean BMI within 18.5-25.9 kg/m^2, 25 – 29.9 kg/m^2, ≥30 kg/m^2, respectively) and age of participants (above vs. below the median). Method specific subgroup analyses were conducted whereby the number of 24-hour diet recalls completed (greater than two vs. two or one) were investigated, and for estimated food records the number of days recorded (greater than four vs. four or less), and the provision of scales to aid estimation (vs. no scales), were investigated. To assess the presence of publication bias, funnel plots were assessed, and Egger tests conducted. As with the subgroup analyses, this was only done for the studies using 24-hour diet recall surveys and estimated food records.

To obtain the relative difference between energy intake and energy expenditure, the absolute difference between the two approaches (as well as the SE of the difference) was log-transformed, following the methods proposed by Higgins et al [16]. Specifically, the approximate difference on the logarithmic scale was calculated by dividing the absolute difference in means (i.e. difference between energy intake and energy expenditure) by the overall mean across groups (i.e. mean of energy intake and energy expenditure) [16]. The log-transformed SE of the difference was obtained by dividing the absolute SE of the difference by the overall mean across groups [16, 18]. The resulting log-transformed values were then expressed as percentage differences (between energy intake and energy expenditure), by multiplying by 100 [16]. This was done separately for females and males. The difference in percent differences (percent difference in males minus percent difference in females) was obtained, and the standard error of the difference was calculated using the same equation as the main "difference in mean difference" analysis (see the **supplementary methods**).

Analyses were conducted using STATA version 16.0 statistical software (Stata Corporation, College Station, TX) and RStudio version 1.1.463 (RStudio, Inc) statistical software.

2.6 Ethical approval

Data was extracted from published papers, and therefore ethical approval was not required.

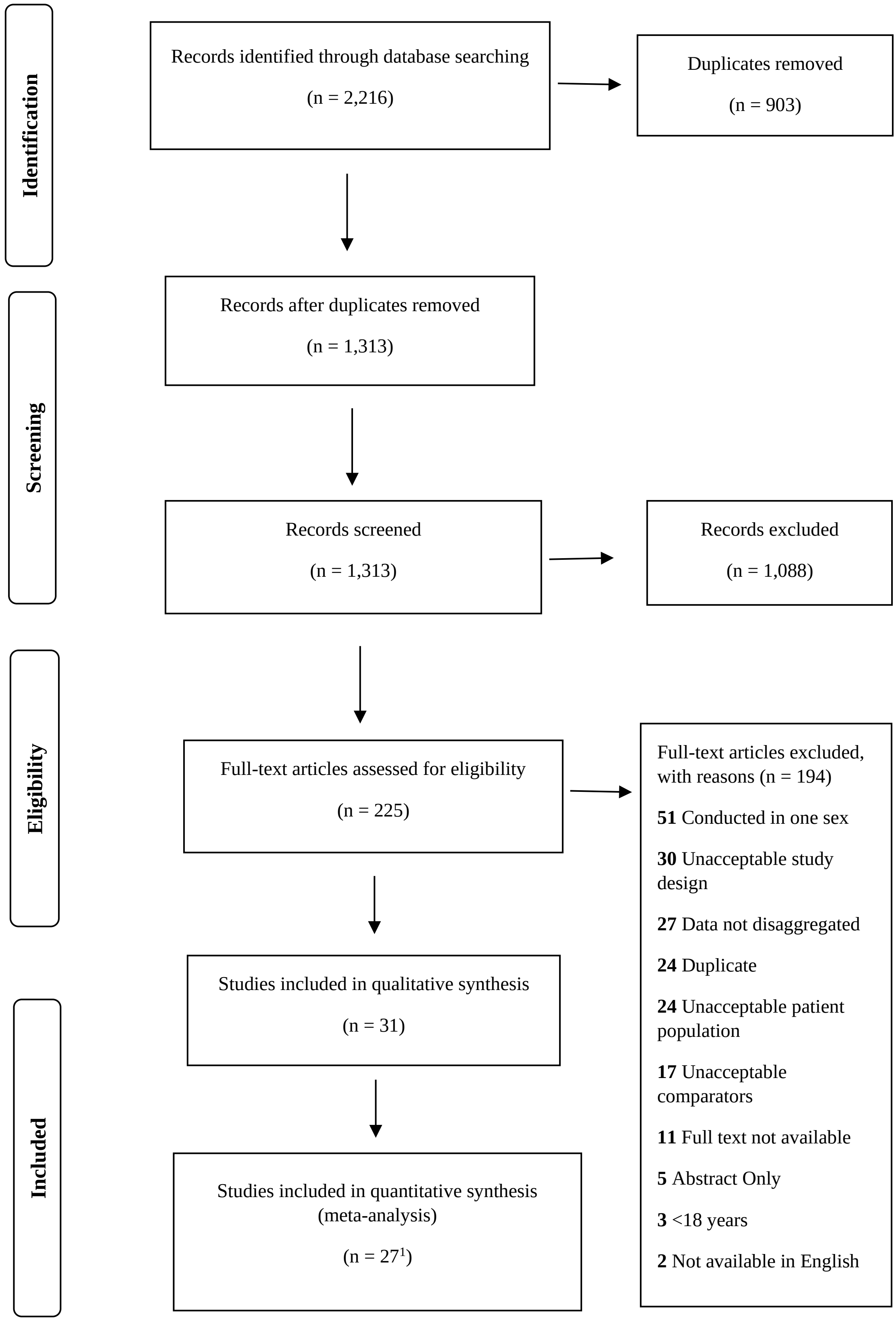


Figure 1. PRISMA flow diagram of studies included in the systematic review. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

[1]23 studies in the main analysis, four studies presented geometric means, and are included in the sensitivity analysis

3. Results

3.1. Characteristics of included studies and narrative synthesis of findings

The database search identified 1,313 studies once duplicates were removed (n=903) (**figure 1)**. Of these, 225 full texts were assessed for eligibility, resulting in 31 studies [13, 14, 19-47] being included in our review from which data were extracted.

Characteristics of these 31 studies are shown in **table 1**. The included studies provided information on 4,518 individuals (2,430 females, 53.8%) and the vast majority (n=26) were conducted in high income countries; 14 in the USA [19, 24, 28, 29, 32, 34, 35, 37-41, 44, 45], three in Japan [14, 43, 47], two each in Australia [20, 46], Sweden [30, 36] and the UK [13, 21], and one each in Germany [25], Ireland [26], New Zealand [23] and Norway [42]. Three studies were conducted in an upper middle-income country (Brazil) [22, 27, 33], and one study [31] included populations in Ghana (lower middle income), South Africa (upper middle income) and Jamaica (upper middle income), along with populations in Seychelles and the USA (both high income countries).

Total energy intake was assessed by a range of methods. Twelve studies used 24-hour diet recalls [13, 19, 23, 27-29, 31-34, 37, 41], two of which used cameras to assist recording of dietary data by photographing food consumed [23, 34]. Eleven studies used estimated food records (EFRs) [24, 25, 27, 30, 35, 38-40, 44, 45, 47], ten used FFQs [14, 19, 22, 30, 32, 33, 37, 41, 42, 47], five used weighed food records (WFRs) [20, 21, 26, 42, 46], two used diet histories [20, 36] and one study used a mixture of estimated food records with photography of foods consumed (by digital camera or smart phone) and an interview with a dietitian [43]. Twelve studies [19, 20, 23, 27, 30, 32, 33, 37, 41-43, 47] investigated multiple methods of dietary assessment; four studies used 24-hour diet recalls and FFQs [19, 33, 37, 41], two studies used EFRs and FFQs [30, 47] one study each used diet histories and WFRs [20], 24-hour diet recalls and 24-hour diet recalls supplemented with information from a wearable camera [23], 24-hour diet recalls and EFRs [27], WFRs and FFQs [42], 24-hour diet recalls, FFQs and EFRs [32], and diet histories supplemented with photographs of foods consumed and an interview administrated EFR [43]. Specific details on how these dietary assessments were carried out in each study, including what resources were provided to participants to aid estimation of food consumed, can be found in **table 1.** Information on TEI and TEE measurements, including study specific correlation coefficients are summarized in **supplementary table 1**. The mean correlation between TEI and TEE by dietary assessment method and by sex is summarised in **supplementary table 2**. Mean correlation differed by dietary assessment method, ranging from 0.13 for males using 24-hour diet recall supplemented with information from photography of foods consumed to 0.68 for females using WFRs.

Sixteen studies were assessed as having a positive study quality [14, 20, 22, 27-30, 32-34, 38, 40, 41, 44, 45, 47], 14 assessed as neutral quality [13, 19, 21, 23-26, 31, 35-37, 39, 42, 46] and one as negative study quality [43] (**supplementary figure 1**). The main reasons for studies being assessed as neutral or negative quality were: unclear or not comparable study groups of males and females (n=9) [13, 19, 21, 23, 25, 35, 36, 43, 46]; potential bias in the selection of study participants (n=6) [13, 24, 37, 39, 43, 46]; conclusion not supported by results or lack of description of limitations (n=5) [24, 35, 37, 39, 46]; lack of detail in describing the intervention/therapeutic regimens/exposure factors and/or procedures or comparators (n=4) [19, 26, 31, 42]; statistical analyses not adequately described (n=4) [21, 26, 43, 46]; and potential bias due to study funding or sponsorship (n=2) [19, 39].

3.2. Meta-analysis

Twenty-three studies were included in the main analysis [13, 14, 20, 21, 23-27, 30, 31, 33-40, 44-47], including one study that had five study population groups, each in a different country (Ghana, South Africa, Jamaica, Seychelles and the USA) [31]. Four studies [19, 22, 42, 43] were not included in the main meta-analyses or in sensitivity analyses; n=3 studies [19, 22, 42] were excluded as they reported results in the form of percentage under or over reporting relative to doubly labelled water (rather than presenting mean intakes and standard deviations) and one study was excluded as it did not have a comparable method of energy intake assessment [43].

Thus, the meta-analyses included ten comparisons for 24-hour diet recall [13, 23, 27, 31, 33, 37], two for 24-hour diet recall with photographs of foods consumed [23, 34], five for FFQs [14, 30, 33, 37, 47], four for WFRs [20, 21, 26, 46], eleven for EFRs [24, 25, 27, 30, 35, 38-40, 44, 45, 47], and two for diet histories [20, 36].

Table 1. Characteristics of included studies

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure. Detail provided if adjustments were made
							Range	Mean ± SD					
24-hour diet recalls or 24-hour multiple pass diet recalls (24h DR or 24h MPR, respectively)													
Foster 2019 [13]	UK, Cambridge	HIC	2-3x web based self-administered 24h MPR ("Intake24")	Photographs of food were shown on the web-based assessment to aid estimation of portion sizes.	98	females n=50 males n=48	40-65	54.3 ±7.30	Overall: 26.6 ± 3.47	9-10	9-10	174 mg/kg $H_2^{18}O$ and 70 mg/kg ^2H_2O	Yes
Moshfegh 2008 [28]	USA, Washington	HIC	3 x 24h MPR, 5 passes in each MPR. 1 MPR was conducted with an interviewer in person, then two were conducted via phone. (covering at least one-week day and one weekend day).	To aid estimation of portion sizes during the in-person interview 47 different 3-dimensional models were provided, along with rulers, measuring cups and spoons. For the phone interviews, participants were given a USDA food model booklet and household measures (e.g. cups and spoons).	524	females n=262 males n=262	30-69	Not reported	21% of sample were obese Non-Hispanic white 77%	14	14	0.10g H_2O and 0.08g $H_2^{18}O$ per kg body weight	Yes Stated that weight change was minimal and so measures were not adjusted.

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
Mossavar-Rahmani 2015 [29]	USA, Chicago, Illinois; Miami, Florida; Bronx, New York; San Diego, California	HIC	2 x 24h diet recall. 1st conducted via telephone, second conducted in person between 5 days to a year post telephone interview.	Specific information on portion size aids was not provided.	477	females n=288 males n=189	18-74	46 (SD not reported)	females: 0.7% underweight 18.8% normal weight 39.6% overweight 41.0% obese males: 1.1% underweight 19.6% normal weight 40.2% overweight 39.2% obese	12	4	1.38 g of 10 atom percent of 18O-labeled water and 0.086 g of 99.9% deuterium labelled water per kilogram of body weight	Yes
Orcholski 2015 [31]	Ghana (rural), South Africa (urban), Seychelles, Jamaica (urban) and the USA (suburban)	Ghana: LMIC South Africa: UMIC Seychelles: HIC Jamaica: UMIC USA: HIC	2 x 24h MPR, 3 passes in each MPR. Assessments conducted in person (interview administrated) and were 6-9 days apart.	Estimation of portion sizes was aided by photos of country appropriate commonly consumed foods, along with the use of spoons, cups, bowls and plates.	324 (USA 63, Seychelles 72, Jamaica 63, South Africa 59, Ghana 67)	females: USA: 30 Seychelles: 37 Jamaica: 34 South Africa: 39 Ghana: 36 males: USA: 33 Seychelles: 35 Jamaica: 29	25–45	females: USA: 35 ± 6 Seychelles: 33 ±6 Jamaica: 35 ±6 South Africa: 34 ±6 Ghana: 35±6 males: USA: 34 ± 5 Seychelles: 34 ±5 Jamaica: 34 ±6 South Africa: 33 ± 6	females: USA: 34 ± 7 Seychelles: 29 ±6 Jamaica: 28 ±6 South Africa: 32 ±9 Ghana: 26 ±7 males: USA: 28 ±8 Seychelles: 25 ±4 Jamaica: 23 ±4 South Africa: 23 ±4 Ghana: 22 ±2	7	5	Not reported	Yes

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
						South Africa: 20 Ghana: 31		Ghana: 36 ± 6					
Ptomey 2015 [34]	USA, Kansas	HIC	Digital photographs for a meal each day over a 7 day period in a cafeteria setting. 7 x 24h MPR were conducted at each cafeteria meal to document foods consumed outside of the cafeteria. Information from the photos and the MPR were combined.	Participants selected foods and then photographed their foods on a tray, with standard measures for liquids and solids placed on the tray to aid the estimation of portion sizes.	91	females n=45 males n=46	18-30	Overall: 22.9 ± 3.2 females: 22.4 ± 3 males: 23.4 ± 3.4	Overall: 30.6 ± 4.6 females: 29.5 ± 4.5 males: 31.7 ± 4.4	14	5	0.10g ^2H_2O and 0.15g $H_2{}^{18}O$ per kg body weight	Yes. Weight was self-reported at baseline.
Food frequency questionnaires (FFQ)													
Ferriolli 2010 [22]	Brazil, São Paulo	UMIC	FFQ	Specific information on the FFQ was not provided in this publication.	19	females n=9 males n=10	60-75	females: 66.5 ± 4.6 males: 66.2 ± 3.3	females: 29.3 ± 6.3 males: 26.8 ± 4.4	10	2	0.15g $H_2{}^{18}O$ and 0.07g ^2H_2O per kg body weight	Baseline only
Okubo 2008 [14]	Japan, across four districts	HIC	FFQ (DHQ), reporting period 1mth, completed by	The FFQ contained 121 food and beverage items (asks about frequency and	140	females n=73 males n=67	20-59	females: 38.5 ± 10.4 males: 39.4 ± 11.1	females: 21.6 ± 2.7 males: 23.3 ± 2.9	14	2	0.06g ^2H_2O and 0.14g $H_2{}^{18}O$ per kg body weight	Yes Correction for change calculated, but not used

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
			participants on paper.	the semi-quantitative portion size).									in the main analysis
Weighed food records (WFR)													
Black 1997 [21]	UK, Cambridge	HIC	WFR: recording period 16d over a period of up to 1 year.	Participants were provided with kitchen scales to weigh foods consumed, and the weight and a spoken description of the foods consumed were recorded by participants.	45	females n=18 males n=27	50 - 87	females: 57.9 ± 4.6 males: 67.5 ± 5.03	females: 25.0 ± 3.9 males: 25.4 ± 3.6	14 - 21	14 – 21	0.07g ^2H_2O and 0.174g $H_2{}^{18}O$ per kg body weight	Baseline only
Livingstone 1990 [26]	Ireland	HIC	WFR: recording period 7d, consecutive.	Participants were provided with scales (miniscale PC international), and were asked to record weighed foods and drinks in a logbook.	31	females n=15 males n=16	NR	females: 35.5 ± 11.4 males: 31.5 ± 7.2	females: 24.3 ± 3.1 males: 25.8 ± 3.3	15	15	Not reported	Baseline only
Warwick 1996 [46]	Australia, New South Wales	HIC	WFR over 28 consecutive days.	Mix of precise weighing and weighed inventory methods. Portable electronic	21 (11 smokers and 10 non-smokers)	females smokers n= 6, non-smokers n=6 males smokers n= 5, non-		Smokers: 25.5 ± 7.3 Non-smokers: 27.9 ± 6.2	Smokers: 21.4 ± 1.7 Non-smokers: 22.3 ± 1.8	8-12	4	approx. 0. I g ^2H_2O/kg body wt and 0.2 g $H_2{}^{18}O$/kg body wt.	Yes

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
				scales were used.		smokers n=4							
Estimated food records (EFR)													
Goran 1992 [24]	USA, Burlington	HIC	3-day self-administered estimated food diary, (2 week days, 1 weekend).	Specific information on how food intake was estimated and recorded was not provided.	13	females n=6 males n=7	56-78	Overall: 67 ± 6 females: 64 ± 5 males: 68 ± 6	Overall weight: 71.62 ± 9.5 females: 65.2 ± 7.8 males: 77.1 ± 7.4 Overall height: 170 ± 8 females: 165 ± 3 males: 175 ± 9	10	2	0.15 g $H_2{}^{18}O$ and 0.075 g ^2H_2O per kg	Baseline only
Koebnick 2005 [25]	Germany, Potsdam	HIC	Semi-quantitative, self-administered 4-day FR (Sunday – Wednesday).	The semi-quantitative food record provided 270 food items with an example of a portion size in grams and in terms of typical household measures (e.g. half a plate).	29	females n=16 males n=13	19-64	Overall: 36.8 ± 11.8	Overall: 23.4 ± 2.7	14	14	0.07g ^2H_2O and 1.74g $H_2{}^{18}O$ per kg body weight	NR

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
Redman 2014 [35]	USA, Boston, St Louis, Durham, New Jersey	HIC	Six-day food diaries were hand recorded, per DLW assessment period.	Specific information on how food intake and portion size were estimated was not provided.	217	females n=151 males n= 66	21-50	females: 37.2 ± 7.1 males: 39.7 ± 7.1	females: 24.9 ± 1.7 males: 25.8 ± 1.7	28 (two consecutive 14 day DLW assessments)	12 (6 per assessment)	1.5 g/kg body weight containing 0.086 g $^{2}H_2O$ (99.98% ^{2}H) and 0.138 g $H_2{}^{18}O$ (100% ^{18}O) per kg body weight	Yes, adjustment for body weight change was not significant.
Seale 2002 [40]	USA, Beltsville	HIC	Self-reported dietary records, over 4 days.	Participants were provided with scales and household measures to quantify food consumed. Unclear whether all foods recorded were weighed.	54	females n=27 males n=27	32-82	females: 62.1 ± 11.9 males: 61.2 ± 15.3	females: 25.8 ± 3.8 males: 27.2 ± 2.4	10-14	6	0.14 g $H_2{}^{18}O$/kg body wt and 0.70 g $^{2}H_2O$/kg body wt	NR
Seale 2002 [39]	USA, rural Pennsylvania	HIC	Self-reported dietary records, over 3 days	Participants were provided with scales and household measures to quantify food consumed. Unclear whether all foods recorded were weighed.	27	females n=13 males n=14	67–82	females: 73.5 ± 4.2 males: 74.1 ± 4.1	females: 27.6 ± 3.2 males: 28.2 ± 2.4	14	6	$H_2{}^{18}O$: 0.14 g/kg body weight and $^{2}H_2O$: 0.70 g/kg body weight	Baseline only

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of sample s	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	**Mean ± SD**					
Seale 1997 [38]	USA, Beltsville	HIC	Self-reported dietary records, over 7 days	Participants were provided with scales and household measures to quantify food consumed. Unclear whether all foods recorded were weighed.	19	females n=11 males n=8	40-62	females: 51.9 ± 4.9 males: 49.5 ± 7.2	females: 22.6 ± 2.5 males: 25.7 ± 1.3	10	6	$H_2{}^{18}O$: 0.14 g/kg body weight and ^2H_2O: 0.70 g/kg body weight	Yes Adjustments were made for change in body weight.
Tomoyasu 1999 [45]	USA, Vermont	HIC	Self-reported food records, over 3 days, 2 weekdays and 1 weekend day.	Participants were provided with food scales, along with measuring instruments and recorded all foods and drinks consumed. Unclear whether all foods recorded were weighed.	82	females n=43 males n=39	aged 55 years or older	females: 68 ± 1 (sem) males: 70 ± 1 (sem)	females: 24.8 ± 0.5 males: 25.1 ± 0.6	10	4	.078 g of 'H,O and .092 g of H,"0 per kilogram of body mass was given to each subject to drink (approximately 70 mL)	Baseline only
Tomoyasu 2000 [44]	USA, Baltimore	HIC	Self-reported food records over 3 days, 2 weekdays and 1 weekend day.	Participants were provided with food scales, along with measuring instruments and recorded all foods and drinks consumed. Unclear whether all	64	African American females n=36 males n=28	52-84	females: 64.6 ± 8.1 males: 65.1 ± 7.0	females: 32.1 ± 6.4 males: 27.6 ± 4.2	10	2	^2H_2O and $H_2{}^{18}O$ (0.075 and 0.092 g/kg body weight, respectively)	Baseline only

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
				foods recorded were weighed.									
Diet histories (DH)													
Rothenberg 1998 [36]	Sweden, Gothenburg	HIC	DH: interview undertaken during a hospital visit and conducted by a dietitian. The reporting period was 1mth.	Different sized bags were used to aid the estimation of portion sizes.	12	females n=9 males n=3	NR	73	females: 25 ± 2.8 males: 25 ± 3.0	20	10	0.12g ^2H_2O and 0.25 g $H_2^{18}O$ per kg body water	Baseline only.
Multiple dietary assessment methods													
Arab 2011[19]	USA, Los Angeles	HIC	24h MPR: 6 x 24h MPR via web-based platform (dietday) over 2 weeks. FFQ (DHQ): recording period 1y.	24h MPR Portion sizes are estimated using images of household measures. FFQ The paper based DHQ covered the portion size and frequency of consumption of 124 food items.	233	females n=158 males n=75	21-69	Median (IQR) Overall: 33.3 (12.5)	Median (IQR) overall: 25.0 (6.1)	15	6	2g of 10 atom % ^{18}O-labeled water and 0.12g of 99.9 atom % deuterium-labelled water per kg body weight	Baseline only
Gemming 2015 [23]	New Zealand, Auckland	HIC	24h MPR: 3 x 24h MPR in-person	24h MPR: Standard household measures (e.g.	40	females n=20 males n=20	18-64	females: 27.1 ± 7.5 males: 34.8 ± 12.6	females: 22.3 ± 2.3 males: 27.1 ± 3.9	15	5	0.1g of 99·9% ^2H_2O/kg and 2 g of	Yes

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
			interviewer administered. 24h MPR, with camera: 3 x wearable camera (SenseCam, camera worn on lanyard) assisted 24h MPR. MPR were conducted and then images from wearable camera were reviewed, with missed foods added to recall data.	crockery and glassware), along with a portion size guide were used to aid estimation of portion sizes.								10% $H_2^{18}O$ per kg total body water	
Lopes 2016 [27]	Brazil, Rio de Janerio	UMIC	24h MPR: 3 x 24h MPR completed in person, each comprised of 5 passes of information collection. FR: Estimated food records completed over 2 non-consecutive days.	Specific information on how the portion sizes were estimated for either method were not provided.	83	females n=50 males n=33	20-60	Not reported	BMI <25: females n = 15, males n = 8 BMI ≥ 25: females n = 35, males n = 25	10	7	2g of 10% $H_2^{18}O$ and 0.12g 99.9% ^2H_2O per kg body weight	Baseline only

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
Park 2018 [32]	USA, Pittsburgh	HIC	24h MPR: 6 x 24h MPR (ASA24), 5 passes. FFQ: 2 x web-based FFQ (DHQ). Reporting period of 1y. FR: 2 x estimated FR each covering a 4-day period, with foods and beverages consumed written down by participants.	24h MPR Images were used depicting incremental portions or sizes to aid portion size estimation. FFQ Each FFQ covered 134 items FR A serving size booklet was provided.	1075	Females n=545 males n=530	50-74	males: 64 females: 62	females BMI 30 to <40 n=32. males: BMI 30 to <40 n=29.	10	7	2 g of 10% and 0.12 g of 99.9% deuterium labelled water per kg body water	Yes
Pfrimer 2015 [33]	Brazil, São Paulo	UMIC	24h MPR: 3 x 24h MPR, interview administrated. FFQ: reporting period 1y interview administered	24h MPR Life-size pictures of utensils and portion sizes of foods were used to aid estimated quantity consumed. FFQ 120 food items.	41	females n=21 males n=20	60-70	females: 67 ± 3 males: 68 ± 4	females: 29 ± 5 males: 26 ± 4	10	5	0.12g 99% deuterium-labelled water and 2g 10% ^{18}O per kg body water	Baseline only

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
Schulz 1994 [37]	USA, Arizona	HIC	24h DR: 10 x 24h interviewer administered recall FFQ: reporting period not specified.	Specifics on how portion sizes were estimated was not provided.	21	Females n=9 males n=12 Pima Indian population	NR	females: 31.3 ± 13.0 males: 35.4 ± 13.8	females: 42.2 ± 12.5 males: 32.3 ± 9.4	14	11	3.144 g/kg of bodyweight of a solution made of 20 parts of 10.4 atom % $H_2{}^{18}O$ and 1 part of 99.9 atom% ^2H_2O.	NR
Subar 2003 [41]	USA, Washington	HIC	24h MPR: 2 x 24h MPR, 5 passes. Interviews were conducted in person and collected on paper. FFQ: FFQ (DHQ), reporting period 1y.	24h MPR Food models were used to aid estimation of portion sizes. FFQ 124 food items	484	females n=223 males n=261	40-69	Not reported	female BMI: <25.0 (n=86) 25.0-29.9 (n=72) >30.0 (n=65) male BMI: <25.0 (n=57) 25.0-29.9 (n=127) >30.0 (n=77)	14	4 + 2 x 24 hr urine samples *DLW collected at 2 time points for a sub sample	0.12g of 99.9 atom % deuterium and 2g of 10 atom % ^{18}O per kg body water Blood sample also collected	Yes
Nybacka 2016 [30]	Gothenburg, Sweden	HIC	FR: Estimated FR, recording period 4d. Record is completed online. FFQ: "MiniMeal-Q" – web-based and self administrated.	FR A list of 1909 food items is provided. A portion size reference guide is provided. FFQ 126 food items. Pictures of portions of	40	females n=20 males n=20	50-64	females: 57.8 ± 4.1 males: 58.6 ± 4.9	females: 25.7 ± 3.1 males: 27.3 ± 3.0	14	5	0.05g 99.9% ^2H and 0.10g 10% ^{18}O per kg body weight	Yes

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
			The reporting period previous few months.	foods were provided to aid estimations of quantities consumed.									
Svendsen 2006 [42]	Norway, Oslo	HIC	WFR: Participants were provided with scales and asked to weigh all foods prior to consumption over 3-4 days. FFQ: Interviewer administered, reporting period 3mths.	FFQ 174 food items. Photos of foods and household measures were supplied to aid portion size estimation.	50	females n=27 males n=23	24–64	43·2 ± 10.3	females:36.6 ± 3.4 males:34.6 ± 2.9	14	8	0.05g ^{2}H and 0.10g ^{18}O/kg body weight	Yes.
Watanabe 2019 [47]	Japan, Kameoka	HIC	FFQ: reporting period 1 year, completed by participants on paper FR: Estimated, 7-day collection period. Completed by participants on paper.	FFQ 47 food and beverage items (detailed information on portion sizes was not asked/collected) . FR Participants were advised to estimate portions of foods consumed,	109	females n=50 males n=59	65-88	females: 72.2 ± 4.6 males: 73.5 ± 6.0	females: 23.0 ± 3.5 males: 22.7 ± 2.8	16	6	0.12 g/kg estimated TBW of $^{2}H_2O$ and 2.5 g/kg estimated TBW of $H_2{}^{18}O$	Baseline only

Reference	Setting (country, city)	Country income level	Diet Assessment Method and recording period	Diet assessment method, supporting information	n	Sex (n)	Age (y)		Participants BMI Mean ± SD	Length of DLW (days)	No. of samples	Dosage of DLW	Body weight measure Detail provided if adjustments were made
							Range	Mean ± SD					
				using household measures. They were also provided a digital scales, but use of this to weigh all foods consumed is not specified.									
Barnard 2002 [20]	Australia, Wollongong	HIC	DH: One open ended interview with a dietitian at the start of the study. WFR: 7-day period.	DH: Specifics on how portion sizes were estimated was not provided. WFR Participants were provided with kitchen scales.	15	females n=8 males n=7	22-59	Overall: 36.2 ± 11.7 females: 37.1 ± 9.6 males: 35.4 ± 13.1	Overall: 24.9 ± 4.6 females: 23.8 ± 5.3 males: 25.9 ± 3.9	14	3	0.05g ^2H_2O and 0.13g $H_2{}^{18}O$ per kg body weight	Yes
Takae 2019 [43]	Japan, Fukuoka	HIC	DH supplemented with photographs of foods consumed over 3-days and dietary interviews with dietitians.	Further information on assessment methods not published.	56	females n=39 males n=17	55-89	females: 72.1 ± 6.9 males: 71.1 ± 6.6	females: 22.6 ± 3.9 males: 23.9 ± 3.3	16	4	0.12 g/kg estimated TBW of ^2H_2O and 2.5 g/kg estimated TBW of $H_2{}^{18}O$	Baseline only

Y = years, SD = standard deviation, DLW = Doubly labelled water, FFQ= food frequency questionnaire, DHQ= Diet History Questionnaire, BMI = body mass index, MPR= multiple pass record, DH= diet history, EFR= estimated food record, FR= food record, WFR= weighed food record, NR= Not reported.

3.2.1. Differences in energy intake and expenditure by dietary assessment method for females and males, and difference in mean differences between sexes in the accuracy of self-reported dietary assessment

24-hour diet recalls

For 24-hour diet recalls (**figure 2 A**), females underestimated TEI by -2,650 kJ/day (95% CI: -3,492, -1,807, I^2=92%) and males underestimated TEI by -2,993 kJ/day (95% CI: -3,705, -2,281, I^2=77%), when compared to TEE, with no difference in the level of underestimation (based on the difference in the mean difference) between sexes.

For 24-hour diet recalls supplemented with camera footage there was no difference between TEI and TEE for females or for males (females MD -242 kJ/day, 95% CI: -1,367, 882, I^2=80%, males MD -649 kJ/day, 95% CI: -2,032, 735, I^2=64%), **figure 2 B**.

Food frequency questionnaires

For females, use of FFQs underestimated TEI by -1,318 kJ/day (95%CI: -1,967, -669, I^2=67%). Males underestimated TEI by -1,764 kJ/day (-2,285, -1,242, I^2=30%), with no difference in the level of underestimation between sexes, **figure 2 C**.

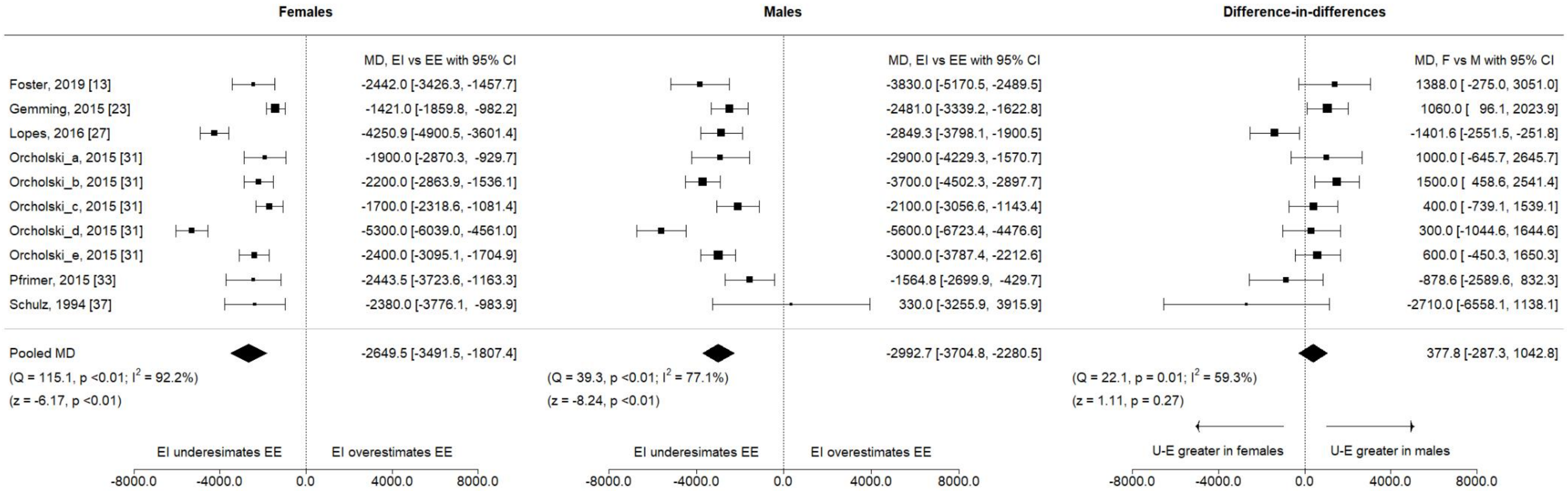
Weighed food records

For females, use of WFRs underestimated TEI by -2,286 kJ/day (95% CI: -3,420, -1,152, I^2=86%). For males, the level of underestimation was -3,438 kJ/day (-5,382, -1,494, I^2=91%), when compared to TEE. There was no difference in the level of underestimation between sexes, **figure 2 D**.

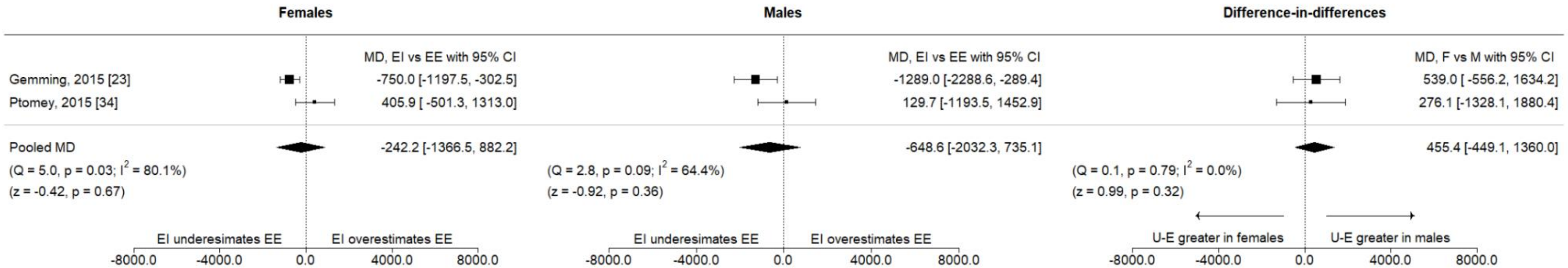
Estimated food records

For females, TEI was underestimated by -1,829 kJ/day (95% CI: -2,347, -1,311, I^2=89%). For males, use of food records underestimated TEI by -2,468 kJ/day (-3,137, -1,799, I^2=88%). Males underestimated TEI to a greater extent than females, by 590 kJ/day (35, 1,146, I^2=70%), **figure 2 E**.

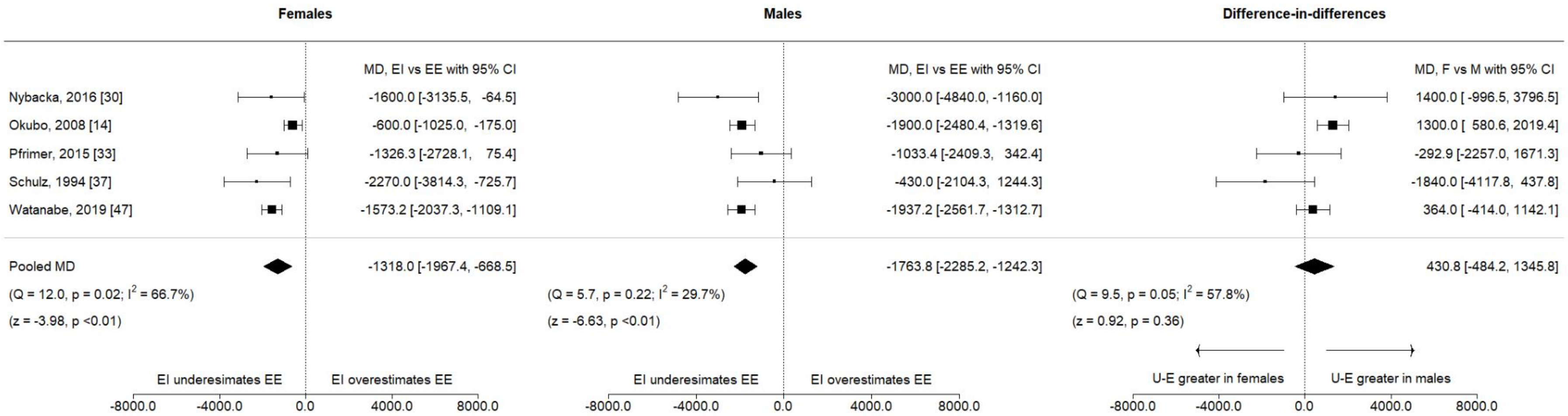
A


Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Foster, 2019 [13]
Gemming, 2015 [23]
Lopes, 2016 [27]
Orcholski_a, 2015 [31]
Orcholski_b, 2015 [31]
Orcholski_c, 2015 [31]
Orcholski_d, 2015 [31]
Orcholski_e, 2015 [31]
Pfrimer, 2015 [33]
Schulz, 1994 [37]
-2442.0 [-3426.3, -1457.7]
-1421.0 [-1859.8, -982.2]
-4250.9 [-4900.5, -3601.4]
-1900.0 [-2870.3, -929.7]
-2200.0 [-2863.9, -1536.1]
-1700.0 [-2318.6, -1081.4]
-5300.0 [-6039.0, -4561.0]
-2400.0 [-3095.1, -1704.9]
-2443.5 [-3723.6, -1163.3]
-2380.0 [-3776.1, -983.9]
-3830.0 [-5170.5, -2489.5]
-2481.0 [-3339.2, -1622.8]
-2849.3 [-3798.1, -1900.5]
-2900.0 [-4229.3, -1570.7]
-3700.0 [-4502.3, -2897.7]
-2100.0 [-3056.6, -1143.4]
-5600.0 [-6723.4, -4476.6]
-3000.0 [-3787.4, -2212.6]
-1564.8 [-2699.9, -429.7]
330.0 [-3255.9, 3915.9]
1388.0 [-275.0, 3051.0]
1060.0 [96.1, 2023.9]
-1401.6 [-2551.5, -251.8]
1000.0 [-645.7, 2645.7]
1500.0 [458.6, 2541.4]
400.0 [-739.1, 1539.1]
300.0 [-1044.6, 1644.6]
600.0 [-450.3, 1650.3]
-878.6 [-2589.6, 832.3]
-2710.0 [-6558.1, 1138.1]
Pooled MD
(Q = 115.1, p <0.01; I² = 92.2%)
(z = -6.17, p <0.01)
-2649.5 [-3491.5, -1807.4]
(Q = 39.3, p <0.01; I² = 77.1%)
(z = -8.24, p <0.01)
-2992.7 [-3704.8, -2280.5]
(Q = 22.1, p = 0.01; I² = 59.3%)
(z = 1.11, p = 0.27)
377.8 [-287.3, 1042.8]
EI underesimates EE
EI overestimates EE
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0
-4000.0
0.0
4000.0
8000.0

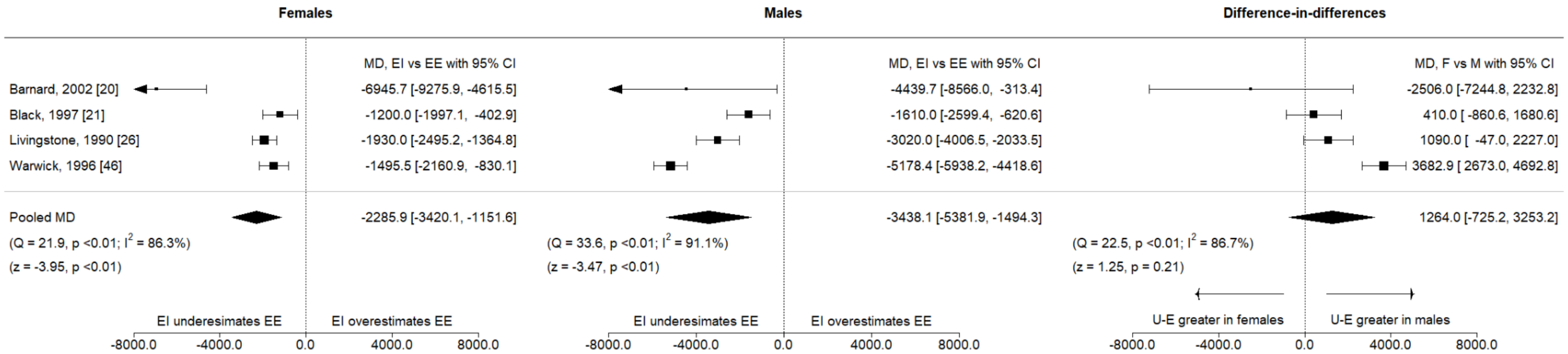
B


Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Gemming, 2015 [23]
Ptomey, 2015 [34]
-750.0 [-1197.5, -302.5]
405.9 [-501.3, 1313.0]
-1289.0 [-2288.6, -289.4]
129.7 [-1193.5, 1452.9]
539.0 [-556.2, 1634.2]
276.1 [-1328.1, 1880.4]
Pooled MD
(Q = 5.0, p = 0.03; I² = 80.1%)
(z = -0.42, p = 0.67)
-242.2 [-1366.5, 882.2]
(Q = 2.8, p = 0.09; I² = 64.4%)
(z = -0.92, p = 0.36)
-648.6 [-2032.3, 735.1]
(Q = 0.1, p = 0.79; I² = 0.0%)
(z = 0.99, p = 0.32)
455.4 [-449.1, 1360.0]
EI underesimates EE
EI overestimates EE
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0
-4000.0
0.0
4000.0
8000.0

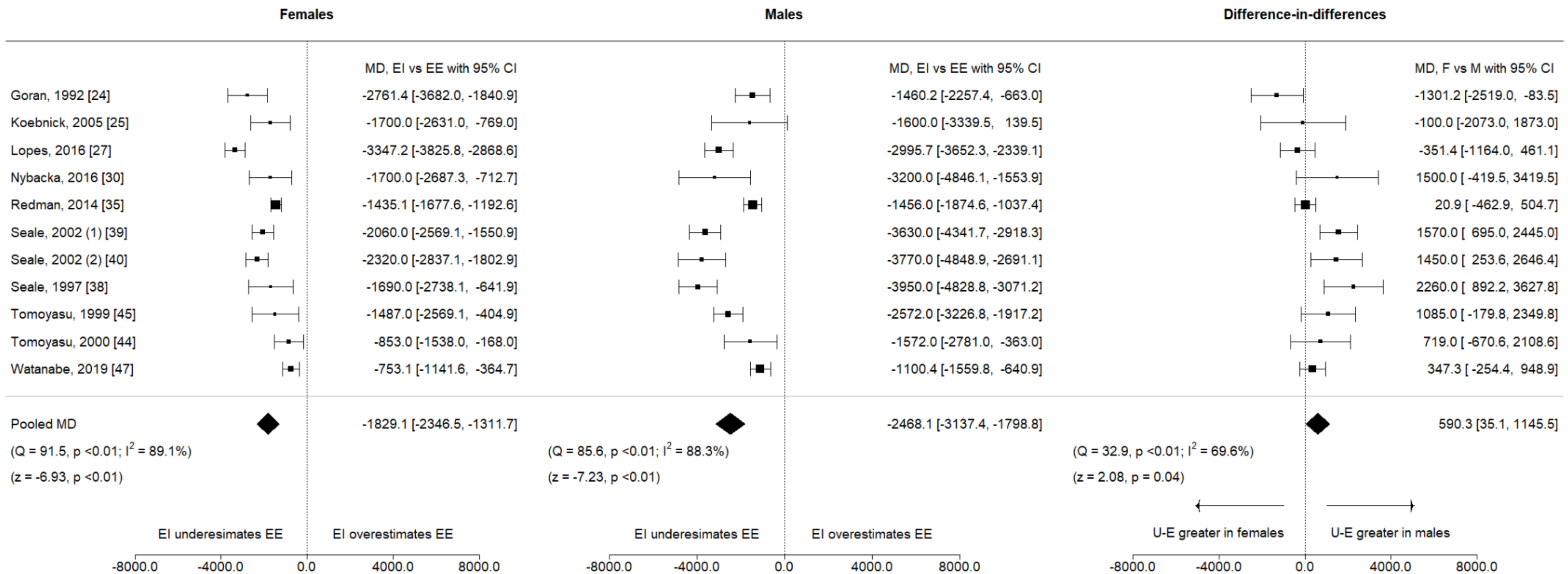
C


Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Nybacka, 2016 [30]
-1600.0 [-3135.5, -64.5]
-3000.0 [-4840.0, -1160.0]
1400.0 [-996.5, 3796.5]
Okubo, 2008 [14]
-600.0 [-1025.0, -175.0]
-1900.0 [-2480.4, -1319.6]
1300.0 [580.6, 2019.4]
Pfrimer, 2015 [33]
-1326.3 [-2728.1, 75.4]
-1033.4 [-2409.3, 342.4]
-292.9 [-2257.0, 1671.3]
Schulz, 1994 [37]
-2270.0 [-3814.3, -725.7]
-430.0 [-2104.3, 1244.3]
-1840.0 [-4117.8, 437.8]
Watanabe, 2019 [47]
-1573.2 [-2037.3, -1109.1]
-1937.2 [-2561.7, -1312.7]
364.0 [-414.0, 1142.1]
Pooled MD
-1318.0 [-1967.4, -668.5]
-1763.8 [-2285.2, -1242.3]
430.8 [-484.2, 1345.8]
(Q = 12.0, p = 0.02; I2 = 66.7%)
(z = -3.98, p <0.01)
(Q = 5.7, p = 0.22; I2 = 29.7%)
(z = -6.63, p <0.01)
(Q = 9.5, p = 0.05; I2 = 57.8%)
(z = 0.92, p = 0.36)
EI underesimates EE
EI overestimates EE
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0 -4000.0 0.0 4000.0 8000.0
-8000.0 -4000.0 0.0 4000.0 8000.0
-8000.0 -4000.0 0.0 4000.0 8000.0

D


Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Barnard, 2002 [20]
-6945.7 [-9275.9, -4615.5]
-4439.7 [-8566.0, -313.4]
-2506.0 [-7244.8, 2232.8]
Black, 1997 [21]
-1200.0 [-1997.1, -402.9]
-1610.0 [-2599.4, -620.6]
410.0 [-860.6, 1680.6]
Livingstone, 1990 [26]
-1930.0 [-2495.2, -1364.8]
-3020.0 [-4006.5, -2033.5]
1090.0 [-47.0, 2227.0]
Warwick, 1996 [46]
-1495.5 [-2160.9, -830.1]
-5178.4 [-5938.2, -4418.6]
3682.9 [2673.0, 4692.8]
Pooled MD
-2285.9 [-3420.1, -1151.6]
-3438.1 [-5381.9, -1494.3]
1264.0 [-725.2, 3253.2]
(Q = 21.9, p <0.01; I2 = 86.3%)
(z = -3.95, p <0.01)
(Q = 33.6, p <0.01; I2 = 91.1%)
(z = -3.47, p <0.01)
(Q = 22.5, p <0.01; I2 = 86.7%)
(z = 1.25, p = 0.21)
EI underesimates EE
EI overestimates EE
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0 -4000.0 0.0 4000.0 8000.0
-8000.0 -4000.0 0.0 4000.0 8000.0
-8000.0 -4000.0 0.0 4000.0 8000.0

E


Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Goran, 1992 [24] -2761.4 [-3682.0, -1840.9] -1460.2 [-2257.4, -663.0] -1301.2 [-2519.0, -83.5]
Koebnick, 2005 [25] -1700.0 [-2631.0, -769.0] -1600.0 [-3339.5, 139.5] -100.0 [-2073.0, 1873.0]
Lopes, 2016 [27] -3347.2 [-3825.8, -2868.6] -2995.7 [-3652.3, -2339.1] -351.4 [-1164.0, 461.1]
Nybacka, 2016 [30] -1700.0 [-2687.3, -712.7] -3200.0 [-4846.1, -1553.9] 1500.0 [-419.5, 3419.5]
Redman, 2014 [35] -1435.1 [-1677.6, -1192.6] -1456.0 [-1874.6, -1037.4] 20.9 [-462.9, 504.7]
Seale, 2002 (1) [39] -2060.0 [-2569.1, -1550.9] -3630.0 [-4341.7, -2918.3] 1570.0 [695.0, 2445.0]
Seale, 2002 (2) [40] -2320.0 [-2837.1, -1802.9] -3770.0 [-4848.9, -2691.1] 1450.0 [253.6, 2646.4]
Seale, 1997 [38] -1690.0 [-2738.1, -641.9] -3950.0 [-4828.8, -3071.2] 2260.0 [892.2, 3627.8]
Tomoyasu, 1999 [45] -1487.0 [-2569.1, -404.9] -2572.0 [-3226.8, -1917.2] 1085.0 [-179.8, 2349.8]
Tomoyasu, 2000 [44] -853.0 [-1538.0, -168.0] -1572.0 [-2781.0, -363.0] 719.0 [-670.6, 2108.6]
Watanabe, 2019 [47] -753.1 [-1141.6, -364.7] -1100.4 [-1559.8, -640.9] 347.3 [-254.4, 948.9]
Pooled MD -1829.1 [-2346.5, -1311.7] -2468.1 [-3137.4, -1798.8] 590.3 [35.1, 1145.5]
(Q = 91.5, p <0.01; I² = 89.1%)
(z = -6.93, p <0.01)
(Q = 85.6, p <0.01; I² = 88.3%)
(z = -7.23, p <0.01)
(Q = 32.9, p <0.01; I² = 69.6%)
(z = 2.08, p = 0.04)
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0 -4000.0 0.0 4000.0 8000.0

F

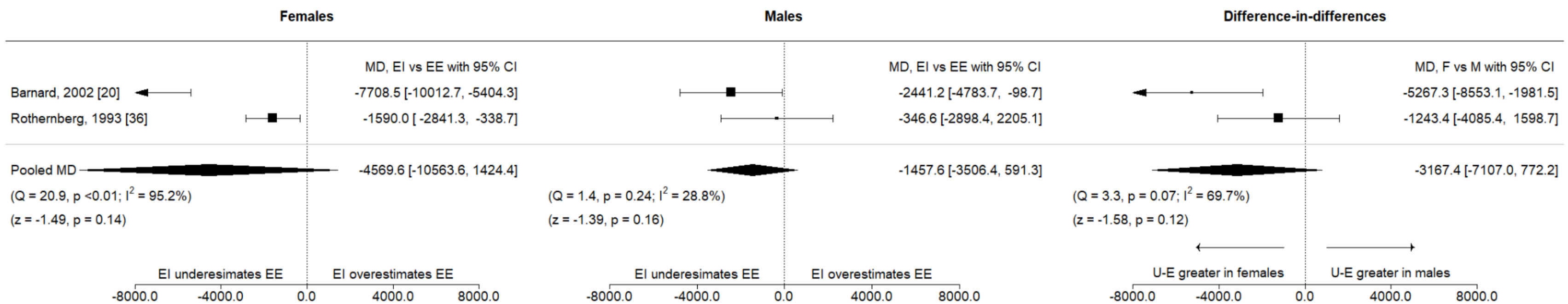

Females
Males
Difference-in-differences
MD, EI vs EE with 95% CI
MD, EI vs EE with 95% CI
MD, F vs M with 95% CI
Barnard, 2002 [20] -7708.5 [-10012.7, -5404.3] -2441.2 [-4783.7, -98.7] -5267.3 [-8553.1, -1981.5]
Rothernberg, 1993 [36] -1590.0 [-2841.3, -338.7] -346.6 [-2898.4, 2205.1] -1243.4 [-4085.4, 1598.7]
Pooled MD -4569.6 [-10563.6, 1424.4] -1457.6 [-3506.4, 591.3] -3167.4 [-7107.0, 772.2]
(Q = 20.9, p <0.01; I² = 95.2%)
(z = -1.49, p = 0.14)
(Q = 1.4, p = 0.24; I² = 28.8%)
(z = -1.39, p = 0.16)
(Q = 3.3, p = 0.07; I² = 69.7%)
(z = -1.58, p = 0.12)
EI underesimates EE
EI overestimates EE
U-E greater in females
U-E greater in males
-8000.0 -4000.0 0.0 4000.0 8000.0

Figure 2. Mean difference between energy intake (EI) and energy expenditure (EE) in kilojoules per day for females and males, and the difference in mean difference between sexes, by dietary assessment method used to estimate EI. Figure panels organised by dietary assessment method: **A** 24-hour diet recalls, **B** 24-hour diet recalls, supplemented with photography of foods consumed, **C** Food frequency questionnaire, **D** Weighed food records, **E** Estimated food records, **F** Diet histories.

Pooled mean differences by sex and dietary assessment method with 95% confidence intervals and pooled difference in mean differences (females compared to males) were calculated using random effects meta-analysis models and the DerSimonian and Laird inverse-variance method.

Diet histories

Underestimation of TEI from diet histories was not significant for females or males: females -4,570 kJ/day (95% CI: -10,563, 1,424, $I^2 = 95\%$), males -1,458 kJ/day (95% CI -3,506, 591, $I^2 = 29\%$), **figure 2 F**.

3.2.2. Sensitivity analyses

Three sensitivity analyses were conducted whereby studies that reported geometric means, studies assessed as of positive quality and studies that reported multiple findings for the same dietary assessment method, were included in the meta-analyses (**supplementary figure 2**). The sensitivity analysis that included studies of positive quality only provided a different pooled estimate for females when TEI was estimated using WFRs. The remaining sensitivity analysis did not produce pooled estimates that differed compared to the main analyses.

3.2.3. Subgroup analyses

24-hour diet recalls

There was no evidence of a difference in the level of underestimation of TEI across the subgroups investigated for females (**supplementary figure 3**). For males, studies that had a shorter collection period of urine following doubly labelled water dosing (<10 days) or who completed two or less 24-hr recalls, underestimated TEI by a greater amount (same studies in both subgroup analyses, subgroup difference, -1,271kJ/day, 95% CI -2,473, -70, p-value= 0.04). There was a greater underestimation of energy intake in males compared to females in high-income countries, not observed in low- and middle-income countries (subgroup difference -1,279 kJ/day, 95% CI -2,320, -238, p-value= 0.02).

Estimated food records

For studies that used EFRs to measure TEI, the level of underestimation was less for females when EFRs were conducted over more than four days compared to less than four days (subgroup difference -846 kJ/day, 95% CI -1,669, -22, p-value= 0.04), **supplementary figure 4**.

Additionally, females in low- and middle-income countries underestimated TEI to a greater extent than females in high income countries (subgroup difference -1,706 kJ/day, 95% CI -2,329, -1,083, p-value<0.01). There was a greater underestimation of energy intake in males compared to females in high-income countries, not observed in low- and middle-income countries (subgroup difference -1,063 kJ/day, 95% CI -2,070, -55, p-value= 0.04).

3.2.4. Assessment of publication bias

Visual assessment of the funnel plots for studies using 24-hour diet recalls and estimated food records suggest the absence of publication bias (**supplementary figure 5**). This was supported by findings from the Egger tests where the tests for funnel plot asymmetry were all non-significant (p-values >0.05).

3.2.5. Estimated percent differences in energy intake compared to energy expenditure, within and between sexes, by dietary assessment method

Supplementary figure 6 shows the estimated percent difference between TEI and TEE, for, and between, females and males. These findings mainly reflect what was found for the absolute data. Looking at the difference between sexes, there was no significant difference in the degree of underestimation between females and males for 24-hour diet recalls (-2.0%, 95% CI: -9.3, 5.3%), 24-hour diet recalls supplemented with photographs (2.4%, -4.7, 9.4%), FFQs (1.1%, -9.1, 11.2%), WFRs (5.0%, -14.6, 24.7%) or diet histories (-34.3%, -71.5, 2.9%). While on an absolute scale we saw a difference in underestimation between sexes for EFRs, the estimated percent difference was not significant (1.3%, -4.6, 7.1%), **supplementary figure 6 E**.

4. Discussion

The current review has identified significant underestimation of TEI in population samples of adults when energy intake is estimated by various retrospective and prospective dietary assessment methods in comparison to an objective reference measure of TEI using doubly labelled water. The extent of underestimation was statistically significant across a range of dietary assessment methods with the exception of 24-hour diet recalls (supplemented with individuals taking photographs of foods consumed) and diet histories. However, in both cases data was only available from two studies, and therefore these findings need to be treated with caution. No significant differences in underestimation were identified based on sex, with the exception of EFRs where males underestimated energy intake more so than females, yet this finding did not remain significant when looking at values as an estimated percent difference. These results will be important to consider when investigating diet-disease relations.

Given that dietary intake is an important modifiable risk factor for non-communicable diseases, accurate monitoring of diets at a population level is crucial. We therefore need to understand the validity of dietary monitoring tools in estimating TEI for different population groups [7]. This review's hypothesis was that females underestimate energy intake to a greater extent than males, given findings from previous narrative reviews [4, 7]. However, the current results do not support this hypothesis, but instead demonstrate the magnitude of under-estimation by both sexes, which highlights the need to be cautious when interpreting self-reported dietary data. Various methods have been used in nutritional epidemiology to account for underestimation due to measurement error when exploring the relationship between diet and disease [48-51] and our findings emphasize the importance of such adjustments. It is also plausible that other participant characteristics have a greater influence on mis-reporting than a participant's sex, or when combined with a participant's sex. For example, in subgroup analyses we found that in studies conducted in high income countries, males underestimated intake to a greater extent than females, a finding that was not observed for studies conducted in low- to upper-middle income countries. Previous literature have also identified greater under-reporting of energy intake by people with overweight or obesity [4, 5], a finding which is not supported by the present subgroup analyses. Additionally, previous studies have shown evidence of individual correction responses, where longer assessment periods provide an estimate closer to TEE [52]. An indication of this was shown in the current review by a smaller level of underestimation of TEI by males who completed greater than two 24-hr diet recalls, compared to two or less, and by females using estimated food records over more than four days, compared to four days or less.

The use of 24-hour diet recalls supplemented with photos of foods and drinks consumed did not show significant underestimation of energy intake. While only two studies were included in the meta-analysis so we need to be wary about drawing strong conclusions, these findings are in line with the growing body of evidence which suggests that use of technology-based dietary assessments can improve accuracy of reporting [53, 54]. Technology based dietary assessment commonly involves taking images of foods consumed. This can add helpful information in terms of eating occasions, portion sizes, brands of foods and foods and drinks that may otherwise be forgotten, omitted or mis-reported by participants [55]. While such methods are yet to be used on a large scale, it is an area showing promise for the future [53, 56, 57], especially with the development of automated picture-supported dietary assessment tools and the utilisation of machine learning to interpret portion sizes [58].

Another factor that may influence the accuracy of the dietary intake reporting is the food composition databases used in the included studies [49, 59]. These databases are used to calculate energy intake, macro- and micro-nutrient intake based on reported foods, and therefore play a key role in the accuracy of estimated dietary intake. Food composition databases used should be developed within the same country that the study was conducted in, so that they reflect country-specific foods and available processed packaged foods [59]. When a country specific database is not available, databases developed in a country with a similar food supply, or adapted from an accessible database, are often used [59]. Further, given the substantial resources required to develop and update food composition databases, and the speed at which the processed packaged food supply can change [60], these food composition databases can quickly become outdated. Therefore, it is important for researchers to consider the relevance and reliability of food composition databases when undertaking dietary assessment methods as this will likely further impact the accuracy of their estimates.

It is important to contextualise our findings with respect to energy requirements. Given that males generally have a greater body weight and fat free muscle mass, their energy requirements are higher than females [3]. As such the degree of underestimation by males would be expected to be a lesser percentage of their total energy intake compared to females if both meet energy requirements. Given that we did not have the raw data from the included studies, we explored an estimated percentage underreporting by using the difference in the natural log of energy intake and energy expenditure, which approximates the percent difference. Results from this mainly reflected results on the absolute scale, which instils confidence in the current findings. The underestimation of energy intake by females and males may also suggest a general lack of awareness of the energy content of foods consumed [61]. With the increasing accessibility and consumption of energy-dense, nutrient-poor processed packaged foods globally [62], it may be becoming harder for people to be aware of how much energy or portion sizes they are consuming and therefore easier to eat in excess of requirements. This is reflected by the growing obesity epidemic [63].

This review has several limitations. The included studies did not report individual level data and therefore we could not calculate a pooled percentage of under-reporting and instead presented the raw amount of underestimation and an estimated percentage difference. Doubly labelled water provides an estimate of overall energy expenditure and therefore we were unable to assess the major food groups contributing to energy intake or nutrient intakes. This is an important area of future research given accuracy of dietary assessment method could differ according to the nutrient of interest. Additionally, doubly labelled water is usually collected over seven to 14 days, and provides an average TEE value over this time period, comparatively while the energy intake assessments were carried out during the same study periods as the doubly labelled water collection period in the included studies, they do cover a range of timeframes. For example, FFQ and diet histories look retrospectively at intake and so likely reflect energy intake outside of the estimated energy expenditure period. Due to the nature of the included studies, we were unable to evaluate how well information was captured or how accurately portion sizes were estimated. It is possible that different dietary assessment methods are better for estimating portion sizes or for picking up on commonly omitted foods and drinks [55, 64, 65]. While our findings indicate that 24-hour diet recalls supplemented with photographs of foods consumed and diet histories do not result in significant underestimation of dietary intakes, these were only assessed in two studies. It is therefore likely that the meta-analyses for these two dietary assessment methods were under-powered to show a difference, particularly for the diet histories as the confidence intervals for the pooled estimate were wide. We also excluded studies that relied on food photography alone, without being supported by a self-report method of intake. It is possible that some food photography could be defined as self-report, for example when people take and choose which photos are uploaded (i.e. 'active' capture), rather than automated ('passive') methods.

We investigated sex differences in the present paper. In our protocol we defined that we would be investigating gender differences in the self-report of energy intake [11], however data was only provided in studies in a binary form (women/females and men/males) and while we hypothesised that any differences identified are likely due to gender-related reasons, we have only been able to look at the data in binary (sex specific) categories. We defined the dietary assessment methods used based on how they were named in the original articles. However, six studies reporting on EFRs provided participants with scales to weigh their foods but did not report whether participants were required to weigh all food consumed [38-40, 44, 45, 47]. This could have impacted our findings as it is possible that some of these studies could be classified as weighted food records. Additionally, while doubly labelled water is the "gold standard" reference measure for energy intake, it can still be prone to error [2, 6].

We made assumptions about some of the correlation coefficients used. Specifically, we used the correlation coefficients for the general study population when a sex specific correlation coefficient was not provided (n=15 studies, 48%). Given the variation of the correlation coefficients across the included studies, we considered use of the study specific correlations coefficients to be more sound than imputing sex specific values [12]. Our analyses showed a high level of heterogeneity between studies. While we made attempts to investigate the reasons for this by undertaking subgroup analyses, this did not completely explain all heterogeneity between studies. Studies that did not report findings disaggregated by sex were excluded along with studies published in languages other than English, and therefore we may not have represented all the evidence available on this topic. We also identified very few studies conducted in low-and-middle income countries. As diet-related diseases are becoming increasing prevalent in low-and-middle income countries [66] it is important that we collect further data to understand whether our findings would be generalisable.

The current review has several important strengths. A systematic literature review across six databases was conducted, limiting the risk of missing relevant studies. We were also able to quantify the amount of under-estimation by dietary assessment method, which to our knowledge has not been done before. This study is also the first to distinguish the accuracy of dietary assessment methods according to sex. Together, the findings from this review address an important gap in the current literature and have practical implications for both researchers and policy makers in the way in which they interpret and use dietary assessment methods across their population of interest.

5. Conclusion

In contrast to previous studies, the current review has found that both females and males significantly underestimate total energy intake across most commonly used dietary assessment methods. These findings need to be accounted for when investigating sex differences in diet-disease relations, particularly those that inform sex and gender-based nutrition policies.

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Author contributions: BLM, DHC, MW and JW designed research; BLM and DHC conducted research; TB and CEC provided expert content knowledge on energy intake and energy expenditure methods; BLM and JAS performed statistical analysis; BLM wrote paper; JW had primary responsibility for final content; All authors contributed to the manuscript and approved the final written manuscript.

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3.4 Supplementary material

Supplementary methods. Analysis

For the studies with the available data, the mean difference between total energy intake (TEI) and total energy expenditure (TEE) was calculated separately for females and males. The standard deviation for the mean difference was calculated [12], as follows:

$SD_{\text{difference between EI and EE}} = \sqrt{SD^2_{EI} + SD^2_{EE} - (2x\text{Corr } x\ SD_{EI}\ x\ SD_{EE})}$

- SD_{EI} = Standard deviation of the mean TEI measure
- SD_{EE} = Standard deviation of the mean TEE measure
- Corr = Correlation coefficient for the relationship between energy intake and energy expenditure

The standard error for the difference was then calculated by dividing the calculated standard deviation for the difference between TEI and TEE by the square root of the number of participants in the study [12].

In order to quantify sex differences, the difference in the mean differences (difference between TEI and TEE among females minus difference between TEI and TEE among males) was calculated per study. The standard error for the difference in the mean difference was then calculated as follows:

$SE_{\text{difference in mean difference}} = \sqrt{(SD^2_{\text{difference EI vs EE females}}/N_{\text{females}}) + (SD^2_{\text{difference EI vs EE males}}/N_{\text{males}})}$

- $SD_{\text{difference EI vs EE females}}$= Standard deviation for the mean difference between TEI and TEE, for females
- $SD_{\text{difference EI vs EE males}}$= Standard deviation for the mean difference between TEI and TEE, for males
- N_{females}= Number of females
- N_{males}= Number of males

Pooled mean differences with 95% CI were calculated using random effects meta-analysis models with inverse variance weighting.

For the estimated percent difference, the approximate difference on the logarithmic scale was calculated by dividing the absolute difference in means (i.e difference between energy intake and energy expenditure) by the overall mean across groups (i.e. mean of energy intake and energy expenditure) [16, 18]. as follows:

$d_{\text{approximate difference}} = d_{\text{absolute difference}} / \bar{x}$

- $d_{\text{absolute difference}}$ = Difference in means between TEI and TEE
- $\bar{x}$ = Across group mean, that is the mean of TEI and TEE

The standard error for the estimated difference was then calculated as follows:

$SE_{\text{approximate difference}} = SE\ (d_{\text{absolute difference}}) / \bar{x}$

- $SE\ (d_{\text{absolute difference}})$ = Standard error for the difference in means between TEI and TEE
- $\bar{x}$ = Across group mean, that is the mean of TEI and TEE

Values were expressed as percent difference by multiplying by 100 [16].

The difference in mean difference for the estimated percentage was calculated using the same approach as the raw (absolute) scale, formula shown above.

Supplementary table 1. Outcome Data

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Arab et. al, 2011 [19]	Difference in means (TEE- EI) for diet day 223kcal and 66k2 for DHQ. Significant difference (P<0.05) between 24h MPR and FFQ for participants who UR. Validity of MPR 24h recall was superior to that of the FFQ. Less underreporting with MPR 24h recall than FFQ. Ethnicity plays a role in UR and OR: more substantial UR and OR among whites than blacks, regardless of the dietary assessment method.	Percentage of participants classified as UR and OR based on comparing EI to EE. UR <70%: 24h MPR: 28% FFQ: 47% UR <80%: 24h MPR: 41% FFQ: 56% OR >120%: 24h MPR: 13% FFQ: 14%	Percentage of participants classified as UR and OR based on comparing EI to EE. UR <70%: 24h MPR: 33% FFQ: 44% UR <80%: 24h MPR: 51% FFQ: 56% OR >120%: 24h MPR: 16% FFQ: 17%	Percentage of participants classified as UR and OR based on comparing EI to EE. UR <70%: 24h MPR: 28% FFQ: 47% UR <80%: 24h MPR: 41% FFQ: 56% OR >120%: 24h MPR: 13% FFQ: 14%	Percentage of participants classified as UR and OR based on comparing EI to EE. UR <70%: 24h MPR: 33% FFQ: 44% UR <80%: 24h MPR: 51% FFQ: 56% OR >120%: 24h MPR: 16% FFQ: 17%	24hr MPR: r= 0.45. Correlations improved with each increased day of recall from 0.24 day 1 to 0.48 day 5. Correlations similar between races FFQ: r= 0.33. Not disaggregated	24hr MPR: r= 0.45. Correlations improved with each increased day of recall from 0.24 day 1 to 0.48 day 5. Correlations similar between races FFQ: r= 0.33 Not disaggregated

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Barnard et. al, 2002 [20]	EI significantly different (P= 0.005) between genders for both DH and FR. NS difference in misreporting between genders for both DH and FR. Mean weight change over the study period was 0.1kg (±1.3) for all participants, 0.1kg (±1.7) in women and 0.1kg (±1.1) in men (NS). Increased misreporting of EI associated with higher TEE. Participants who are highly active or who have variable dietary and exercise habits are more likely to misreport energy intake.	Mean: 15,189.4 kJ SD: 4531.7 kJ	Mean: 17,218.5 kJ SD: 6857.9 kJ	DH Mean: 7480.9 kJ SD: 1403.7 kJ FR Mean: 8243.7 kJ SD: 1685.7 kJ	DH Mean: 14,777.3 kJ SD: 5140.9 kJ FR: Mean: 12,778.8 kJ SD: 1764.4 kJ	Degree of miss-reporting (difference between EI and DLW): DH 7708.6 kJ (4187.3) FR: 6945.7 kJ (4386.6) Correlation coefficients not disaggregated: DH r=0.9, FR r= 0.79	Degree of miss-reporting (difference between EI and DLW): DH 7962.5 kJ (5430.6) FR: 4892.4 kJ (5965.4) Correlation coefficients not disaggregated: DH r=0.9, FR r= 0.79
Black et. al, 1997 [21]	Image review underreported intakes with some gender differences indicated with men more likely to underreport than woman.	Mean: 2626 kcal/day SD: 492 kcal/day	Mean: 3546 kcal/day SD: 681 kcal/day	Mean: 2182 kcal/day SD: 577 kcal/day	Mean: 2694 kcal/day SD: 794 kcal/day	Mean percentage of the amount of under reporting for women: 10%, sd 10% - 444 kcal/day difference Correlation coefficients: 0.45	Mean percentage of the amount of under reporting for men: 12%, sd 11% - 852 kcal/day difference. Correlation coefficient: 0.28
Ferriolli et. al, 2010 [22]	EI UR when using FFQ in urban-living Brazilians age 60-75. Higher degree of UR in men	Under-reported energy intake by 12.6%	Under-reported energy intake by 19.7%	Under-reported energy intake by 12.6%	Under-reported energy intake by 19.7%	Under-reported energy intake by 12.6%	Under-reported energy intake by 19.7%

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Foster et. al, 2019 [13]	Compared with TEE, participants under-reported EI by 25 % (95 % limits of agreement −73 % to +68 %) in the first recall, 22 % (−61 % to +41 %) for average of first two, and 25 % (−60 % to +28 %) for first three recalls. UR evident for both genders.	Overall (both sexes): 11 670 (SD 2279·8) kJ/d 1 recall (n=50): 10,450 (SD 1588) 2 recall (n=40): 10,435 (SD 1562) 3 recall (n=29): 10,317 (SD 1601)	Overall: 11 670 (SD 2279·8) kJ/d 1 recall (n=48): 13,629 (1934) 2 recall (n=34): 13,586 (1950) 3 recall (n=24): 13,306 (1877)	Overall: 9240 (SD 4008·5) kJ/d 1 recall: 8008 (SD 3598) 2 recall: 8434 (3708) 3 recall: 8329 (3703)	Overall: 9240 (SD 4008·5) kJ/d 1 recall: 9799 (SD 4772) 2 recall: 10123 (SD 4185) 3 recall: 10190 (SD 4130)	Correlation EI and TEE 1 recall: 0.25 2 recall: 0.17 3 recall: 0.07	Correlation EI and TEE 1 recall: 0.22 2 recall: 0.29 3 recall: 0.19
Gemming et. al, 2015 [23]	EI UR when using 24h MPR and 24h MPRc. Wearable camera significantly reduced under-reporting for both women and men as compared to 24h MPR only.	Mean: 10,841 kJ/day SD: 1639 kJ/day	Mean: 14,485 kJ/day SD: 2632 kJ/day	Mean: 9,420 kJ/day SD: 1,694 kJ/day	Mean: 12,004 kJ/day SD: 2122 kJ/day	r= 0.82 for MP24 r= 0.81 for MP24+camera	r=0.68 for MP24 r= 0.61 for MP24+camera
Goran et. al, 1992 [24]	Self-reported energy intake underestimated total energy expenditure by 31% in women and 12% in men.	Mean: 2,092 kcal/day SD 231	Mean: 2,675 kcal/day SD: 394	Mean: 1,432 kcal/day SD: 410	Mean: 2,326 kcal/day SD: 249	Level of underrporting in women: 31% ± 18% Overall r=0.77	Level of undereporting in men: 12% ± 11% Overall r=0.77
Koebnick et. al, 2005 [25]	Under-reporting and over-reporting observed, ranging from -49% to 34%. NS differences between genders. Negative association between the difference in EI and TEE with BMI r = -0.385, P = 0.039.	Mean difference between EE and EI: 1.7 SD: 1.9	Mean difference between EE and EI: 1.6 SD: 3.2	Mean difference between EE and EI: 1.7 SD: 1.9	Mean difference between EE and EI: 1.6 SD: 3.2	Adjusted for body weight: r= 0.402, p-value= 0.049	Adjusted for body weight: r=0.604, p-value=0.037

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Livingstone et. al, 1990 [26]	When split into thirds of EI, the energy intake ratio of EI: TEE in the upper third was close to 1.0 with (mean (SE) 0.96 ±0.08 for women and 1.01 ±0.11 for men. (NS) Participants in middle and lower thirds of EI UR significantly, 0.89 ± 0.05 (P<0.05) and 0.61 ±0.07 (P<0.01) for women, 0.74 ±0.05 (P<0.05) and 0.70 ±0.07 (P<0.05) for men.	Mean: 9.93 MJ/day SD: 1.53	Mean: 14.23 MJ/day SD: 2.95	Mean: 8.00 MJ/day SD: 1.88	Mean: 11.21 MJ/day SD: 2.48	r=0.79, not disaggregtaed Energy intake/energy expenditure: 0.82 (0.21)	r=0.79, not disaggregtaed Energy intake/energy expenditure: 0.81 (0.22)
Lopes et. al, 2016 [27]	Significantly (P<0.05) more women (29%) than men (6%) UR EI using 24h MPR. NS difference between genders when using FR. NS difference between EI and TEE for men using both methods. No relationship to misreporting by sex, BMI or age.	Mean: 2411 kcal SD: 404	Mean: 2733 kcal SD: 449	24h MPR mean: 1395 kcal SD: 392 FR mean: 1611 kcal SD: 452	24h MPR mean: 2052 kcal SD: 513 FR mean: 2017 kcal SD: 548	24h MPR: r= 0.01, p-value= 0.98 FR: r=0.54, p-value=0.01	24h MPR: r= 0.05, p-value= 0.53 FR: r=0.59, p-value=0.01
Moshfegh et. al, 2008 [28]	Greater under-reporting of EI with higher BMI. 24h MPR may be useful for estimating EI in normal weight adults but there is a tendency to under-report as BMI increases.	Geometric mean: 2,190 kcal/day 95% CI: 2140,2242 Normal weight: 2070 (2007, 2135) Overweight: 2218 (2134, 2304) Obese: 2452 (2338, 2570)	Geometric mean: 2861 kcal/day 95% CI: 2795, 2928 Normal weight: 2596 (2506, 2690) Overweight: 2964 (2869, 3062) Obese: 3161 (3014, 3316)	Geometric mean: 1926 95% CI: 1851, 2005 Normal weight: 1953 (1870, 2040) Overweight: 1884 (1783, 1991) Obese: 1928 (1807, 2057)	Geometric mean: 2561 95% CI: 2461, 2666 Normal weight: 2593 (2464, 2729) Overweight: 2545 (2430, 2666) Obese: 2541 (2377, 2717)	Women: r= 0.25 P values not reported	Men: r= 0.32 P values not reported

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Mossavar-Rahmani et. al, 2015 [29]	Energy intake was underestimated by 25.3% (men, 21.8%; women, 27.3%) and having a higher BMI and being of Hispanic/Latino background were associated with underestimation of energy intake.	Age adjusted geometric mean: 2,170 kcal/day 95% CI: 2,128-2,213	Age adjusted geometric mean: 2,721 kcal/day 95% CI: 2,655-2,788	Age adjusted geometric mean: 1,579 kcal/day 95% CI: 1,513-1,647	Age adjusted geometric mean: 2,127 kcal/day 95% CI: 2,019-2,242	Overall r= 0.58	Overall r=0.58
Nybacka et. al, 2016 [30]	EI UR by both dietary assessment methods. FR may be more accurate in estimating EI in a group than FFQ.	Mean: 9.0 MJ 95% CI: 8.1-9.9	Mean: 12.5 MJ 95% CI: 11.5-13.6	FR mean: 7.3 MJ 95% CI: 6.5-8.1 FFQ mean: 7.4 MJ 95% CI: 6.2-8.6	FR mean: 9.3 MJ 95% CI: 7.9-10.7 FFQ mean: 9.5 MJ 95% CI: 7.8-11.2	FR r= 0.33 FFQ r= -0.05	FR r= 0.12 FFQ r= 0.17
Okubo et. al, 2008 [14]	EI/TEE ratio was significantly (P<0.05) lower for men than women. Significant (P<0.01) mean weight change in men by -23 ±55g/day	Mean: 8.3 MJ/day SD: 1.2	Mean: 10.7 MJ/day SD: 1.7	FFQ 1 mean: 7.7 MJ/day SD: 1.7 FFQ 2 mean: 7.4 MJ/day SD: 1.5	FFQ 1 mean: 8.8 MJ/day SD: 2.4 FFQ 2 mean: 8.9 MJ/day SD: 2.5	FFQ1 r= 0.22 (P>0.05) FFQ2 r= 0.11 (P>0.05)	FFQ1 r= 0.34 (P<0.01) FFQ2 r= 0.35 (P<0.01)
Orcholski et. al, 2015 [31]	Significant difference between EI and EE, by sites, most extreme difference for participants at the Sout African site.	USA: 9.8 ± 1.5 MJ/day Seychelles: 9.3 ± 1.6 MJ/day Jamaica: 8.7 ± 1.3 MJ/day South Africa: 9.7 ± 1.8 MJ/day Ghana: 10.0 ± 1.9 MJ/day	USA: 13.0 ± 2.9 Seychelles: 12.1 ± 1.9 Jamaica: 10.6 ± 1.9 South Africa: 10.0 ± 1.8 Ghana: 12.1 ± 1.9	USA: 7.9 ± 2.7 Seychelles: 7.1 ± 1.8 Jamaica: 7.0 ± 1.7 South Africa: 4.4 ± 1.2 Ghana: 7.6 ± 1.6	USA: 10.1 ± 3.5 Seychelles: 8.4 ± 2.1 Jamaica: 8.5 ± 2.4 South Africa: 4.4 ± 1.5 Ghana: 9.1 ± 1.8	Overall with the exception of South Africa (r 20·20), the correlation between TEI and TEE was consistent across the other four sites, ranging from 0·21	Overall with the exception of South Africa (r 20·20), the correlation between TEI and TEE was consistent across the other four sites, ranging from 0·21 to 0·28

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
						to 0·28 (mean of all sites r 0·27).	(mean of all sites r 0·27).
Park et. al 2018 [32]	Average weight change was -0.3% ±3.7 for men and 0.1 ±4.4 for women. All energy intakes were unreported when compared to the DLW method. Energy intake from ASA24 were comparable with 4DFR and both provided the best estimates for dietary intakes.	Geometric mean: 2136 kcal/day 25th-75th percentile: 1892-2382	Geometric mean: 2748 kcal/day 25th-75th percentile: 2439-3045	24 hr recall 3 ASA24s: 1807 (1528-2218) All ASA24s: 1821 (1529-2177) 4- day food record 4DFR-1: 1725 (1433-2084) 4DFR-2: 1727 (1476-2098) FFQ FFQ-1: 1516 (1204-1950) FFQ-2: 1404 (1119-1800)	24 hr recall 3 ASA24s: 2274 (1956-2749) All ASA24s: 2276 (1950-2750) 4- day food record 4DFR-1: 2244 (1891-2741) 4DFR-2: 2177 (1826-2671) FFQ FFQ-1: 1932 (1556-2407) FFQ-2: 1809 (1422-2329)	NR	NR

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Pfrimer et. al, 2015 [33]	Significant difference between ratio of EI and TEE for different body fatness in women but not in men. EI UR when using FFQ and 24h MPR. Women had greater tendency to UR in both dietary assessment methods. Higher body fatness associated, in older people, with higher rates of under-reporting, especially by women.	Mean: 2,220 kcal/day SD: 563	Mean: 2,627 kcal/day SD: 586	FFQ mean: 1,883 kcal/day SD: 662 24hr recall mean: 1,616 kcal/day SD: 604	FFQ mean: 2,380 kcal/day SD: 593 24hr recall mean: 2,253 kcal/day SD: 394	FFQ r= 0.19, P=0.221, 24hr: r= 0.25, P= 0.112 Not disaggregated	FFQ r= 0.19, P=0.221, 24hr: r= 0.25, P= 0.112 Not disaggregated
Ptomey et. al, 2015 [34]	Bias did not change with increasing energy intakes Mean weight change throughout study period was 0.29 ±0.98kg and 0.25 ± 1.2kg for women and men respectively (NS).	Mean: 2453 kcal/d SD: ± 608	Mean: 3236 kcal/d SD: 667	Mean: 2550 kcal/d SD: ± 423	Mean: 3267 kcal/d SD: ± 665	r = − 0.004, p = 0.98	r = − 0.35, p = 0.02
Redman et. al, 2014 [35]	both men and women significantly underreported energy intake by 350 kcal/d (12% and 15%, respectively; P , 0.0001	Mean: 2266.6 kcal/day SD: 255.6	Mean: 2850.6 SD:361.3	Mean: 1923.6 SD: 447.3	Mean: 2502.6 SD:503.6	R2: 0.34 r: 0.58	R2: 0.34 r: 0.58

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Rothernberg et. al, 1998 [36]	Mean EI/TEE ratio: 0.88 ± 0.22. DH appears to underestimate true EI by 12%	Participants with DLW measure: 2 - 9.53 MJ/day 4 - 8.55 5 - 10.43 6 - 10.04 7 - 10.36 8 - 11. 44 9 - 9.91 10 - 8.00 11 - 8.13 Calculated mean: 9,598.90 kJ/day SD: 1,160.30 kJ/day	Participants with DLW measure: 14 - 8.80 19 - 10.69 20 - 12.89 Calculated mean: 10,793.33 kJ/day SD: 2,047.00 kJ/day	DH for participants with a DLW measure: 2 - 7.56 4 - 5.60 5 - 10.75 6 - 6.87 7 - 8.13 8 - 5.94 9 - 10.79 10 - 8.93 11 - 7.51 Calculated mean: 8,008.90 kJ/day SD: 1,868.90 kJ/day	DH for participants with a DLW measure: 14 - 11.11 19 - 8.57 20 - 11.66 Calculated mean: 10,446.70 kJ/day SD: 1,648.34 kJ/day	NS correlation between EI and TEE r= 0.27.	NS correlation between EI and TEE r= 0.27.
Schulz L et. al, 1994 [37]	There were no significant correlations between EI estimates with both methods and measures of body size. FFQs and 24h recalls both UR and have comparable accuracy in assessing EI in Native American populations.	Mean: 11.67 MJ/day SD: 1.84	Mean: 13.27 MJ/day SD: 2.96	FFQ: 9.40 MJ.day SD: 2.61 24h recall: 9.29 MJ/day SD: 2.78	FFQ: 12.84 MJ/day SD: 2.84 24h recall: 13.60 MJ/day SD: 7.81	FFQ: r= 0.48, P =0.03 24hr: r= 0.64, p = 0.03	FFQ: r= 0.48, P =0.03 24hr: r= 0.64, p = 0.03
Seale et. al, 2002 (1) [39]	EI was significantly lower (25 ± 15%) than TEE. difference in TEE EE between the women (21 ± 15%) and men (29 ± 13%)	Mean: 9.55 MJ/day SD: ± 0.70 (8.20–10.90)	Mean: 12.85 MJ/day SD: ± 1.47 (9.66–15.90)	Mean: 7.49 MJ/day SD: ± 1.52 (4.77–12.13)	Mean: 9.22 MJ/day SD: ± 2.15 (4.80–13.16)	NR	NR

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure-Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Seale et. al, 2002 (2) [40]	EI (men: 8.66 ± 2.34 MJ, women: 7.12 ± 0.93 MJ) was significantly less than TEE (men: 12.43 ± 1.63 MJ, women: 9.44 ± 0.90 MJ)	Mean: 9.44 MJ/day SD: 0.90	Mean: 12.43 MJ/day SD: 1.63	Mean: 7.12 MJ/day SD: 0.93	Mean: 8.66 MJ/day SD: 2.34	NR	NR
Seale et. al, 1997 [38]	EI was significantly less the EE by 18% in women and 30% in men.	Mean: 9.57 MJ/day SD: 0.47	Mean: 12.91 MJ/day SD: 1.15	Mean: 7.88 MJ/day SD: 1.94	Mean: 8.96 MJ/day SD: 1.38	NR	NR
Subar et. al, 2003 [41]	Under-reporting tended to increase with BMI. Under-reporting tends to increase with increased EE. Under-reporting of EI is higher with FFQ compared to 24h MPR. Women UR EI to a greater extent than men for both methods.	Geometric mean: 2,277 kcal 95% CI: 2,226-2,329	Geometric mean: 2,849 kcal 95% CI: 2,788, 2,912	24HR 1 geometric mean: 1,919 95% CI: 1,833, 2,009 24HR 2 geometric mean: 1,814 95% CI: 1,732, 1,899 DHQ1: 1,514 95% CI: 1,438, 1,594 DHQ2: 1,405 95% CI: 1,333, 1,481	24HR 1 geometric mean: 2,512 95% CI: 2,416, 2,610 24HR 2 geometric mean: 2,436 95% CI: 2,338, 2,537 DHQ1: 1,959 95% CI: 1,863, 2,061 DHQ2: 1,818 95% CI: 1,727, 1,914	24hr: r= 0.39, FFQ: r= 0.19,	24hr: r =0.24 FFQ: Men r= 0.10
Svendsen et. al, 2006 [42]	NS differences by gender for reported EI relative to TEE. Mean weight change in all participants 0·1kg ±1·0 (range -3·6 to 1·8kg). WFR and FFQs UR EI in obese men and women.	FFQ Relative to TEE 20.6% (SD: 24.1) under-reported EI WFR Relative to TEE 31.0% (SD: 22) under-reported EI	FFQ Relative to TEE 14.1% (SD: 18.9) under-reported EI WFR Relative to TEE 27.9% (SD:14.4) under-reported EI	FFQ Relative to TEE 20.6% (SD: 24.1) under-reported EI WFR Relative to TEE 31.0% (SD: 22) under-reported EI	FFQ Relative to TEE 14.1% (SD: 18.9) under-reported EI WFR Relative to TEE 27.9% (SD:14.4) under-reported EI	NR	NR

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure-Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Takae et. al 2019 [43]	This study focused on protein intake and physical activity on fat free mass. They found that either increased protein intake or increased physical activity improves fat free mass.	Mean: 1734 kcal/day SD: 260 kcal/day	Mean: 2126 kcal/day SD: 440 kcal/day	Mean: 1704 kcal/day SD: 240 kcal/day	Mean: 2066 kcal/day SD: 349 kcal/day	NR	NR
Tomoyasu et. al, 1999 [45]	93% of men and 83% of women under-reported energy intake	Mean: 8354 KJ/day SEM: 257 SD: 1685	Mean: 11303 KJ/day SEM: 354	Mean: 6867 SEM: 255	Mean: 8731 SEM: 318	NR	NR
Tomoyasu et. al, 2000 [44]	Older African-American men and women under-reported total energy intake to a modest degree and there were no gender differences in the magnitude of the misreporting	Mean: 8744 KJ/day SD: 1695	Mean: 11321 KJ/day SD: 1840	Mean: 7891 KJ/day SD: 2240	Mean 9749 KJ/day SD: 3793	NR	NR

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Warwick et. al, 1996 [46]	Comparing EE to an intake balance (IB) measure (which incorporated EI). IB was 13.8% different to DLW for smokers and 6.2% different to DLW for non-smokers.	Smokers: 1. 10.184 KJ.d 2. 8634 3. 11067 4. 10813 5. 10151 6. 11866 Non-smokers: 12. 11434 13. 6225 14. 8087 15. 10243 16. 9826 17. 8807 Calculated mean: 9,778.10 kJ/day SD: 1,598.07 kJ/day	Smokers: 7. 12351 8. 15180 9. 13549 10. 14302 11. 14174 Non-smokers: 18. 13691 19. 12353 20. 10552 21. 14997 Calculated mean: 13,461 kJ/day SD: 1,479.55	Smokers: 1. 6784 2. 8287 3. 9096 4. 7604 5. 7797 6. 8460 Non-smokers: 12. 10598 13. 8618 14. 7952 15. 7686 16. 7504 17. 9005 Calculated mean: 8282.60 kJ/day SD: 986.40	Smokers: 7. 12187 8. 11110 9. 12953 10. 9640 11, 12235 Non-smokers: 18. 10336 19. 10911 20. 11351 21. 13235 Calculated mean: 11,550 kJ/day SD: 1,196.14	NR	NR
Watanabe et. al, 2019 [47]	EI assessed by FFQ and DR were both significantly lower than TEE. The ratio of EI to EE was significantly and negatively correlated with body mass index.	Mean: 1955 kcal/day SD: 284	Mean: 2368 kcal/day SD: 430	7-day diet recall: Mean: 1815 kcal/day SD: 205 FFQ: Mean: 1619 SD: 341	7-day diet recall: Mean: 2105 kcal/day SD: 302 FFQ: Mean: 1905 SD: 546	7-day diet recall: Pearson's correlation coefficient: 0.09 Spearman's correlation coefficient: 0.08 FFQ: Pearson's: 0.19 Spearman's: 0.12	7-day diet recall: Pearson's correlation coefficient: 0.35 Spearman's correlation coefficient: 0.34 FFQ: Pearson's: 0.30 Spearman's: 0.33

		Energy expenditure		Energy intake		Accuracy	
Reference	**Summary of main findings**	**Mean Energy Expenditure- Females**	**Mean Energy Expenditure- Males**	**Mean energy intake - Females**	**Mean energy intake - Males**	**Measures of accuracy (comparison of EI to EE) for females (e.g. correlation coefficients)**	**Measures of accuracy (comparison of EI to EE) for males (e.g. correlation coefficients)**
Y = years, SD = standard deviation, DLW = Doubly labelled water, FFQ= food frequency questionnaire. BMI = body mass index, MPR= multiple pass record, DH= diet history, FR= Food record, WFR= weighed food record, NR= Not reported, PDA= personal digital assistant, DR: dietary record.							

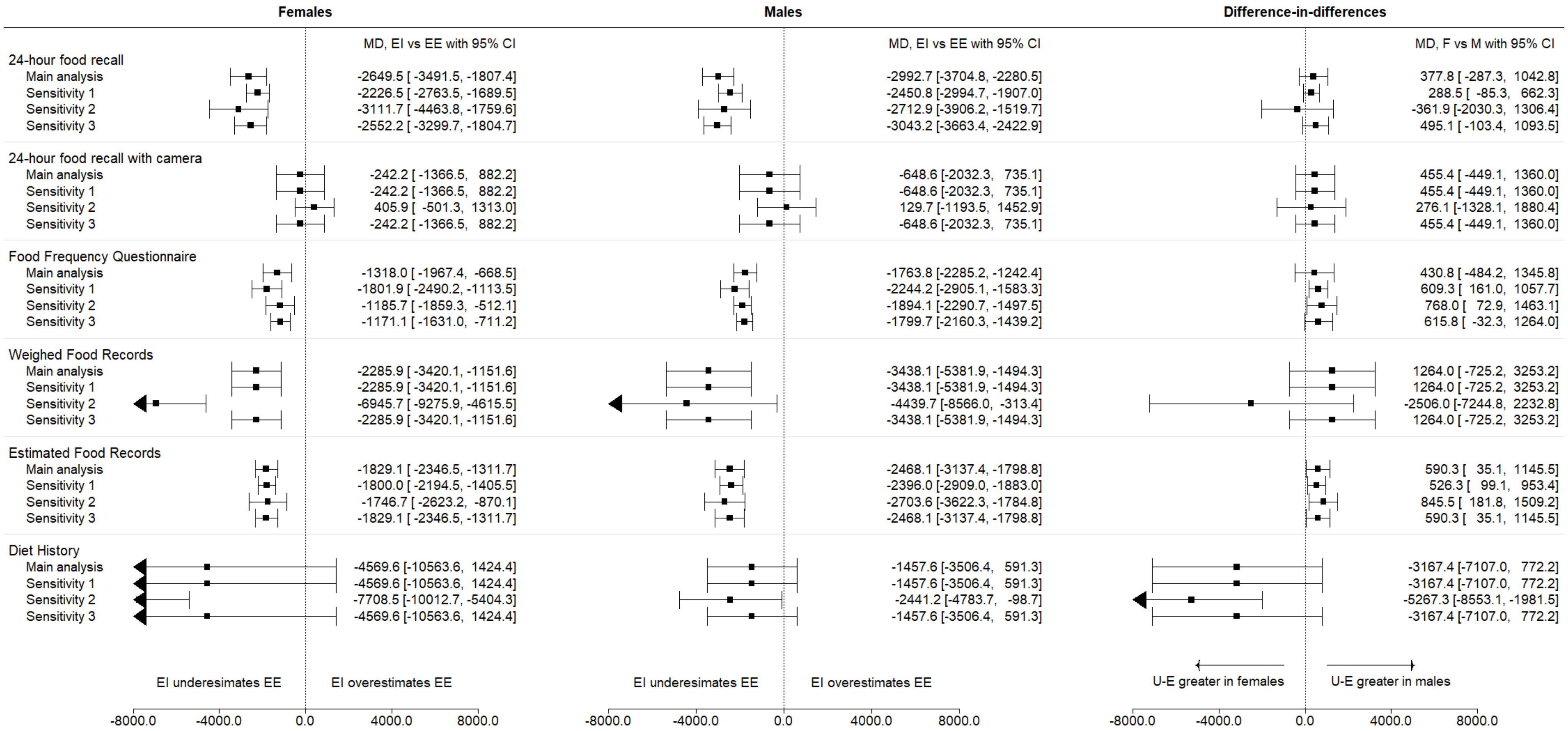
Supplementary table 2. Mean of extracted correlation coefficients between total energy expenditure and total energy intake for females and males, by dietary assessment method

Dietary assessment type	Mean correlation, females	Mean correlation, males
24-hour diet recall	0.31	0.30
24-hour diet recall, with camera	0.40	0.13
Diet history	0.59	0.59
Food frequency questionnaire	0.21	0.27
Weighed food record	0.68	0.62
Estimated food record	0.46	0.51
Overall mean of correlation	**0.39**	**0.39**

Supplementary figure 1. Quality assessment of included studies

Criteria: Q1: Was the research question clearly stated? Q2: Was the selection of study participants/patients free from bias? Q3: Were study groups comparable? Q4: Was method of handling withdrawals described? Q5: Were intervention/therapeutic regimens/exposure factor or procedure and any comparison(s) described in detail? Q6: Were outcomes clearly defined and the measurements valid and reliable? Q7: Was the statistical analysis appropriate? Q8: Were conclusions supported by results with biases and limitations? Q9. Is bias due to study's funding or sponsorship unlikely?

Abbreviations: 24HDR: 24-hour diet recall FFQ: Food frequency questionnaire WFR: Weighed food record EFR: Estimated food record DH: Diet history

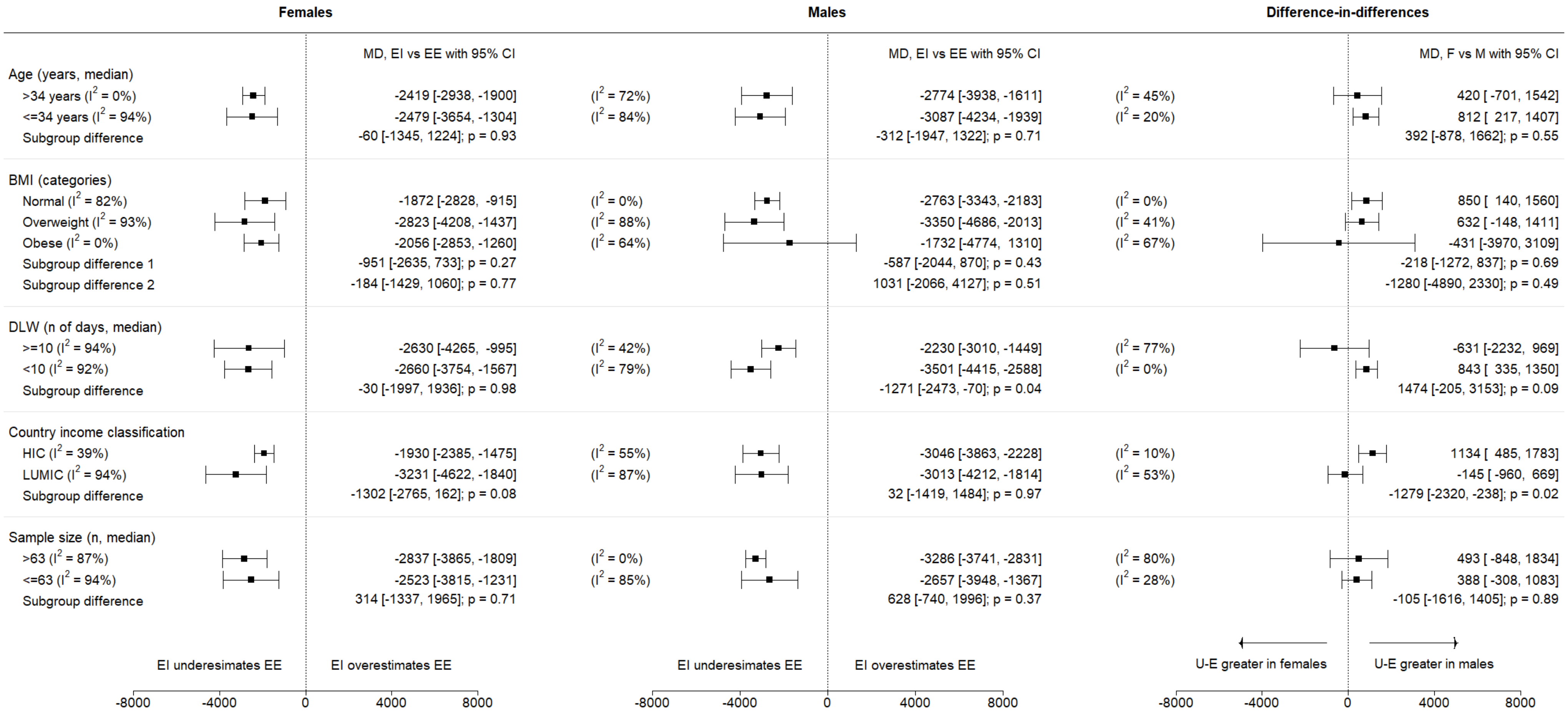


Supplementary figure 2. Sensitivity analyses for the mean difference between energy intake (EI) measured by 24-hr diet recalls and energy expenditure (EE) measured by doubly labelled water, for (a) females, (b) males and (c) the difference in mean differences between females and males.

Sensitivity 1: Inclusion of studies that reported geometric means (converted for meta-analysis to raw means and standard deviations)

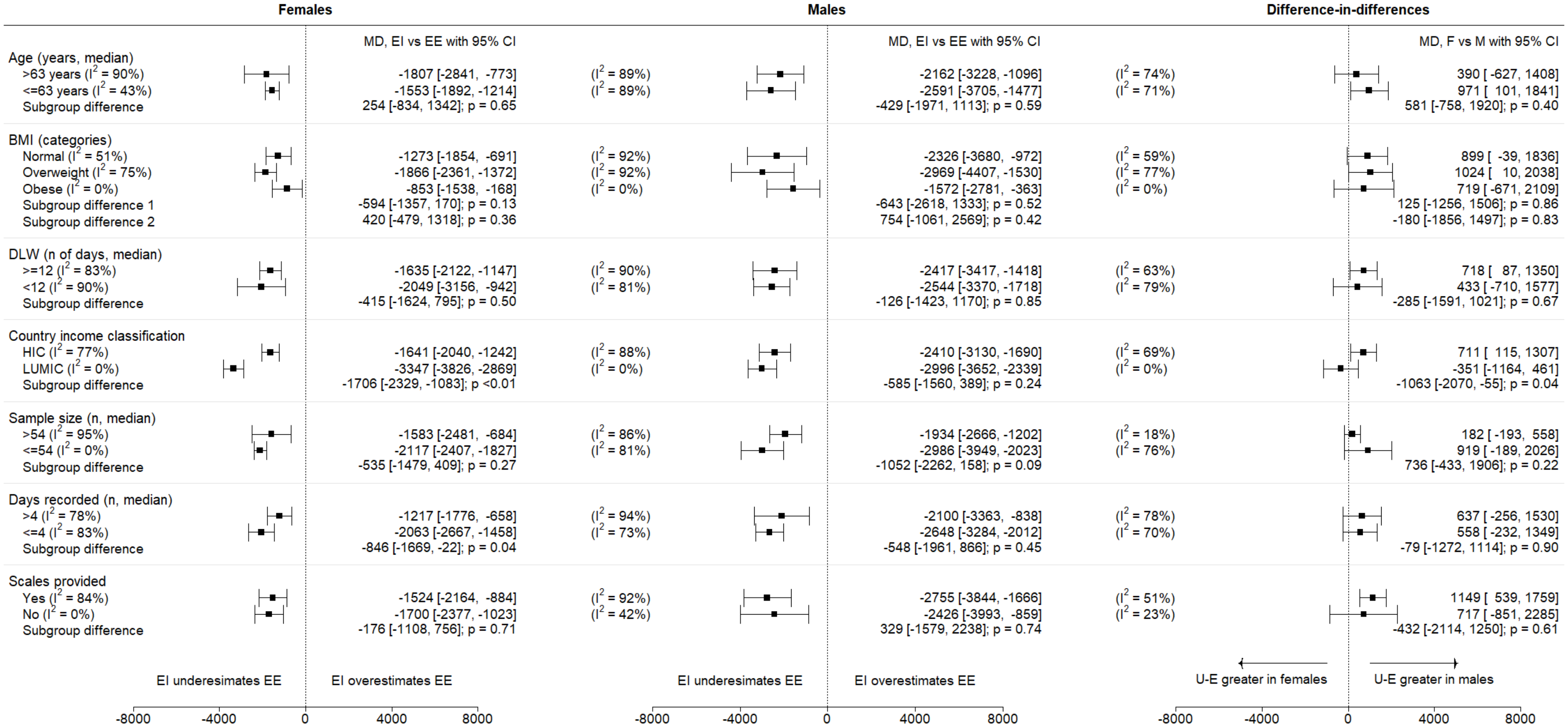
Sensitivity 2: Inclusion of studies that were assessed as of "positive" quality only

Sensitivity 3: Inclusion of the different mean measures of energy intake for the Foster et al and Okubo et al studies

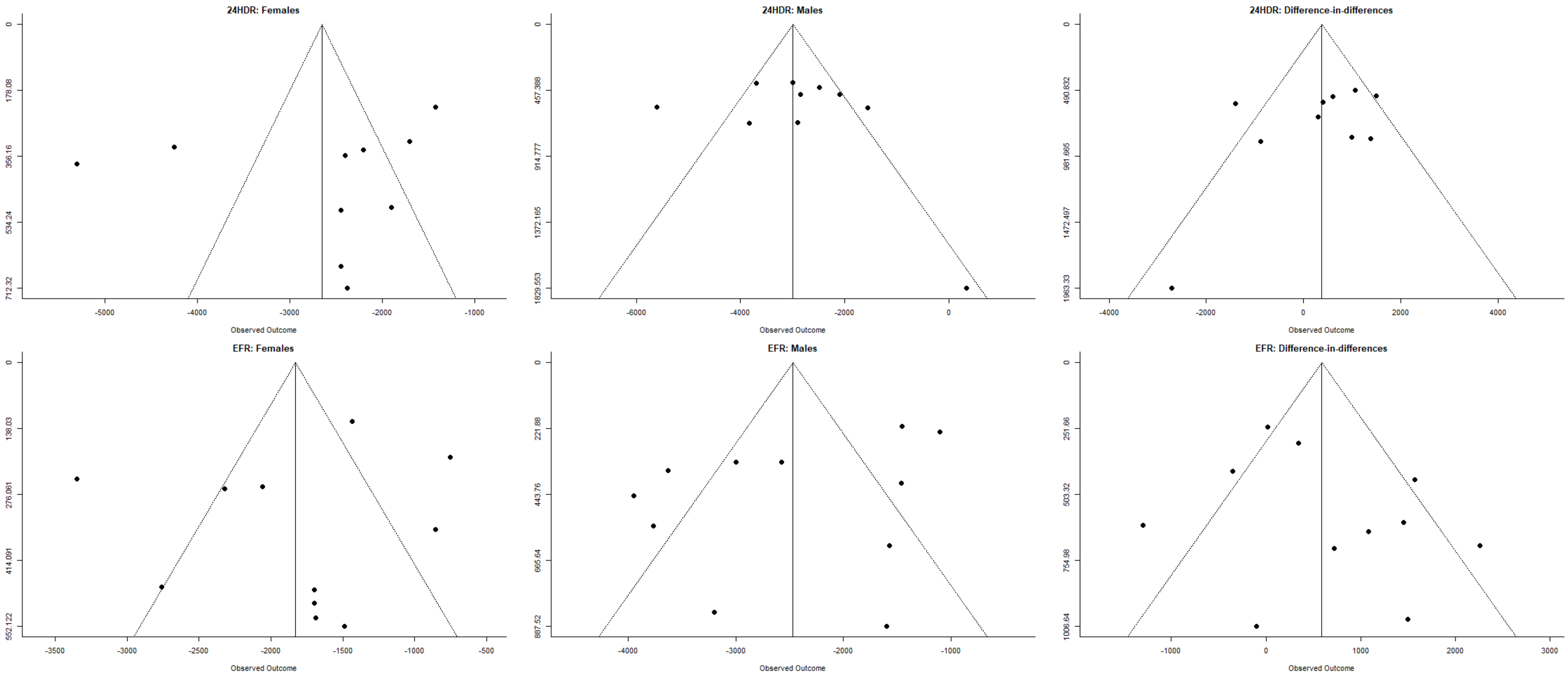


Supplementary figure 3. Subgroup analyses for the mean difference between energy intake (EI, kJ/day) measured by 24-hr diet recalls and energy expenditure (EE, kJ/day) measured by doubly labelled water (DLW), for (a) females, (b) males and (c) the difference in mean differences between females and males.

*The same studies were included in the subgroup analysis exploring number of 24-hr diet recalls (less than or equal to two, compared to greater than two) as the analysis for length of doubly labelled water collection, that is studies with less than or equal to two 24-hr diet recalls had a DLW collection period of less than 10 days. As such the results for these subgroup analyses are the same, and only the DLW analysis is shown.



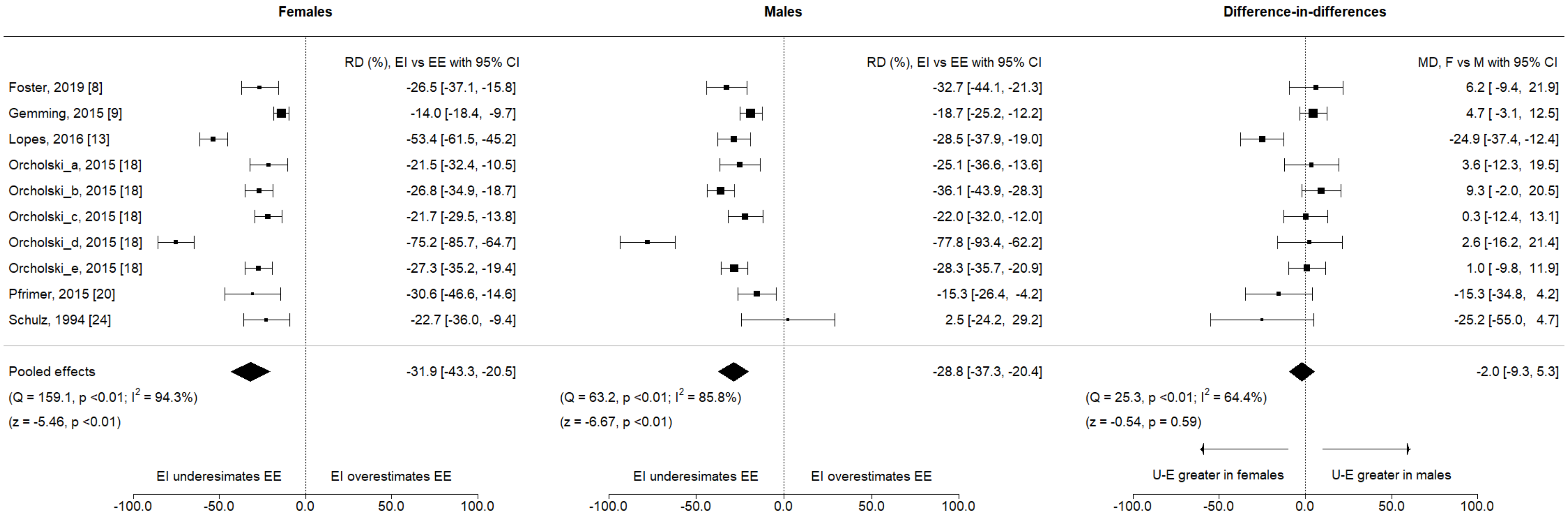
Supplementary figure 4. Subgroup analyses for the mean difference between energy intake (EI, kJ/day) measured by estimated food records and energy expenditure (EE, kJ/day) measured by doubly labelled water (DLW), for (a) females, (b) males and (c) the difference in mean differences between females and males.



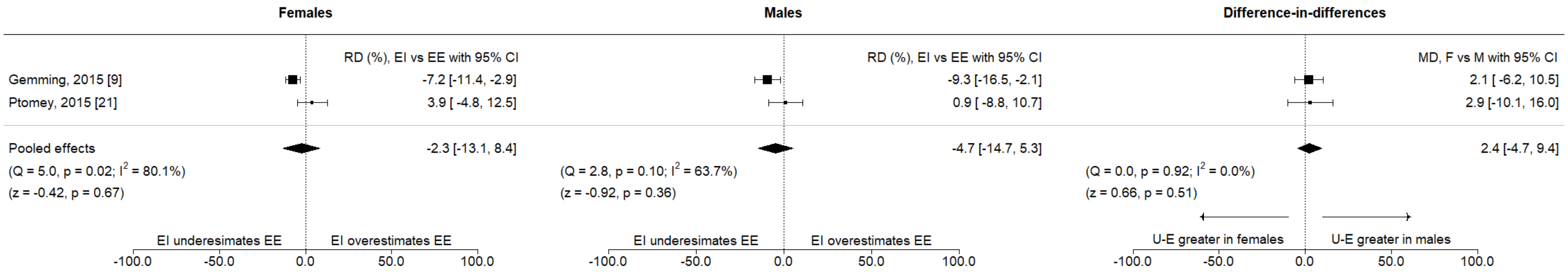
Supplementary figure 5. Assessment of publication bias for studies using 24-hour diet recalls (24HDR) or estimated food records (EFR) compared to energy expenditure measured by doubly labelled water

Supplementary figure 6. Estimated percent differences in energy intake compared to energy expenditure, within and between sexes, by dietary assessment method

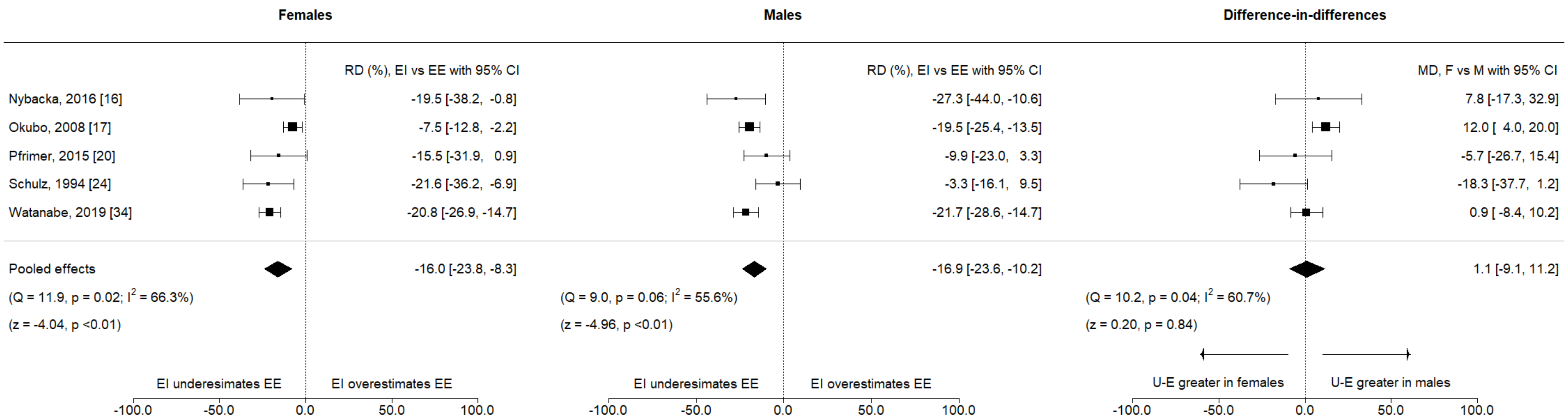
(a) 24-hour diet recall



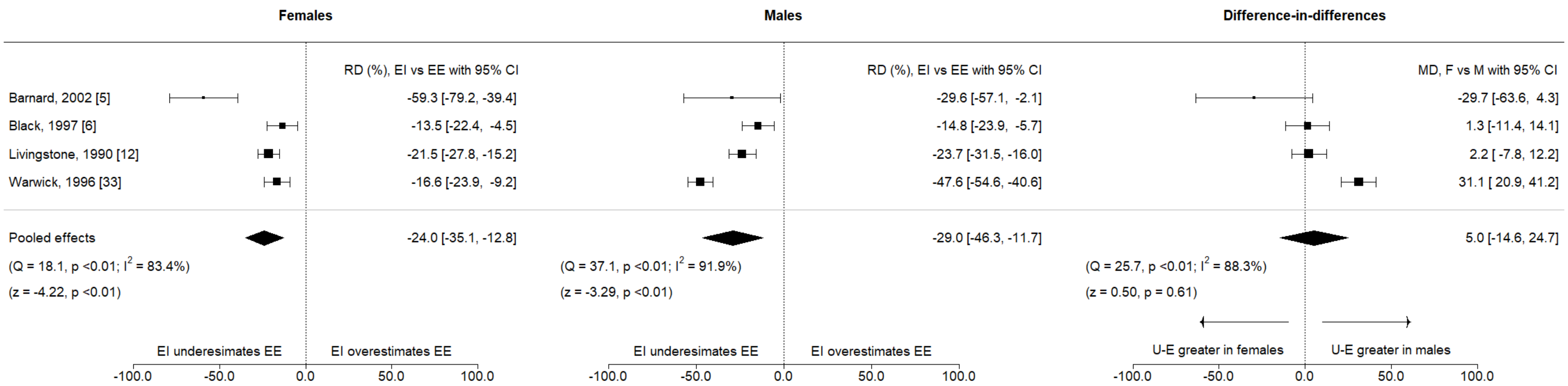
(b) 24-hour diet recalls, supplemented with photography of foods consumed



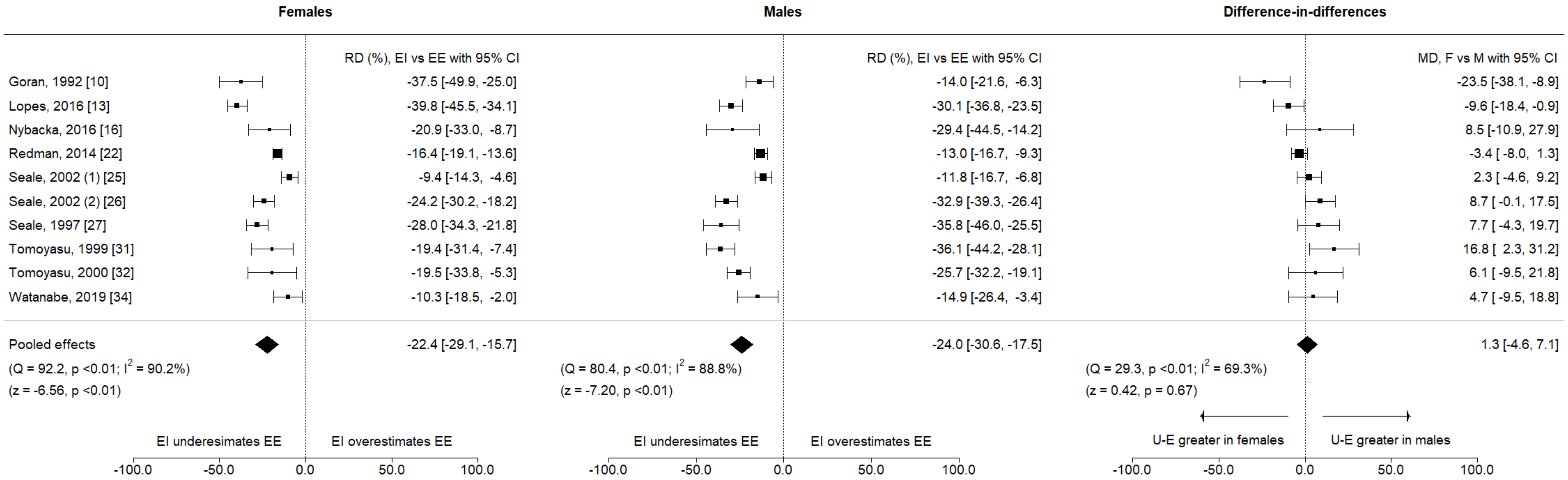
(c) Food frequency questionnaires



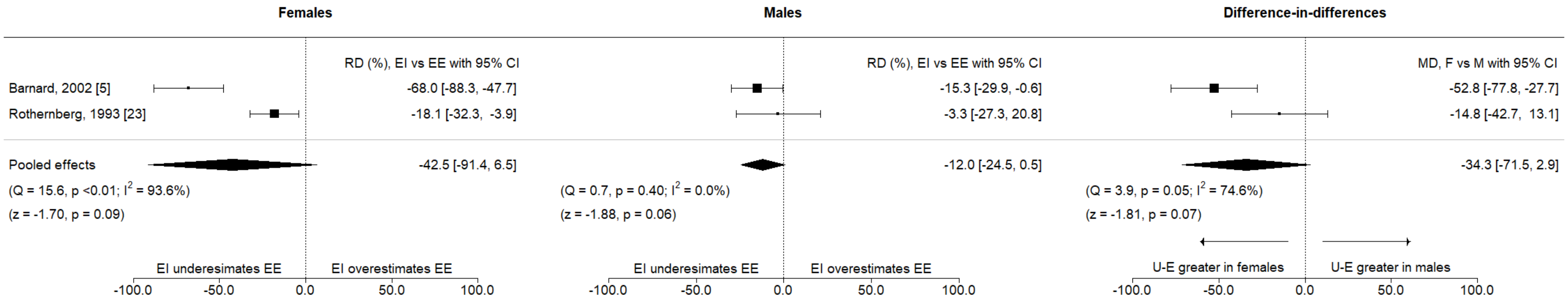
(d) Weighed food records



(e) Estimated food records



(f) Diet histories



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Chapter 4. Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: A cross-sectional study of nationally representative surveys in seven low- and middle-income countries

4.1 Chapter overview

This chapter consists of an analysis of sex differences in dietary behaviours (fruit and vegetable intake, salt use and type of fat and oil used in cooking) and cross-sectional associations between behaviours and cardiometabolic risk factors and disease (having hypertension, diabetes, or a high waist circumference), across seven LMICs. This chapter consists of a published manuscript.

This study used data from seven nationally representative surveys, from Bhutan, Eswatini, Georgia, Guyana, Kenya, Nepal and St Vincent and the Grenadines. These countries are in five different regions of the world (South Asia, Southern Africa, Europe, South America, East Africa and the Caribbean). While they are all LMICs, they differ in resource levels and have different food environments, with differing levels of reliance on imported processed foods (*see the discussion section of this chapter*). These countries were included in this study, given they all had World Health Organization STEPwise approach to surveillance (WHO STEPS) surveys conducted that included questions on salt use behaviour, fruit and vegetable consumption and type of oil used in cooking (*see methods section "Classification of dietary behaviour" within this chapter for specifics on diet behaviour questions*). WHO STEPS surveys are designed for the surveillance of NCD risk. They are nationally representative surveys, based on standardised methodology, developed by WHO with expert consultation for aspects of the survey. WHO STEPS covers three areas: demographic and behavioural information (including questions on diet behaviour); physical measurements (for example blood pressure); and biochemical measurements (for example blood glucose). The dietary behaviours included within this chapter were the only dietary behaviours consistently reported on by countries, at the time of data analyses. While there were some sex differences identified in dietary behaviours and in cross-sectional associations between dietary behaviours and cardiometabolic outcomes, the magnitude of these differences was small. Instead, what the study highlighted was poor fruit and vegetable consumption and salt use behaviour across countries. While the findings do not suggest the need for tailoring of diet interventions by sex in the included countries, the findings may have been limited by the general lack of adherence to fruit and vegetable recommendations and positive (good) salt use behaviours. Further, this study was limited by the cross-sectional nature of the analysis, with both dietary behaviour and presence of cardiometabolic risk factors and disease information collected at the same time point. This limitation is addressed in chapter 5, which presents findings on the association between dietary intake and prospectively collected health outcome data from a large cohort study.

4.2 Publication details

McKenzie BL, Santos JA, Geldsetzer P, Davies J, Manne-Goehler J, Gurung MS, Sturua L, Gathecha G, Aryal KK, Tsabedze L, Andall-Brereton G, Bärnighausen T, Atun R, Vollmer S, Woodward M, Jaacks LM, Webster J. Evaluation of sex differences in dietary behaviours and their relationship with cardiovascular risk factors: a cross-sectional study of nationally representative surveys in seven low- and middle-income countries. *Nutrition Journal*. 2020 Dec;19(1):1-5.

4.2.1 Author contributions

As the first author on this publication, I contributed significantly to this piece of work. I conceived the research question and developed the research plan in collaboration with the senior authors (LMJ and JW). I led the statistical analysis, with support when needed from author JAS. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors and from journal reviewers. Approval was provided for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows (and as published): BLM, LMJ and JW conceived the research question and research plan for this analysis. MSG, LS, GG, KKA, LT and GA-B provided essential materials (datasets necessary for the research). BLM and JAS performed the statistical analysis. BLM wrote the first draft of the manuscript. All authors provided feedback on the manuscript and approved the final version.

4.3 Manuscript

Abstract

Background

Cardiovascular diseases (CVD) are the leading causes of death for men and women in low-and-middle income countries (LMIC). The nutrition transition to diets high in salt, fat and sugar and low in fruit and vegetables, in parallel with increasing prevalence of diet-related CVD risk factors in LMICs, identifies the need for urgent action to reverse this trend. To aid identification of the most effective interventions it is crucial to understand whether there are sex differences in dietary behaviours related to CVD risk.

Methods

From a dataset of 46 nationally representative surveys, we included data from seven countries that had recorded the same dietary behaviour measurements in adults; Bhutan, Eswatini, Georgia, Guyana, Kenya, Nepal and St Vincent and the Grenadines (2013-2017). Three dietary behaviours were investigated: positive salt use behaviour (SUB), meeting fruit and vegetable (F&V) recommendations and use of vegetable oil rather than animal fats in cooking. Generalized linear models were used to investigate the association between dietary behaviours and waist circumference (WC) and undiagnosed and diagnosed hypertension and diabetes. Interaction terms between sex and dietary behaviour were added to test for sex differences.

Results

24,332 participants were included. More females than males reported positive SUB (31.3 vs. 27.2% p-value <0.001), yet less met F&V recommendations (13.2 vs. 14.8%, p-value<0.05). The prevalence of reporting all three dietary behaviours in a positive manner was 2.7%, varying by country, but not sex. Poor SUB was associated with a higher prevalence of undiagnosed hypertension for females (13.1% vs. 9.9%, p-value=0.04), and a higher prevalence of undiagnosed diabetes for males (2.4% vs. 1.5%, p-value=0.02). Meeting F&V recommendations was associated with a higher prevalence of high WC (24.4% vs 22.6%, p-value=0.01), but was not associated with undiagnosed or diagnosed hypertension or diabetes.

Conclusion

Interventions to increase F&V intake and positive SUBs in the included countries are urgently needed. Dietary behaviours were not notably different between sexes. However, our findings were limited by the small proportion of the population reporting positive dietary behaviours, and further research is required to understand whether associations with CVD risk factors and interactions by sex would change as the prevalence of positive behaviours increases.

Trial Registration Not applicable

Background

Cardiovascular diseases (CVD) are the leading causes of death for men and women in low- and middle-income countries [1, 2]. Current evidence suggests that this burden is partly the result of a rapid nutrition transition [3-5], and consequent increases in cardiovascular risk factors, including obesity [6], diabetes [7], and hypertension [8]. Earlier systematic reviews and prospective cohort studies have provided evidence of the effect of dietary factors, such as high salt intake [9, 10], low consumption of fruits and vegetables [11-14], and the increased consumption of trans- and saturated fat in place of mono- and poly-unsaturated fat [12, 13, 15-17] on increased cardiovascular risk.

The weight of the evidence demonstrating the burden of ill health due to diets high in salt [9, 10], low in fruits and vegetables [11-14], and high in trans- and saturated fats [12, 13, 15-17] has enabled the development of global targets and recommendations by the World Health Organization (WHO) to reduce dietary risks for CVD, and non-communicable diseases (NCD) more broadly. The WHO Global NCD Action Plan [18] specifies targets to reduce population salt intake by 30%, and for adults to consume at least 400 g of fruit and vegetables a day (approximately five servings a day). There are also global targets to eliminate the use of trans-fats [19] and a recommendation to reduce the intake of saturated fats, aiming for intake to be 10% or less of total energy intake [20]. In order to monitor population-level NCD risk factors, including dietary behaviours, the WHO has supported the implementation of national surveys called the "STEPwise approach to surveillance" or "STEPS" [21]. These surveys contain questions on dietary behaviours such as salt use, fruit and vegetable consumption, and type of fat and oil used in cooking. Analysis of these surveys can inform country-specific strategies for reducing NCD risk, on reduction of dietary risk.

In the past decade a growing body of high-quality research has identified differing impacts of non-dietary cardiovascular risk factors, such as high systolic blood pressure, diabetes and smoking, on disease outcomes for men and women [22, 23]. There is evidence from studies conducted in high income countries that self-reported dietary behaviours differ for men and women [24, 25]. However, there is a dearth of similar research from low-and-middle income countries, and on potential differences in the association between dietary behaviours and disease outcomes by sex. Given the Sustainable Development Goals (SDG) of achieving good health and well-being (SDG 3) and gender equality (SDG 5) [26], it is important to investigate sex differences in dietary behaviours and any relationship with health outcomes in a global setting to inform nutrition interventions and thereby reduce the burden of CVD and its adverse financial consequences [27].

The objectives of this study were to use individual-level data from nationally representative surveys to investigate sex differences in (1) the dietary behaviours of salt use, fruit and vegetable consumption and type of oil and fat used in cooking, and (2) the association of these behaviours with the prevalence of three key CVD risk factors: high waist circumference, hypertension and diabetes. Given the hypothesis that disease diagnosis may change behaviour, and therefore those with diagnosed disease may be more likely to report more positive dietary behaviours [28], investigation of associations with both undiagnosed and diagnosed hypertension and diabetes were conducted.

Methods

Data sources

This study utilised data from nationally representative surveys conducted in Bhutan, Eswatini, Georgia, Guyana, Kenya, Nepal and St Vincent and the Grenadines; all upper-middle, lower-middle, or low-income countries [29] at the time the surveys were conducted. The method of data acquisition and pooling have previously been described [30-32]. In brief World Health Organization (WHO) Stepwise Approach to Surveillance (STEPS) surveys [33] conducted in low, low- middle, or upper-middle income countries since 2005 were searched for. The search was limited to surveys conducted since 2005, as these studies were considered contemporary enough to be included in the same analysis. WHO STEPS surveys use a standardised questionnaire and protocol to monitor non-communicable disease risk at a population level, with the questionnaire comprising three steps: step one “behavioural measurements”, step two “physical measurements” and step three “biochemical measurements” [21, 33, 34]. Survey contacts were approached for the de-identified individual level data to be pooled for analyses. Data was pooled if signed agreement was made and they had a response rate ≥50%; participants were aged 15 years or older; included data on waist circumference, and/or a biomarker for diabetes (either a glucose measurement or HbA1c), and/or a measurement of blood pressure. For the current analyses surveys were included if questions on salt behaviour, fruit and vegetable intake, and the use of fats and oils for cooking were asked, seven out of 46 surveys. The surveys used a two-stage cluster random sampling design, with one person from each household (within the defined age range) randomly selected to complete the survey. All surveys were carried out by a trained data collection team member in the household setting, or at a conveniently-located health center and data on the three questionnaire steps were collected during the same visit.

Terminology – Sex - gender

A person’s sex is recorded in the WHO STEPS surveys by the interviewer documenting the observed sex of the participant (binary, male or female) [21]. While acknowledging that the self-report of dietary behaviours is likely to be influenced by a person’s identity and social constructs, and therefore also related to a person’s gender, to be in line with the data collected, the term “sex”, and corresponding terms “male” and “female”, are used throughout this paper [35].

Classification of dietary behaviours

Diet behaviours [36] of salt use, fruit and vegetable consumption and type of oil and fat used in cooking are included within “Step 1 – Behavioural Measurements” of the questionnaire, and are the only dietary behaviour variables included in STEPS [21]

Salt use behaviours

There are seven salt use behaviour questions included in STEPS [21]: 1. *How often do you add salt or salty sauce such as soy sauce to your food right before you eat it or as you are eating it?* 2. *How often is salt, salty seasoning or a salty sauce added in cooking or preparing foods in your household? Do you do any of the following on a regular basis to control your salt intake:* 3. *Limit consumption of processed foods?* 4. *Look at the salt or sodium content on food labels?* 5. *Buy low salt/sodium alternatives?* 6. *Use spices other than salt when cooking?* 7. *Avoid eating foods prepared outside of a home?* The first two questions used a 5-point Likert response scale with options of: always, often, sometimes, rarely, or never. These answers were assigned a value of 0, 0.25, 0.5, 0.75 or 1, respectively. The other five questions used a "yes" or "no" response, which was assigned a value of 1 and 0, respectively. To investigate the prevalence of positive (good) compared to poor salt used behaviour, the response values for all the seven questions were summed, and individuals with a score of 0.5 (50%) or greater were labelled as having positive (good) salt use behaviour. Another method of scoring salt use behaviour and categorising into positive vs. poor behaviour was not identified in the literature, and therefore other options of quantification were tested. These included an ordinal 4-point score (categorising into of 25%, 50%, 75% and 100% of the salt behaviour questions answered positively) and a 7-point score ("1" being one question answered positively, through to "7", being all questions answered positively). Given the low prevalence of positive salt use behaviour the 50% cut-off was used in the main analyses, with the 4-point score and 7-point score used in sensitivity analyses for the association of salt use behaviour with undiagnosed hypertension.

Fruit and vegetable intake

In the surveys, participants were asked to report the number of days per week they consume fruits and vegetables. If participants reported that they consumed fruits or vegetables on one or more days a week, they were then asked to state on any given day how many portions of fruits and vegetables they consume. To aid their response, they were shown pictures of local fruits and vegetables to refer to as a portion, corresponding to approximately 80 g. Fruit and vegetable intake (per day) was then calculated using the methods of Frank S et al [31]. Briefly, individuals were categorised as meeting, or not meeting, the fruit and vegetable recommendations, based on the WHO- recommendation of five 80 g portions of fruit and vegetables, or more, on a given day, equivalent to 400 g or more a day [18].

Oil and fat use

Participants were asked to pick the main oil or fat used to prepare meals in their home. Options, specific to the types of oils and fats used in each country, were provided to the participant. Responses were categorized as: vegetable, animal, other, none in particular, or none used. For analysis, this was further collapsed into vegetable oil, all other oils and fats, and no fat or oil used, given the small number of individuals who reported using other types of fats and oils or no use of fats or oils. "Vegetable oil" was used as the reference (or "positive behaviour") category, based on evidence that suggests plant-based oils are protective for heart health [13, 17].

Classification of cardiovascular risk factors

Waist circumference

Waist circumference in each survey was conducted following the STEPS data collection manual [37]. Data collectors used constant tension tape to measure waist circumference directly against the participant's skin where possible, or over light clothing if direct contact was not possible. Measurement was taken with a participant in a standing position, with arms relaxed at their sides and at the end of a normal expiration. The point of measurement was the midpoint between the lower section of the last palpable rib and the top of the hip bone. Waist circumference was then recorded to the nearest 0.1 cm, and only one measurement per participant was recorded. Participants were classified as having a "high waist circumference" if their measured value was ≥102 cm for males and ≥88 cm for females [38].

Hypertension

Detailed country-specific methods of blood pressure measurement are described elsewhere [32]. Briefly, the included surveys followed the STEPS data collection manual [37], which specifies measures to be conducted using digital, automated upper arm monitors, following 15 minutes of rest. The majority of participants had three blood pressure readings taken, with three minutes rest between each measure. The average of the last two readings were then taken. For individuals with only two measures, the mean of both available measurements was taken; for individuals with only one measure that measure was taken. A person was classified as having hypertension if their average systolic blood pressure (SBP) measurement was greater than 140mmHg, or their average diastolic blood pressure (DBP) measurement was greater than 90mmHg, or they reported taking medication for hypertension. We defined a categorical variable of non-hypertensives (reference), undiagnosed hypertension, and diagnosed hypertension. Individuals with self-reported diagnosed hypertension were those who met the criteria for hypertension and also reported a diagnosis of hypertension. Undiagnosed individuals were those who had a high SBP (>140mmHg) or a high DBP (>90mmHg), did not report taking hypertension medication, and did not report a hypertension diagnosis.

Diabetes

Detailed country-specific methods of diabetes measurement are described elsewhere [30]. Briefly, point-of-care fasting capillary glucose measurement was the diabetes biomarker in all surveys apart from the survey conducted in Nepal, where laboratory-based assessment of fasting plasma glucose was used. For the six countries that measured capillary glucose, plasma equivalents were provided. Individuals were asked if they fasted or not prior to the measurement, for those who reported not fasting their blood glucose level was interpreted as a random blood glucose measure. Diabetes was defined as having an average fasting blood glucose (FBG) level of 7 mmol/L or greater, or having a random blood glucose (RBG) level of 11.1 mmol/L or greater, or on medication for diabetes. We evaluated a categorical variable of non-diabetics (reference), undiagnosed diabetes, and diagnosed diabetes. Individuals with self-reported diagnosed diabetes were those who met the criteria for diabetes and also reported a diagnosis of diabetes. Undiagnosed individuals were those who had a high FBG (>7 mmol/L) or a high RBG (>11.1 mmol/L), did not report taking diabetes medication, and did not report a diabetes diagnosis.

Socioeconomic and behavioural variables

Socioeconomic and behavioural factors of interest were sex, age, education, working status, physical activity levels, alcohol use and tobacco use [21].

Socio-demographic variables

Age was defined based on the dates of an individual's birth and the survey, or self-reported age. Age was then categorised into 10-year categories: 15-24, 25-34, 35-44, 45-54, 55-64 and 65 or older. For education a range of options were given including: no formal schooling, less than primary school, primary school completed, secondary school completed, high school completed, college/university completed and post graduate degree. For analysis, education was categorised into "no formal schooling/education", "primary school attendance only" and "secondary schooling or above". For working status, a range of occupations were reported including: government employee, non-government employee, self-employed, non-paid, student, homemaker, retired, and unemployed. Of these we classified the self-report of any paid occupation as "working" and any unpaid occupation (for example homemaker) as "not working".

Behavioural variables

STEPS surveys include physical activity questions, covering physical activity at work, for transport and for recreation. For physical activity at work or for recreation, participants were asked if they participate in vigorous or moderate intensity activity, on how many days during the week, and for how long. For transport participants were asked if they walk or cycle for at least 10 minutes at a time to get to/from places. If they answered "yes" to this question they were then asked on how many days, and during the day how long, they walked or cycled for transport. Answers to these questions were translated into metabolic equivalents (METs), and the WHO recommendation of achieving at least 600 METs [18] used as the cut-off for individuals to be categorised as physically active.

Alcohol consumption is also self-reported, participants were asked if they consumed alcohol in the past 12 months, and then if so the frequency of consumption in the past week. For analyses individuals were classified as “non-drinkers” (had not consumed alcohol in the past 12 months, or did not report consuming alcohol in the previous week) or “drinkers” (reported consuming at least one alcoholic beverage in the past week).

Tobacco use was based on reported frequency of smoking tobacco (cigarettes) and/or using smokeless tobacco (for example snuff or chewing tobacco), in a similar manner to questions on physical activity and alcohol use. Individuals were also asked if they previously used tobacco. Therefore, this variable was categorised as “no reported tobacco use”, “past tobacco use” and “current tobacco use”.

Analyses

Analyses for the population and dietary behaviour characteristics were performed on the sample of individuals with data on all three dietary behaviours from the seven countries. The complex survey design was accounted for, via the Stata *svy* command [39], and data were weighted so that data from each country contributed equally to the results. Percentages for categorical variables and means for continuous variables of demographic, behavioural and disease characteristics, by sex, were described and differences between sexes tested using Pearson's chi-squared test for categorical variables and regression analysis for continuous variables.

Generalized linear models with country-level fixed effects were used to investigate cross-sectional associations between the dietary behaviours and waist circumference. Given that our outcome variables were discrete (i.e. dichotomous), we have fitted our generalized linear models using the binomial family distribution. For the hypertension and diabetes outcomes, separate multinomial logistic regression models with country-level fixed effects were used, comparing undiagnosed and self-reported diagnosed hypertension or diabetes with non-hypertensives or non-diabetics, respectively. For the waist circumference outcome models were adjusted for age, educational attainment, working status, physical activity, alcohol use and tobacco use. For the hypertension and diabetes outcomes, models were adjusted for age, educational attainment, working status, physical activity, alcohol use, tobacco use and waist circumference. Complete case analyses were conducted. Information on the number and proportion of participants with missing data on the outcome, independent or confounding variables is provided overall and by country in **supplementary table 1**.

To investigate the interaction of sex with the dietary behaviours on the outcomes, interaction terms were used and marginal estimates (proportion of males and females with the outcome for the dietary behaviour) were calculated. For these interactions a more lenient *p*- value of ≤ 0.10 was used to identify significance. Given the high proportion of respondents who reported using vegetable oil in cooking (93%) we have not presented the results by type of oil used, as findings were not informative. For the hypertension outcome two sensitivity analyses were conducted using the 4-point, and the 7-point salt behaviour score.

The results are presented with 95% confidence intervals. All analyses were conducted in Stata version 15.1 (StataCorp, College Station, Texas, US).

Table 1. Characteristics of individuals with data on dietary behaviours (n=24,332) in seven low- and middle- income countries, overall and by sex [a]

	Overall (95% CI)	Male (95% CI)	Female (95% CI)	*p-value**
Socio-demographic characteristics				
Sex (%)				
Males	49.89 (48.81. 50.96)	-	-	
Females	50.11 (49.04, 51.18)	-	-	
Age (mean, years)	36.33 (36.03, 36.63)	36.24 (35.81, 36.66)	36.42 (36.08, 36.76)	*0.47*
Educational Attainment (%)				
No formal schooling	14.79 (13.48, 16.20)	11.29 (9.96, 12.77)	18.26 (16.64, 20.01)	
Primary school	30.51 (29.18, 31.88)	32.25 (30.42, 34.14)	28.78 (27.53, 30.07)	*<0.001*
Secondary school or above	54.70 (53.23, 56.17)	56.46 (54.45, 58.45)	52.95 (51.37, 54.53)	
Working (%)	54.18 (52.50, 55.83)	68.74 (66.98, 70.45)	39.70 (37.29, 42.16)	*<0.001*
Behavioural characteristics				
Physical Activity (%)				
Achieving 600 MET a week	84.50 (82.61, 86.21)	88.92 (87.62, 90.11)	80.10 (77.30, 82.63)	*<0.001*
Alcohol consumption				
Mean number of drinks per week	3.84 (3.45, 4.24)	6.47 (5.80, 7.15)	1.23 (1.00, 1.45)	*<0.001*
Consuming alcohol during a week (%)				
No alcohol use reported	70.65 (69.26, 71.99)	56.15 (54.29, 57.99)	85.06 (83.62, 86.40)	*<0.001*
Consume one alcoholic drink or more	29.35 (28.01, 30.74)	43.85 (42.01, 45.71)	14.94 (13.60, 16.38)	
Tobacco use, smoke or smokeless (%)				
No tobacco use	69.69 (68.31, 71.04)	51.51 (49.54, 53.49)	87.79 (86.84, 88.68)	
Past use of tobacco	19.29 (18.13, 20.50)	32.15 (30.300, 34.05)	6.48 (5.83, 7.19)	*<0.001*
Current use of tobacco	11.02 (10.34, 11.74)	16.33 (15.21, 17.53)	5.73 (5.18, 6.33)	
Cardiovascular risk factors				
Waist circumference				
Mean waist circumference	85.22 (84.76, 85.68)	84.45 (83.98, 84.92)	86.01 (85.34, 86.68)	*<0.001*
High waist circumference (%) [b]	26.01 (24.96, 27.08)	11.02 (10.20, 11.89)	41.35 (39.73, 43.00)	*<0.001*
Blood pressure measures				
Mean systolic blood pressure	125.83 (125.47, 126.19)	128.47 (127.96, 128.97)	123.21 (122.76, 123.67)	*<0.001*
Mean diastolic blood pressure	79.76 (79.39, 80.13)	79.90 (79.39, 80.41)	79.62 (79.26, 79.98)	*0.26*
Hypertension (%) [c]	26.69 (25.82, 27.58)	27.44 (26.12, 28.81)	25.95 (25.01, 26.92)	*0.05*
Self-reported diagnosed hypertension	11.26 (10.76, 11.79)	8.74 (8.10, 9.43)	13.77 (13.06, 14.51)	*<0.001*
Undiagnosed hypertension	15.43 (14.71, 16.18)	18.70 (17.54, 19.92)	12.18 (11.49. 12.91)	
Blood glucose measures				
Mean blood glucose measure	4.83 (4.79, 4.87)	4.79 (4.74, 4.83)	4.87 (4.82, 4.93)	*0.006*
Diabetes (%) [d]	5.82 (5.23, 6.47)	4.94 (4.30, 5.66)	6.66 (5.92, 7.49)	*<0.001*
Self-reported diagnosed diabetes	3.38 (2.86, 3.99)	2.59 (2.10, 3.19)	4.13 (3.45, 4.93)	*<0.001*
Undiagnosed diabetes	1.79 (1.53, 2.10)	1.72 (1.35, 2.18)	1.86 (1.54, 2.25)	

[a] Percentages and means accounts for sampling design with survey weights re-scaled by the survey's sample size such that all countries contribute equally to estimates. Differences between sexes tested using Pearson's chi-squared test for categorical variables and linear regression analysis for continuous variables.

[b] Definition of high waist circumference, waist ⩾ 102cm for males and waist ⩾ 88cm for females.

[c] Hypertension was defined as an average systolic blood pressure (SBP) measurement >140mmHg, or their average diastolic blood pressure (DBP) measurement > 90mmHg, or they reported taking medication for hypertension. Self-reported diagnosed

hypertension were those who met the criteria for hypertension and also reported a diagnosis of hypertension.Undiagnosed individuals were those who had a high SBP (>140mmHg) or a high DBP (>90mmHg), did not report taking hypertension medication, and did not report a hypertension diagnosis.

[d] Diabetes was defined as having an average fasting blood glucose (FBG) level ≥7 mmol/L, or having a random blood glucose (RBG) level of ≥11.1 mmol/L or on medication for diabetes. Individuals with self-reported diagnosed diabetes met the criteria for diabetes and also reported a diagnosis of diabetes. Undiagnosed individuals were those who had a high FBG (≥7 mmol/L) or a high RBG (≥11.1 mmol/L), did not report taking diabetes medication, and did not report a diabetes diagnosis.

*p-value for difference between males and females

Results

Sample characteristics and dietary behaviours

The sample included 25,324 participants from Bhutan, Eswatini, Georgia, Guyana, Kenya, Nepal, and St Vincent and the Grenadines (**supplementary table 2**). The final analytic sample included 24,332 participants with the required information on the three dietary behaviours, of which 20,784 had waist circumference measurements, 22,907 had the required information on hypertension status, and 16,830 had the required information on diabetes status. Population characteristics are presented in **table 1**, with characteristics for each outcome sample shown in **supplementary table 3**. Mean age was 36 years and 50% of the sample was female. On average, males were more likely to have had a formal education, to consume alcohol and to use tobacco (**table 1**). For overall disease prevalence (95% CI), 26.0% (25.0-27.1%) of the sample analyzed had a high waist circumference, 11.0% (10.2-11.9%) of males and 41.4% (39.7-43.0%) of females. Just under a third of the sample were affected by hypertension (26.7%, 25.8-27.6% overall, 27.4%, 26.1-28.8% of males and 26.0%, 25.0-26.9% of females), 11.3% (10.8-11.8%) of which was self-reported diagnosed (8.7%, 8.1-9.4% of males, 13.8%, 13.1-14.5% of females) and 15.4% (14.7-16.2%) of which was undiagnosed (18.7%, 17.5-19.9% of males, 12.2%, 11.5-12.9% of females). Around six percent of the sample had diabetes (5.8%, 5.2-6.5% overall, 4.9%, 4.3-5.7% of males, 6.7%, 5.9-7.5% of females), 3.4% (2.9-4.0%) reported being diagnosed with diabetes (2.6%, 2.1-3.2 of males, 4.1%, 3.5-4.9% of females) and 1.8% (1.5-2.1%) had undiagnosed diabetes (1.7%, 1.4-2.2% of males, 1.9%, 1.5-2.3% of females).

Table 2. Self-reported salt use behaviour, fruit and vegetable consumption and the type of fat and oil used in cooking, in seven low-and middle-income countries (n=24,332), by sex [a]

	Overall Percentage (95% CI)	Male Percentage (95% CI)	Female Percentage (95% CI)	*p-value**
Salt use behaviour				
Positive salt behaviour (>50%)	29.27 (26.75, 31.93)	27.19 (24.60, 29.95)	31.34 (28.61, 34.21)	*<0.001*
Specific salt behaviours				
Add salt to meal				*<0.001*
Always	8.44 (7.64, 9.32)	9.39 (8.26, 10.66)	7.50 (6.74, 8.33)	
Often	5.28 (4.76, 5.85)	5.27 (4.62, 6.01)	5.28 (4.69, 5.95)	
Sometimes	17.35 (16.45, 18.28)	18.09 (16.86, 19.39)	16.61 (15.60, 17.67)	
Rarely	15.83 (14.58, 17.16)	16.17 (14.64, 17.82)	15.49 (14.16, 16.93)	
Never	53.10 (50.92, 55.27)	51.08 (48.69, 53.47)	55.11 (52.76, 57.44)	
Add salt during cooking				*0.26*
Always	63.78 (61.88, 65.65)	63.48 (61.28, 65.62)	64.09 (62.07, 66.06)	
Often	7.62 (6.95, 8.35)	7.58 (6.72, 8.53)	7.67 (6.96, 8.45)	
Sometimes	11.34 (10.50, 12.24)	11.74 (10.65, 12.92)	10.95 (10.05, 11.92)	
Rarely	7.59 (6.91, 8.32)	7.21 (6.35, 8.18)	7.95 (7.20, 8.78)	
Never	9.67 (8.75, 10.67)	10.00 (8.84, 11.29)	9.34 (8.39, 10.38)	
Limit Processed foods to reduce salt				
Yes	43.3 (40.94, 45.70)	42.35 (39.78, 44.96)	44.25 (41.67, 46.87)	*0.07*
Look at salt content on food labels				
Yes	18.03 (16.71, 19.42)	16.96 (15.51, 18.51)	19.09 (17.56, 20.72)	*0.01*
Buy low salt alternatives				
Yes	18.16 (16.69, 19.72)	16.81 (15.17, 18.59)	19.49 (17.89, 21.21)	*<0.001*
Use other spices				
Yes	32.94 (29.72, 36.34)	31.24 (28.16, 34.48)	34.64 (31.00, 38.64)	*<0.001*
Avoid eating foods prepared outside of home				
Yes	34.05 (31.92, 36.24)	31.34 (29.12, 33.65)	36.74 (34.36, 39.19)	*<0.001*
Fruit and vegetable consumption				
Met WHO guidelines (400g per day)	14.01 (12.80, 15.32)	14.81 (13.23, 16.55)	13.21 (12.09, 14.43)	*0.02*
Fat and oil used in cooking				*0.45*
Vegetable	93.39 (92.20, 94.40)	92.95 (91.48, 94.19)	93.81 (92.69, 94.77)	
Animal	2.49 (2.02, 2.06)	2.62 (2.00, 3.41)	2.36 (1.92, 2.89)	
Other	2.98 (2.14, 4.14)	3.17 (2.15, 4.65)	2.78 (2.04, 3.78)	
None in particular	0.47 (0.36, 0.61)	0.49 (0.33, 0.71)	0.45 (0.33, 0.62)	
None	0.69 (0.51, 0.91)	0.77 (0.51, 0.12)	0.60 (0.45, 0.80)	

[a] Percent accounts for sampling design with survey weights re-scaled by the survey's sample size such that all countries contribute equally to estimates. Differences between sexes tested using Pearson's chi-squared test.

*p-value for difference between males and females

A third of the sample (29.3%, 95% CI 26.8-31.9%) reported positive salt use behaviour, slightly higher in females than in males (31.3%, 28.6-34.2% compared to 27.2%, 24.6-30.0%, *p*-value<0.001 **table 2**). Analysis of the salt behaviour from the seven questions asked in the survey revealed a higher proportion of participants responded positively to questions regarding adding salt to meals (*never*, 53.1%, 50.9-55.3%) and limiting processed foods to reduce salt intake (*yes*, 43.3%, 40.9-45.7%). However, 63.8% (61.9-65.7%) of the population reported always adding salt during cooking and 18.0% (16.7-19.4%) reported looking at the salt content on food labels. Fourteen percent (14.0%, 12.8-15.3%) of the sample met the WHO fruit and vegetable recommendations, with a lower proportion of females meeting the recommendations compared to males (13.2%, 12.1-14.4% compared to 14.8%, 13.2-16.6%, *p*-value=0.02). The majority of the sample reported using vegetable oil in cooking (93.4%, 92.2-94.4%, **table 2**). Overall, 2.7% of the population reported positive behaviours for all three dietary factors (**figure 1**), with no sex differences evident (**supplementary figure 1**). The prevalence of positive dietary behaviours was similar for each outcome population (**supplementary table 4**). The prevalence of positive dietary behaviours varied by country (**figure 2**), ranging from 64.7% (60.8-68.4%) reporting positive salt behaviour in St. Vincent & the Grenadines to 5.8% (4.3-7.9%) reporting positive salt use behaviour in Nepal (**figure 2a**), and 37.3% (34.4-40.3%) reporting meeting fruit and vegetable recommendations in Georgia to 1.1% (0.7-1.8%) meeting fruit and vegetable recommendations in Nepal (**figure 2b**).

Individuals with missing data for the diabetes outcome were compared to individuals with data in an unweighted analysis. Those with data were older (39 vs. 36 years), had a higher mean waist circumference (88.28 vs. 85.11 cm), had a higher average systolic (129.78 vs. 125.19 mmHg) and diastolic blood pressure (81.68 vs. 79.21 mmHg), a higher proportion were hypertensive (17.6 vs. 12.6%), and had higher average blood glucose levels (5.73 vs. 4.27 mmol/L). However, no differences were evident in the reported dietary behaviours. The proportion of participants with missing data from the hypertension and waist circumference outcome groups were minimal, 321 (1.4%) and 1,059 (4.4%) participants, respectively (**supplementary table 3**).

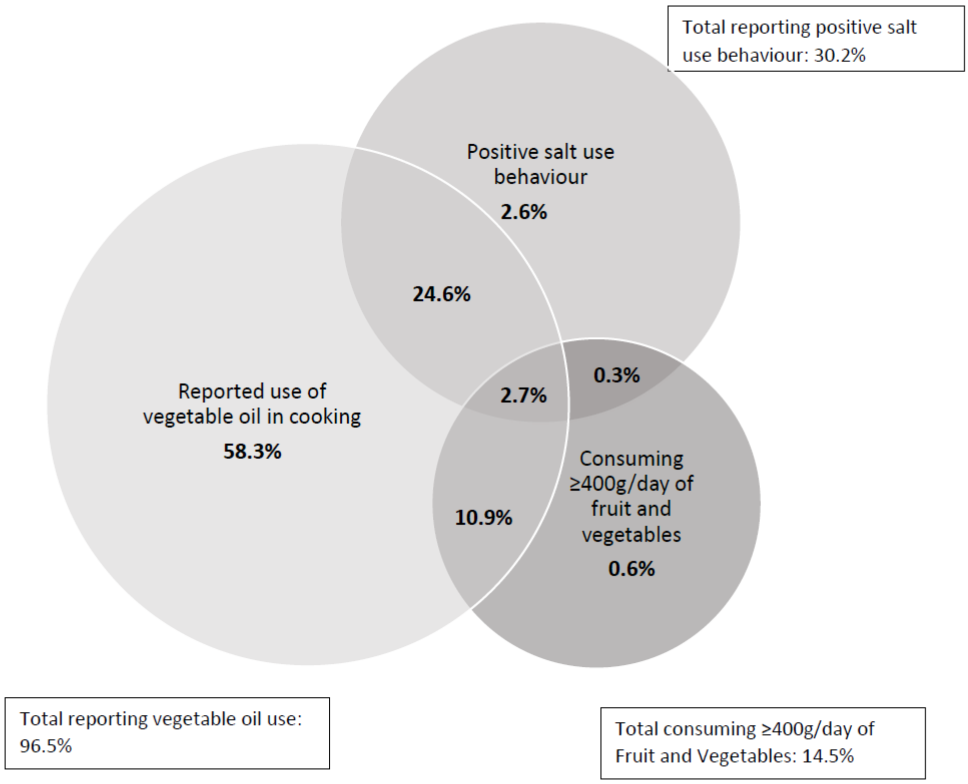
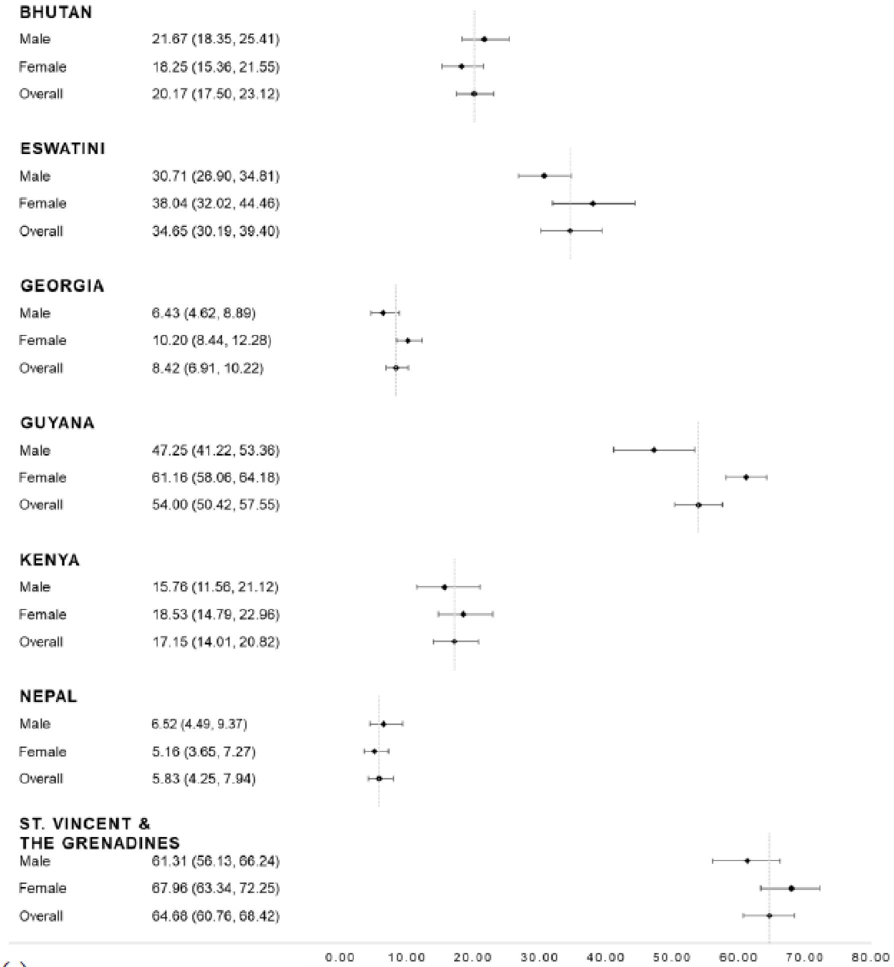
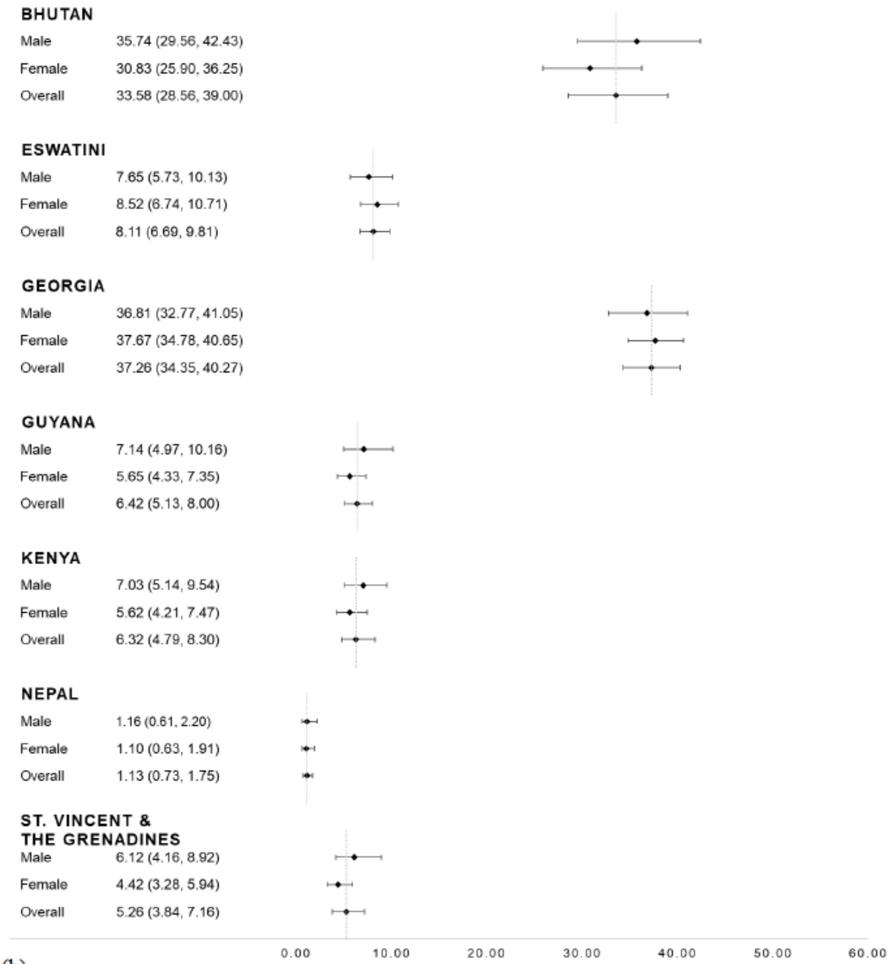


Figure 1. Weighted proportion of participants reporting positive dietary behaviours (n= 23,511), in seven low-and middle-income countries


BHUTAN
Male 21.67 (18.35, 25.41)
Female 18.25 (15.36, 21.55)
Overall 20.17 (17.50, 23.12)
ESWATINI
Male 30.71 (26.90, 34.81)
Female 38.04 (32.02, 44.46)
Overall 34.65 (30.19, 39.40)
GEORGIA
Male 6.43 (4.62, 8.89)
Female 10.20 (8.44, 12.28)
Overall 8.42 (6.91, 10.22)
GUYANA
Male 47.25 (41.22, 53.36)
Female 61.16 (58.06, 64.18)
Overall 54.00 (50.42, 57.55)
KENYA
Male 15.76 (11.56, 21.12)
Female 18.53 (14.79, 22.96)
Overall 17.15 (14.01, 20.82)
NEPAL
Male 6.52 (4.49, 9.37)
Female 5.16 (3.65, 7.27)
Overall 5.83 (4.25, 7.94)
ST. VINCENT &
THE GRENADINES
Male 61.31 (56.13, 66.24)
Female 67.96 (63.34, 72.25)
Overall 64.68 (60.76, 68.42)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
(a)


BHUTAN
Male 35.74 (29.56, 42.43)
Female 30.83 (25.90, 36.25)
Overall 33.58 (28.56, 39.00)
ESWATINI
Male 7.65 (5.73, 10.13)
Female 8.52 (6.74, 10.71)
Overall 8.11 (6.69, 9.81)
GEORGIA
Male 36.81 (32.77, 41.05)
Female 37.67 (34.78, 40.65)
Overall 37.26 (34.35, 40.27)
GUYANA
Male 7.14 (4.97, 10.16)
Female 5.65 (4.33, 7.35)
Overall 6.42 (5.13, 8.00)
KENYA
Male 7.03 (5.14, 9.54)
Female 5.62 (4.21, 7.47)
Overall 6.32 (4.79, 8.30)
NEPAL
Male 1.16 (0.61, 2.20)
Female 1.10 (0.63, 1.91)
Overall 1.13 (0.73, 1.75)
ST. VINCENT &
THE GRENADINES
Male 6.12 (4.16, 8.92)
Female 4.42 (3.28, 5.94)
Overall 5.26 (3.84, 7.16)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
(b)

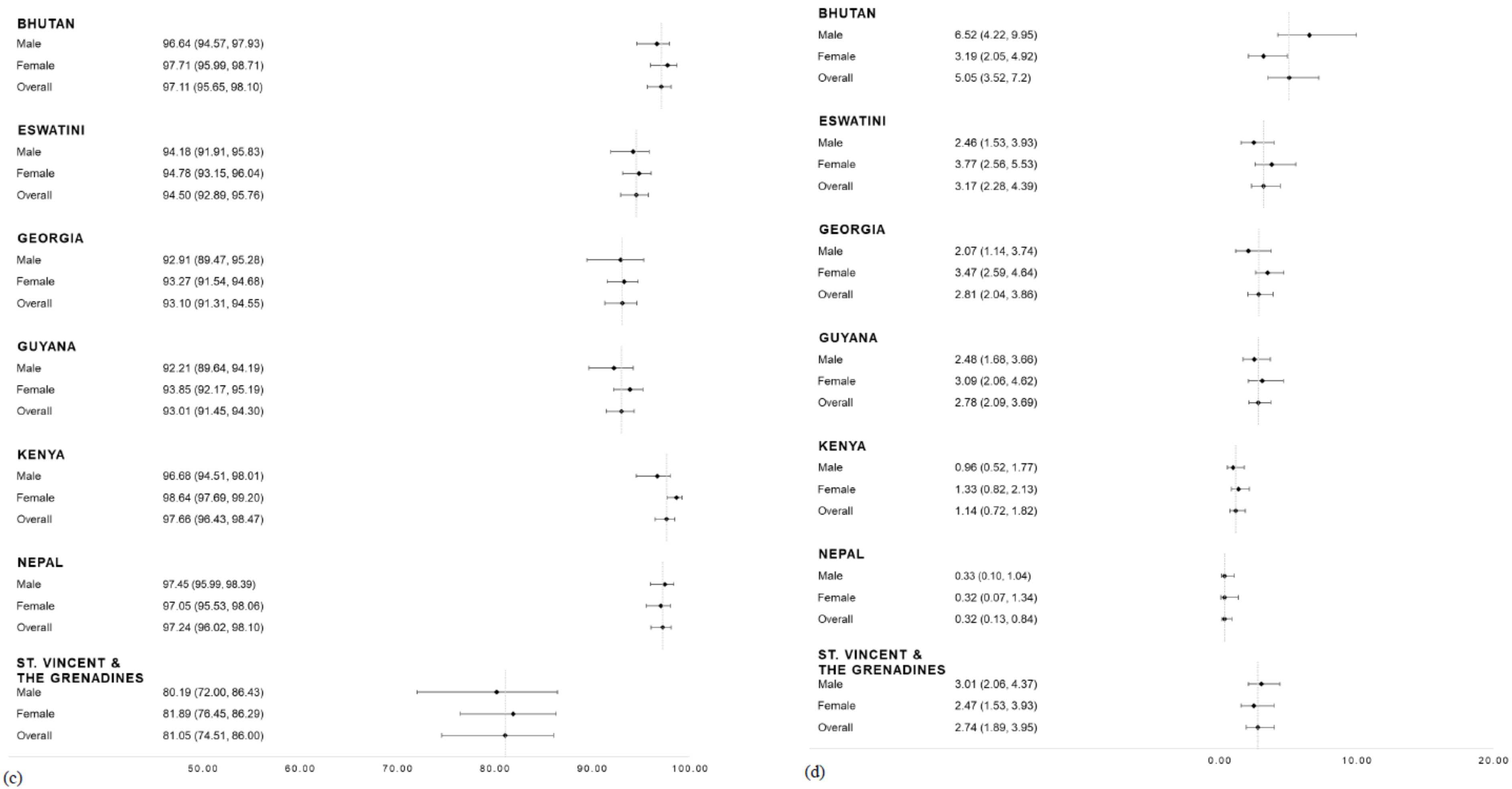


Figure 2. Prevalence (percentage, 95% confidence interval) of (a) reporting positive salt use behaviour, (b) meeting fruit and vegetable recommendations, (c) use of vegetable oil, and (d) reporting all three behaviours positively, by sex and country.

Cross-sectional associations of sex and dietary behaviours with waist circumference, hypertension, and diabetes

From the adjusted models (adjusted for age, waist circumference (for associations with diabetes and hypertension), educational attainment, working status, physical activity, alcohol use and tobacco use) a higher proportion of females exceeded waist circumference recommendations in comparison to males (40.5%, 95% CI 35.6-45.4% vs. 10.1%, 6.6%-13.5%). For hypertension, a higher proportion of males had undiagnosed hypertension in comparison to females (19.2%, 17.8-20.7% vs. 12.2%, 11.0-13.5%), with no difference in the proportion with diagnosed hypertension between the sexes (10.7%, 9.8-11.6% for males, 11.7%, 10.9-12.4% for females). For diabetes, there were no sex differences in the proportion with undiagnosed or diagnosed diabetes (undiagnosed diabetes, 2.1%, 1.6-2.6% of males, 1.7%, 1.4-2.0% of females, diagnosed diabetes, 8.3%, 7.4-9.2% of males, 7.0, 6.7-7.4% of females).

Overall, salt behaviour was associated with diagnosed diabetes only (**table 3**). A higher proportion of those with diagnosed diabetes reported positive salt use behaviour, compared to those who reported poor salt behaviour (8.0%, 95% CI 7.9-8.2% vs. 6.5%, 6.3-6.8% respectively, *p*-value= 0.001). However, when looking at the interaction by sex there were further significant differences (**table 3**). For undiagnosed hypertension there was a significant interaction by sex (*p*-value for interaction=0.04), the proportion of females with undiagnosed hypertension reporting poor salt behaviour was 13.1% (11.8-14.4%) compared to 9.9% (8.4-11.5%) of those who reported positive salt behaviour. However, in males there was no difference in the proportion of undiagnosed hypertension for those who reported positive or poor salt behaviour. Salt behaviour was also associated with undiagnosed diabetes, with a significant interaction by sex (*p*-value for interaction= 0.02). The proportion of males with undiagnosed diabetes reporting poor salt behaviour was 2.4% (2.0-2.9%) compared to 1.5% (0.6-2.4%) for those who reported positive salt behaviour, yet there was no difference in the prevalence of undiagnosed diabetes by salt behaviour for females. In the sensitivity analyses (**supplementary figures 2 and 3**) a downwards trend was seen for the prevalence of undiagnosed hypertension with increasing numbers of salt behaviour questions answered positively for females. Comparatively, for males a slight upward trend was seen for both the 7-point and the 4-point scores. In both cases, the confidence intervals for each prevalence-point overlap.

Table 3. Cross-sectional associations of salt behaviour with exceeding waist circumference [a] recommendations, having undiagnosed or diagnosed hypertension [b] or diabetes [b], in seven low-and middle-income countries

	Waist circumference [c] (n=20,784)	Hypertension [d] (n=22,907)		Diabetes [e] (n=16,643)	
	Percentage (95% CI) exceeding recommendations	Percentage (95% CI) undiagnosed	Percentage (95% CI) diagnosed	Percentage (95% CI) undiagnosed	Percentage (95% CI) diagnosed
Overall					
good salt behaviour	24.3 (22.3, 26.2)	14.8 (13.1, 16.4)	12.1 (11.1, 13.1)	1.7 (1.3, 2.2)	8.0 (7.9, 8.2)
poor salt behaviour	22.3 (21.4, 23.1)	16.0 (15.5, 16.6)	10.9 (10.5, 11.4)	1.9 (1.7, 2.2)	6.5 (6.3, 6.8)
p-value	*0.81*	*0.67*	*0.34*	*0.20*	*0.001*
Male					
good salt behaviour	10.4 (7.7, 13.1)	19.7 (15.2, 24.1)	11.5 (9.9, 13.0)	1.5 (0.6, 2.4)	9.3 (8.5, 10.2)
poor salt behaviour	9.9 (5.4, 14.3)	19.1 (18.4, 19.8)	10.3 (9.0, 11.7)	2.4 (2.0, 2.9)	6.8 (5.4, 8.1)
Female					
good salt behaviour	43.3 (38.3, 48.4)	9.9 (8.4, 11.5)	12.5 (11.8, 13.2)	1.9 (1.6, 2.2)	7.3 (6.9, 7.7)
poor salt behaviour	39.3 (33.9, 44.7)	13.1 (11.8, 14.4)	11.3 (10.2, 12.4)	1.6 (1.2, 2.0)	6.4 (5.4, 7.4)
p-value for sex interaction	*0.64*	*0.04*	*0.79*	*0.02*	*0.29*

[a] Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use and tobacco use

[b] Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use, tobacco use and waist circumference

[c] Definition of high waist circumference, waist ⩾ 102cm for males and waist ⩾ 88cm for females

[d] Hypertension was defined as an average systolic blood pressure (SBP) measurement >140mmHg, or their average diastolic blood pressure (DBP) measurement > 90mmHg, or they reported taking medication for hypertension. Self-reported diagnosed hypertension were those who met the criteria for hypertension and also reported a diagnosis of hypertension. Undiagnosed individuals were those who had a high SBP (>140mmHg) or a high DBP (>90mmHg), did not report taking hypertension medication, and did not report a hypertension diagnosis.

[e] Diabetes was defined as having an average fasting blood glucose (FBG) level ≥7 mmol/L, or having a random blood glucose (RBG) level of ≥11.1 mmol/L or on medication for diabetes. Individuals with self-reported diagnosed diabetes met the criteria for diabetes and also reported a diagnosis of diabetes. Undiagnosed individuals were those who had a high FBG (≥7 mmol/L) or a high RBG (≥11.1 mmol/L), did not report taking diabetes medication, and did not report a diabetes diagnosis.

Table 4. Cross-sectional associations of meeting fruit and vegetable recommendations with exceeding waist circumference recommendations [a], having undiagnosed or diagnosed hypertension [b] or diabetes [b], in seven low-and middle-income countries

	Waist circumference [c] (n= 20,784)	Hypertension [d] (n=22,907)		Diabetes [e] (n=16,643)	
	Percentage (95% CI) exceeding recommendations	Percentage (95% CI) undiagnosed	Percentage (95% CI) diagnosed	Percentage (95% CI) undiagnosed	Percentage (95% CI) diagnosed
Overall					
Met F&V[f] recommendations	24.4 (22.5, 26.4)	15.9 (13.8, 18.0)	11.2 (10.2, 12.2)	1.8 (0.7, 2.9)	5.9 (4.5, 7.2)
Did not meet F&V recommendations	22.6 (22.3, 23.0)	15.6 (15.3, 16.0)	11.3 (11.1, 11.5)	1.9 (1.8, 2.0)	7.5 (7.4, 7.6)
p-value	*0.01*	*0.84*	*0.88*	*0.75*	*0.33*
Male					
Met F&V recommendations	13.1 (6.6, 19.6)	18.9 (17.0, 20.9)	10.6 (9.4, 11.7)	2.0 (1.0, 3.0)	6.5 (3.1, 9.9)
Did not meet F&V recommendations	9.5 (6.6, 12.4)	19.3 (17.4, 21.1)	10.7 (9.5, 12.0)	2.1 (1.5, 2.7)	8.4 (7.5, 9.4)
Female					
Met F&V recommendations	39.8 (32.5, 47.1)	13.1 (10.7, 15.4)	11.6 (10.5, 12.8)	1.6 (0.2, 3.3)	5.6 (4.2, 6.9)
Did not meet F&V recommendations	40.6 (35.9, 45.3)	12.1 (11.0, 13.2)	11.7 (11.0, 12.4)	1.7 (1.5, 2.0)	7.1 (6.5, 7.6)
p-value for sex interaction	*0.06*	*0.17*	*0.79*	*0.97*	*0.90*

[a]Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use and tobacco use

[b]Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use, tobacco use and waist circumference

[c] Definition of high waist circumference, waist ⩾ 102cm for males and waist ⩾ 88cm for females

[d] Hypertension was defined as an average systolic blood pressure (SBP) measurement >140 mmHg, or their average diastolic blood pressure (DBP) measurement > 90mmHg, or they reported taking medication for hypertension. Self-reported diagnosed hypertension were those who met the criteria for hypertension and also reported a diagnosis of hypertension. Undiagnosed individuals were those who had a high SBP (>140mmHg) or a high DBP (>90mmHg), did not report taking hypertension medication, and did not report a hypertension diagnosis.

[e] Diabetes was defined as having an average fasting blood glucose (FBG) level ≥7 mmol/L, or having a random blood glucose (RBG) level of ≥11.1 mmol/L or on medication for diabetes. Individuals with self-reported diagnosed diabetes met the criteria for diabetes and also reported a diagnosis of diabetes. Undiagnosed individuals were those who had a high FBG (≥7 mmol/L) or a high RBG (≥11.1 mmol/L), did not report taking diabetes medication, and did not report a diabetes diagnosis.

[f] "F&V" – Fruit and vegetable intake, categorised into meeting or not meeting fruit and vegetable recommendations of 400g/day

Overall, self-reported fruit and vegetable consumption was associated with waist circumference (**table 4**), with a higher proportion of those who met fruit and vegetable recommendations exceeding waist circumference recommendations (24.4%, 95% CI 22.5-26.4% vs 22.6%, 22.3-23.0% respectively, *p*- value= 0.01). At the *p*-value ≤0.10 significance level a significant interaction was observed by sex for fruit and vegetable consumption with waist circumference (*p*-value for interaction= 0.06), with a higher proportion of males who met fruit and vegetable recommendations exceeding waist circumference recommendations (13.1%, 6.6-19.6% compared to 9.5%, 6.6-12.4%). There was no difference in the prevalence of high waist circumference by fruit and vegetable consumption for females. No associations were identified between fruit and vegetable consumption and prevalence of undiagnosed or diagnosed hypertension (*p*-values of 0.84 and 0.88, respectively), or the prevalence of undiagnosed or diagnosed diabetes (*p*-values 0.75 and 0.33, respectively). Further, no significant interactions by sex were found (*p*-values 0.17 for undiagnosed hypertension, 0.79 for diagnosed hypertension, 0.97 for undiagnosed diabetes and 0.90 for diagnosed diabetes).

Discussion

This study revealed an exceptionally low prevalence of positive dietary behaviours for salt use and fruit and vegetable consumption, with only 2.7% of the population reporting positive salt use, meeting fruit and vegetable recommendations and reporting use of vegetable oil in cooking. Small sex differences were evident in the self-report of salt use and fruit and vegetable consumption, but associations between the self-reported dietary behaviours and the outcomes were minimal. This was unexpected but can likely be explained by the low prevalence of positive dietary behaviours overall.

The results for positive salt use behaviour and meeting the WHO recommendations for fruit and vegetables varied hugely by country. 64.7% of the population from St Vincent & the Grenadines reported positive salt use behaviour, and 37.3% of the Georgian population met fruit and vegetable recommendations, compared to just 5.8% and 1.1% of the Nepalese population for the respective behaviours. Across the countries, discretionary salt use was high, with 63% of the sample *always adding salt during cooking*. These responses suggest discretionary salt is a key contributor to salt intake in these countries [40-42]. We found a small proportion of participants reported looking at the salt content on food labels (18% overall, 17% of males and 19% of females). This is much lower than that found in two separate reviews of nutrition label use in other low-and-middle income countries [43] and in high-income countries [44], finding 40-70% and 60-80% self-reported use, respectively. Both of these reviews found that self-reported use of labels was high, comprehension of back-of-pack nutrition panels was low, and interpretative front-of-pack labels, for example the multiple traffic light label, were easier to understand, making it more likely to influence consumer choice. As consumption of processed foods increases, it is important that clear and effective labelling systems are introduced. Monitoring of the main sources of salt in diets is also needed [45], to inform future intervention strategies. The identified low fruit and vegetable consumption across the countries, echoes findings by Frank et al [31] and the Prospective Urban and Rural Epidemiological (PURE) Study [14, 46]. However, the PURE study [46], which covers 18 counties did identify a decrease in cardiovascular disease with increasing fruit, vegetable and legume intake. Differing LMICs included in studies, the lack of legume measurement in WHO STEPS and the cross-sectional nature of studies in our review potentially explain the differing findings.

Our findings imply poor overall diet quality in the included countries, particularly for Nepal, Kenya and Eswatini, where the prevalence of meeting fruit and vegetable recommendations and reporting positive salt use behaviors were very low. The recent review on the State of Diet Quality Globally [47] looked at unhealthy and healthy dietary patterns using the 2015 Global Dietary Database. The authors found that adherence to both “unhealthy” and “healthy” dietary patterns were low in Nepal, Kenya and Eswatini. Their unhealthy dietary pattern score was based on the consumption of refined grains, total processed meats, sugar-sweetened beverages and added sugar, where as their healthy dietary pattern score focused on 11 dietary factors including fruits, vegetables, legumes, wholegrains and unprocessed animal products. These results further highlight the need to increase “healthy” foods, including fruits and vegetables. Accessibility, affordability, and safety of fruits and vegetables are key barriers to consumption in low-resource settings [14, 48], and policies that focus on contextually appropriate systems, fostering production of fruits and vegetables by local farmers, and proper storage and handling of produce to point of sale, at potentially subsidized prices may aid consumption [49, 50].

Examination of cross-sectional associations of the dietary behaviours with outcomes produced differing results for males and females. For waist circumference, once adjusted for socioeconomic and behavioural factors, 41% of females exceeded waist circumference recommendations, compared to 10% of males. Our findings are consistent with the obesity transition where females tend to transition to obesity before males [4, 6]. Individuals who met fruit and vegetable recommendations were more likely to exceed waist circumference recommendations. Whilst we were not able to adjust for total energy intake, it is highly likely that this is because people who meet fruit and vegetable recommendations may eat more in general. It is also acknowledged that the use of waist circumference cut-offs have their limitations, and different cut-offs exist for different populations [51, 52]. We have used binary variables in this paper for ease of interpretation, however cut-offs, either for waist circumference or the categories of body mass index may not predict the same disease risk for all population groups. Therefore, we could be overestimating the burden of high-waist circumference in our sample, which is inclusive of a range of ethnicities. We found that poor self-reported salt behaviour was associated with increased odds of having undiagnosed hypertension for females, with no relationship evident for males. This is interesting as some sodium reduction trials also show that reducing sodium has more of an impact on blood pressure in females than males [53]. Given we cannot equate the behavioural questionnaire in the present study to actual sodium intake, a next step investigation could be to examine the association of the salt behaviour questions included in STEPS surveys with actual salt intake measured by 24-hr urine/spot urine, which has been measured in recent STEPS surveys. The fact that a higher proportion of males with poor salt behaviour had undiagnosed diabetes compared to males with good salt behaviour was intriguing, albeit the percentage difference between the groups was only 0.9%. The relationship between salt intake and diabetes is not well established, however it is likely to be associated given diets high in salt may also be energy dense, leading to excess adiposity and therefore risk of type 2 diabetes [54, 55].

Overall, it is important to reflect on the dietary behaviours measured in the STEPS survey given that for many LMICs, the STEPS surveys are the only source of national dietary intake data. In particular, ultra-processed foods and drinks are important overlooked dietary risk factors [56, 57] and countries should consider including questions on these in future iterations of the STEPS survey. These products are high in salt, fat and/or sugar, and people who frequently consume ultra-processed products in their diets often have low intakes of fresh fruits and vegetables [57]. Sales of ultra-processed products have been shown to be increasing globally, including in LMICs, with corresponding increases in body mass index [58]. While we have investigated components of diet quality, we were not able to investigate the level of consumption of ultra-processed products, which may be a reason for the overall minimal associations observed between the diet behaviours and cardiovascular risk factors.

These findings have several policy implications for the included countries. First, they identify the need to improve consumption of fruits and vegetables, and salt use behaviour. As discussed, policies need to focus on improving the accessibility and affordability of fruit and vegetables, and decreasing the use of salt during cooking, while monitoring the consumption of ultra-processed products which are becoming more accessible in LMICs. Second, there is not sufficient evidence from this review to support the idea that we need sex specific policies and interventions for fruit and vegetable consumption and salt use. This investigation was limited by the small proportion of individuals reporting positive fruit and vegetable consumption and salt use behaviour. If future policies are implemented to improve dietary behaviours it would be worthwhile investigating effectiveness by sex, in addition to overall effectiveness. Given that WHO STEPS surveys are regularly conducted, they can be used to monitor policy effectiveness and a similar study to the present could be conducted as a method of monitoring and evaluation in individual countries.

The strengths of our study are that to our knowledge, this is the first study that has examined sex differences in dietary behaviours and their association with CVD risk factors in multiple LMICs. The study pooled data from 7 nationally representative surveys, across 7 countries meaning 24,332 people were included in the analysis. Given all of these surveys were STEPS surveys they used the same standardised methodology to measure all variables included in the present analyses. Additionally, in country collaborators are authors on the present study, and therefore were able to aid interpretation of our results by adding contextual information in addition to their oversight of the development of this paper. However, our study has several weaknesses. First, the data is cross-sectional and therefore the associations discussed do not imply causation. Second, only seven STEPS surveys were included as only more recent STEPS surveys have included dietary behaviour questions. It would be worthwhile to rerun this analysis in coming years as more countries collect this data. Third, 93.4% of the study sample reported the use of vegetable oil and therefore it was not useful to include an analysis of the cross-sectional association of oil type used with CVD risk factors in our results. This question has since been removed by WHO in the updated version of the STEPS survey questionnaire [21], on this basis. Finally, the dietary behaviour questions analysed do not provide a comprehensive picture of an individual's diet, and do not allow for the quantification of dietary intake. Additionally, the self-report of dietary behaviours is subject to multiple biases [59]. While overall dietary intake is not assessed by STEPS surveys, the survey has been used widely throughout low-and middle-income countries to assess risk of non-communicable disease based on the key dietary behaviours. This provides useful insight on the need for dietary interventions at a population level in resource poor settings [34]. Urinary markers of sodium intake have been collected in more recent STEPS surveys [21, 45], however these data were not available for the current project.

Conclusion

In conclusion, just 2.7% of respondents from seven countries in this study reported positive behaviours for salt use, fruit and vegetable consumption and use of vegetable oil in cooking, with variability seen by country. Given the high burden of cardiovascular diseases in the countries studied, there is an urgent need to implement suitable policies to encourage greater intake of fruit and vegetables and reduced consumption of salt. We identified small sex differences in the self-report of salt use behaviour and fruit and vegetable consumption, along with some interesting interactions by sex with the dietary behaviours for having a high waist circumference, hypertension or diabetes. As such our evidence is not sufficient to endorse the tailoring of diet related interventions by sex in the included countries as our findings were limited by the small proportion of the population reporting positive dietary behaviours. However, if adherence to healthy diets were greater it is plausible that greater associations and sex differences would have been identified, and therefore this hypothesis should be a focus of future research.

Declarations

Ethics

This study received ethics approval from the University of New South Wales (protocol #HC190279) and the Harvard T.H. Chan School of Public Health (protocol #IRB16-1915). This was a secondary analysis of de-identified survey data. For each survey, informed consent was provided by participants prior to survey completion.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

BLM, LMJ and JW conceived the research question and research plan for this analysis. MSG, LS, GG, KKA, LT and GA-B provided essential materials (datasets necessary for the research). BLM and JAS performed the statistical analysis. BLM wrote the first draft of the manuscript. All authors provided feedback on the manuscript and approved the final version.

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4.4 Supplementary material

Supplementary table 1. Number and percent of individuals with missing data on outcome, independent and confounding variables*, overall and by country

	Overall		Bhutan		Eswatini		Georgia		Guyana		Kenya		Nepal		St. Vincent & the Grenadines	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Waist circumference	1,367	5.40	79	0.31	447	1.77	296	1.17	115	0.45	321	1.27	60	0.24	49	0.19
Hypertension	607	2.40	6	0.02	340	1.34	160	0.63	13	0.05	60	0.24	17	0.07	11	0.04
Diabetes	7,047	27.83	86	0.34	652	2.57	1,231	4.86	1,993	7.87	381	1.50	370	1.46	2,334	9.22
Salt use behaviour	261	1.03	3	0.01	255	1.01	0	0.00	0	0.00	3	0.01	0	0.00	0	0.00
Fruit and vegetable consumption	933	3.68	40	0.16	380	1.50	23	0.09	45	0.18	270	1.07	94	0.37	81	0.32
Type of oil used in cooking	326	1.29	3	0.01	263	1.04	35	0.14	4	0.02	9	0.04	0	0.00	12	0.05
Sex	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Age	21	0.08	3	0.01	0	0.00	0	0.00	0	0.00	16	0.06	0	0.00	2	0.01
Educational attainment	496	1.96	3	0.01	256	1.01	229	0.90	2	0.01	0	0.00	0	0.00	6	0.02
Working status	268	1.06	2	0.01	257	1.01	6	0.02	0	0.00	0	0.00	0	0.00	3	0.01
Physical activity	289	1.14	3	0.01	259	1.02	0	0.00	1	0.00	4	0.02	22	0.09	0	0.00
Alcohol consumption	318	1.26	19	0.08	269	1.06	14	0.06	1	0.00	8	0.03	0	0.00	7	0.03

*Percent missing data on outcomes (waist circumference, hypertension and diabetes), independent variables (self-reported salt use behaviour, fruit and vegetable consumption and type of oil used in cooking) and potential confounding factors (age, educational attainment, working status, physical activity and alcohol consumption) for the sample of individuals aged 15 years or older, n= 25,324.

Supplementary table 2. Survey characteristics

Country	Number of respondents	Female	Male	% Female (unweighted)	Country income status	Year of WHO STEPs survey	WHO Region
Bhutan	2,822	1,748	1,074	61.94	Lower middle income	2014	South Asia
Eswatini	3,531	2,303	1,228	65.22	Lower middle income	2014	Southern Africa
Georgia	4,212	2,940	1,272	69.80	Lower middle income	2016	Europe
Guyana	2,655	1,589	1,066	59.85	Upper middle income	2016	Caribbean
Kenya	4,488	2,692	1,796	59.98	Lower middle income	2015	East Africa
Nepal	4,143	2,807	1,336	67.75	Low income	2013	South Asia
St. Vincent & the Grenadines	3,473	1,941	1,532	55.89	Upper middle income	2013	Caribbean
Total	25,324	16,020	9,304	63.26			

*WHO - World Health Organization

Supplementary table 3. Characteristics of individuals with data on dietary behaviours, and data on waist circumference (n=23,273) hypertension (n=24,011), diabetes (n=17,724) status

	Population with data on waist circumference (n =23,273)				Population with data on hypertension status (*n*= 24,011)				Population with data on diabetes status (*n*= 17,724)			
	Overall	Male	Female	*p-value*	Overall	Male	Female	*p-value*	Overall	Male	Female	*p-value*
Sex*												
Males	50.57 (49.51, 51.64)	-	-	-	49.82 (48.75, 50.88)	-	-	-	47.93 (46.67, 49.31)	-	-	-
Females	49.43 (48.36, 50.49)	-	-	-	50.18 (49.12, 51.25)	-	-	-	52.07 (50.69, 53.43)	-	-	-
Age												
Mean age	36.44 (36.13, 36.74)	36.12 (35.69, 36.56)	36.75 (36.41, 37.10)	*0.014*	36.35 (36.05, 36.65)	36.25 (35.82, 36.68)	36.45 (36.10, 36.80)	*0.438*	37.37 (36.94, 37.81)	36.88 (36.24, 37.52)	37.82 (37.33, 38.31)	*0.012*
Educational Attainment*												
No formal schooling	14.74 (13.43, 16.14)	11.33 (11.00, 12.82)	18.22 (16.60,19.96)		14.80 (13.49, 16.21)	11.32 (9.99, 12.80)	18.25 (16.63, 19.99)		14.71 (13.48, 16.03)	11.54 (10.20, 13.04)	17.62 (16.10, 19.24)	
Less than primary school	9.87 (9.09, 10.71)	10.65 (9.60, 11.80)	9.07 (8.23, 9.99)		9.85 (9.07, 10.69)	10.62 (9.55, 11.78)	9.09 (8.26, 10.0)		10.04 (9.30, 10.82)	10.74 (9.70, 11.89)	9.39 (8.48, 10.39)	
Primary school completed	20.58 (19.22, 22.02)	21.57 (19.85, 23.39)	19.58 (18.22, 21.01)	*<0.001*	20.67 (19.30, 22.11)	21.68 (19.96, 23.51)	19.67 (18.31, 21.11)	*<0.001*	21.04 (19.28, 22.92)	20.69 (18.42, 23.15)	21.37 (19.52, 23.34)	*<0.001*
Some secondary school	20.63 (19.03, 22.32)	21.03 (19.20, 22.99)	20.21 (18.53, 22.01)		20.51 (18.94, 22.18)	20.89 (19.08, 22.83)	20.14 (18.49, 21.89)		21.17 (19.57, 22.87)	22.08 (20.04, 24.27)	20.34 (18.58, 22.22)	
Secondary school or above	34.18 (32.03, 36.39)	35.41 (33.13, 37.76)	32.92 (30.49, 35.44)		34.16 (32.01, 36.38)	35.49 (33.20,37.85)	32.85 (30.42, 35.36)		33.04 (31.17, 34.97)	34.95 (32.56, 37.41)	31.29 (29.15, 33.51)	
Working *	54.37 (52.68, 56.05)	68.83 (67.04, 70.56)	39.58 (37.15, 42.06)	*<0.001*	54.08 (52.39, 55.76)	68.74 (66.97, 70.46)	39.54 (37.13, 41.99)	*<0.001*	53.07 (50.82, 55.30)	67.59 (65.23, 69.87)	39.70 (36.78, 42.74)	*<0.001*
Physical Activity												
Achieving 600 MET a week	84.79 (82.93, 86.47)	89.16 (87.88, 90.32)	80.31 (77.56, 82.80)	*<0.001*	84.62 (82.71, 86.35)	88.99 (87.68, 990.18)	80.28 (77.46, 82.84)	*<0.001*	84.36 (82.42, 86.12)	89.26 (87.64)	79.85 (77.18, 82.28)	*<0.001*
Alcohol consumption												
Mean number of drinks per week	3.86 (3.46, 4.26)	6.43 (5.76, 7.10)	1.24 (1.01. 1.46)	*<0.001*	3.81 (3.42, 4.21)	6.43 (5.76, 7.10)	1.22 (1.00, 1.44)	*<0.001*	3.67 (3.24, 4.10)	6.36 (5.58, 7.14)	1.19 (0.96, 1.42)	*<0.001*
Consuming alcohol during a week												
No alcohol use reported	70.35 (68.94, 71.73)	56.13 (54.24, 58.00)	84.90 (83.42, 86.27)	*<0.001*	70.67 (69.29, 72.01)	56.16 (54.28, 58.01)	85.06 (83.63, 86.39)	*<0.001*	71.68 (69.92, 73.38)	56.89 (54.47, 59.28)	85.28 (83.57, 86.85)	*<0.001*
Consume one alcoholic drink or more	29.64 (28.27, 31.06)	43.87 (42.00, 45.76)	15.10 (13.73, 16.58)		29.33 (27.99, 30.71)	43.84 (41.99, 45.72)	14.94 (13.61, 16.37)		28.32 (26.62, 30.81)	43.11 (40.72, 45.53)	14.72 (13.15, 16.43)	
Tobacco use (smoke or smokeless) *												
No tobacco use	69.454 (68.09, 70.79)	51.75 (49.78, 53.71)	87.57 (86.61, 88.47)		69.71 (68.33, 71.05)	51.50 (49.51, 53.48)	87.78 (86.83, 88.67)		70.90 (69.56, 72.21)	52.02 (49.89, 54.14)	88.29 (87.11, 89.37)	
Past use of tobacco	19.41 (18.26, 20.61)	31.87 (30.06. 33.73)	6.66 (6.00, 7.39)	*<0.001*	19.26 (18.10, 20.48)	32.10 (30.24, 34.01)	6.52 (5.87, 7.24)	*<0.001*	17.59 (16.48, 18.77)	30.20 (28.33, 32.13)	5.99 (5.32, 6.74)	*<0.001*
Current use of tobacco	11.14 (10.45, 11.87)	16.38 (15.24, 17.59)	5.77 (5.21, 6.39)		11.03 (10.35, 11.79)	16.40 (15.27, 17.60)	5.70 (5.15, 6.30)		11.50 (10.54, 12.54)	17.78 (16.02, 19.69)	5.72 (4.96, 6.59)	
Obesity measures												
Waist circumference												
Mean wasit circumference	85.25 (84.81, 85.70)	84.49 (84.02, 84.96)	86.03 (85.38, 86.68)	*<0.001*	85.21 (84.76, 85.66)	84.48 (84.01, 84.95)	85.96 (85.30, 86.62)	*<0.001*	86.13 (85.50, 86.76)	84.99 (84.34, 85.64)	87.22 (86.38, 88.06)	*<0.001*
High waist circumference**	26.11 (25.07, 27.17)	11.15 (10.32, 12.03)	41.42 (39.82, 43.04)	*<0.001*	26.02 (24.99, 27.08)	11.10 (10.28, 11.98)	41.33 (39.72, 42.96)	*<0.001*	28.86 (27.28, 30.50)	12.21 (10.94, 13.61)	44.73 (42.51, 46.97)	*<0.001*

	Population with data on waist circumference (n =23,273)				Population with data on hypertension status (*n*= 24,011)				Population with data on diabetes status (*n*= 17,724)			
	Overall	Male	Female	*p-value*	Overall	Male	Female	*p-value*	Overall	Male	Female	*p-value*
Blood pressure measures												
Mean systolic blood pressure	126.00 (125.65, 126.35)	128.33 (127.83, 128.82)	123.61 (123.14, 124.07)	*<0.001*	125.85 (125.50, 126.21)	128.49 (127.99, 128.99)	123.24 (122.78, 123.69)	*<0.001*	127.02 (126.56, 127.48)	129.51 (128.84, 130.19)	124.72 (124.18, 125.26)	*<0.001*
Mean diastolic blood pressure	79.87 (79.50, 80.25)	79.87 (79.34, 80.39)	79.88 (79.51, 80.26)	*0.945*	79.78 (79.41, 80.15)	79.92 (79.41, 80.43)	79.64 (79.28, 80.00)	*0.257*	80.46 (80.06, 80.56)	80.71 (80.09, 81.33)	80.23 (79.86, 80.60)	*0.136*
Hypertension*	26.95 (26.05, 27.86)	27.22 (25.88, 28.61)	26.67 (25.69, 27.67)	*0.487*	26.75 (25.88, 27.64)	27.49 (26.16, 28.85)	26.02 (25.07, 26.98)	*0.057*	30.04 (28.77, 31.34)	30.67 (28.75, 32.67)	29.46 (28.15, 30.80)	*0.251*
Self-reported diagnosed hypertension	11.30 (10.79, 11.83)	8.52 (7.87, 9.21)	14.15 (13.43, 14.90)	*<0.001*	11.32 (10.82, 11.85)	8.79 (8.15, 9.48)	13.83 (13.12, 14.58)	*<0.001*	14.23 (13.33, 15.17)	11.00 (9.91, 12.21)	17.19 (16.04, 18.41)	*<0.001*
Undiagnosed hypertension	15.65 (14.92, 16.41)	18.70 (17.55, 19.91)	12.52 (11.80, 13.27)		15.43 (14.71, 16.17)	18.69 (17.54, 19.91)	12.18 (11.49, 12.91)		15.18 (14.93, 16.73)	19.67 (18.17, 21.26)	12.26 (11.41, 13.18)	
Blood glucose measures												
Blood glucose												
Mean BGL	4.84 (4.80, 4.88)	4.79 (4.74, 4.84)	4.89 (4.84, 4.95)	*0.001*	4.83 (4.79, 4.87)	4.79 (4.74, 4.84)	4.87 (4.82, 4.93)	*0.008*	4.82 (4.76, 4.89)	4.73 (4.67, 4.80)	4.91 (4.82, 5.00)	*<0.001*
Diabetes*	5.80 (5.20, 6.45)	4.89 (4.24, 5.62)	6.69 (5.94, 7.54)	*<0.001*	5.80 (5.22, 6.44)	4.94 (4.30, 5.67)	6.63 (5.89, 7.44)	*<0.001*	10.02 (8.98, 11.17)	7.59 (6.48, 8.87)	12.26 (10.90, 13.76)	*<0.001*
Self-reported diagnosed diabetes	3.37 (2.84, 3.99)	2.55 (2.06, 3.14)	4.18 (3.49, 5.01)	*<0.001*	3.36 (2.84, 3.97)	2.58 (2.10, 3.18)	4.11 (3.43, 4.91)	*<0.001*	7.54 (6.51, 8.71)	5.22 (4.23, 6.43)	9.67 (8.31, 11.21)	*<0.001*
Undiagnosed diabetes	1.76 (1.50, 2.05)	1.72 (1.35, 2.18)	1.79 (1.51, 2.14)		1.78 (1.52, 2.08)	1.72 (1.36, 2.19)	1.83 (1.51, 2.22)		1.91 (1.61, 2.27)	1.76 (1.33, 2.31)	2.05 (1.67, 2.51)	

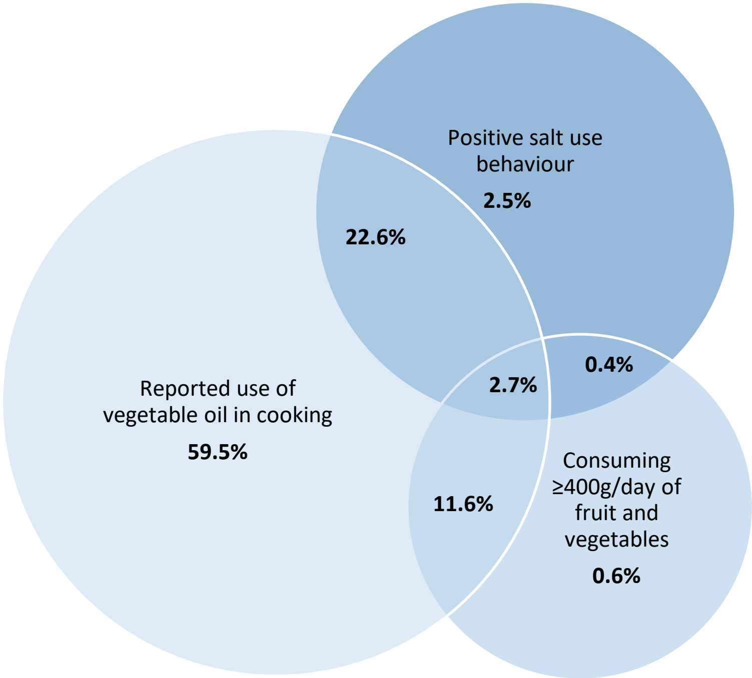
* Percent accounts for sampling design with survey weights re-scaled by the survey's sample size such that all countries contribute equally to estimates, for each outcome sample.

**Definition of high waist circumference, waist ≥ 102cm for males and waist ≥ 88cm for females

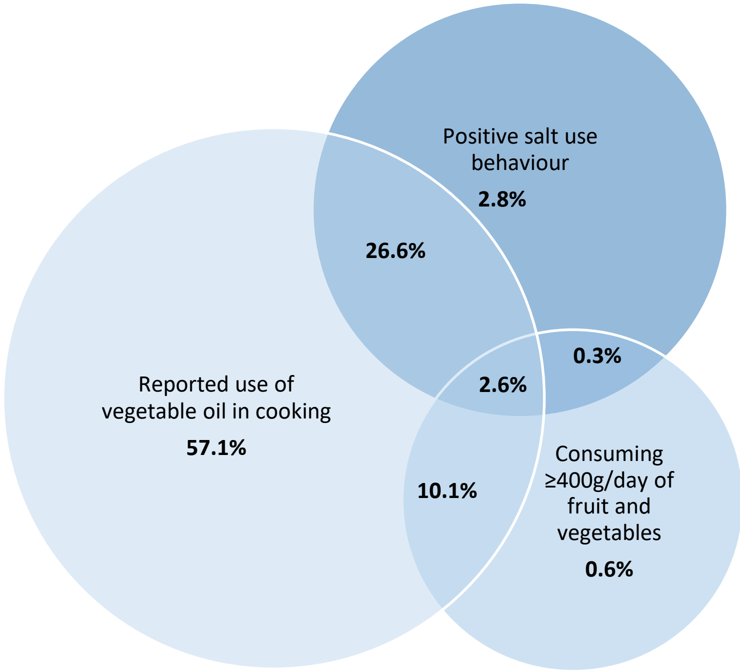
Supplementary table 4. Prevalence of dietary behaviours among participants with data on waist circumference (n=23,273) hypertension (n=24,011), or diabetes (n=17,724) status

	Population with data on waist circumference (*n* =23,957)				Population with data on hypertension status (*n*= 24,719)				Population with data on diabetes status (*n*= 17,724)			
	Overall	Male	Female	*p-value*	Overall	Males	Females	*p-value*	Overall	Male	Female	*p-value*
Salt use behaviour												
Positive salt behaviour (>50%)	29.19 (26.64, 31.90)	27.18 (24.59, 29.94)	31.26 (28.46, 34.22)	*<0.001*	29.28 (26.77, 31.92)	27.24 (24.64, 30.01)	31.30 (28.59, 34.13)	*<0.001*	30.68 (27.90, 33.61)	27.85 (24.87, 31.03)	33.29 (30.30, 36.43)	*<0.001*
Fruit and vegetable consumption												
Met WHO guidelines (400g per day)	13.96 (12.75, 15.26)	14.67 (13.08, 16.42)	13.23 (12.09, 14.46)	*0.047*	13.99 (12.79, 15.30)	14.76 (13.18, 16.50)	13.22 (12.09, 14.44)	*0.025*	13.86 (12.70, 15.11)	14.84 (13.23, 16.60)	12.96 (11.76, 14.25)	*0.027*
Fat and oil used in cooking												
Vegetable	93.39 (92.22, 94.40)	93.05 (91.57, 94.29)	93.75 (92.67, 94.68)		93.40 (92.21, 94.42)	93.01 (91.53, 94.25)	93.79 (92.67, 94.74)		93.39 9(91.97, 94.59)	92.85 (90.97, 94.36)	93.90 (92.57, 95.00)	
Animal	2.48 (2.01, 3.06)	2.54 (1.92, 3.35)	2.42 (1.97, 2.97)		2.48 (2.01, 3.05)	2.57 (1.96, 3.38)	2.38 (1.94, 2.92)		2.22 (1.85, 2.69)	2.43 (1.87, 3.16)	2.04 (1.68, 2.48)	
Other	2.97 (2.14, 4.12)	3.13 (2.11, 4.61)	2.82 (2.09, 3.78)	*0.500*	2.97 (2.13, 4.13)	3.16 (2.13, 4.64)	2.78 (2.04, 3.77)	*0.521*	3.14 (2.11, 4.64)	3.41 (2.11, 5.47)	2.89 (2.00, 4.14)	*0.482*
None in particular	0.47 (0.36, 0.62)	0.49 (0.34, 0.72)	0.46 (0.33, 0.63)		0.47 (0.36, 0.62)	0.49 (0.33, 0.71)	0.45 (0.33, 0.62)		0.59 (0.41, 0.84)	0.59 9(0.34, 0.99)	0.59 (0.40, 0.88)	
None	0.68 (0.50, 0.91)	0.79 (0.52, 1.20)	0.68 (0.50, 0.91)		0.69 (0.51, 0.91)	0.77 (0.51, 0.12)	0.60 (0.44, 0.80)		0.65 (0.48, 0.87)	0.72 (0.45, 1.13)	0.58 (0.42, 0.81)	

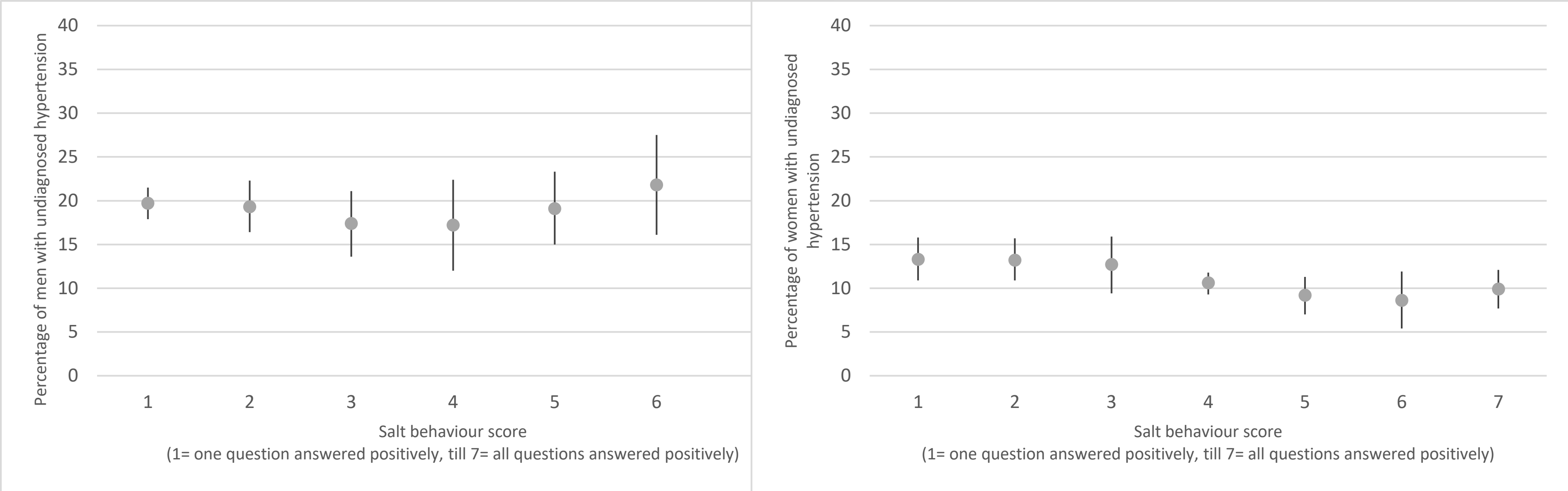
* Percent accounts for sampling design with survey weights re-scaled by the survey's sample size such that all countries contribute equally to estimates, for each outcome sample.



Supplementary figure 1a. Weighted proportion of men (n=8,551) reporting positive dietary behaviours, in seven low-and middle-income countries



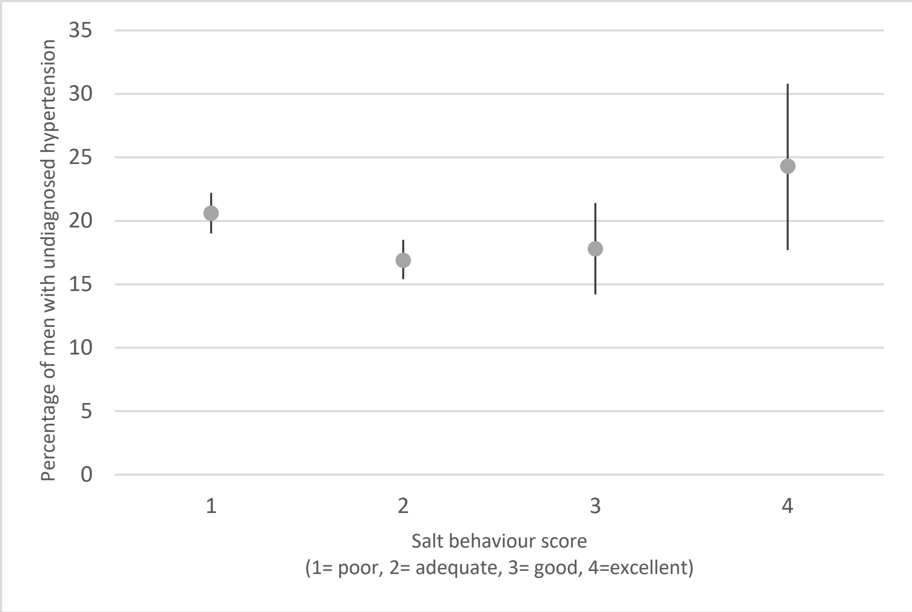
Supplementary figure 1b. Weighted proportion of women (n=14,960) reporting positive dietary behaviours, in seven low-and middle-income countries

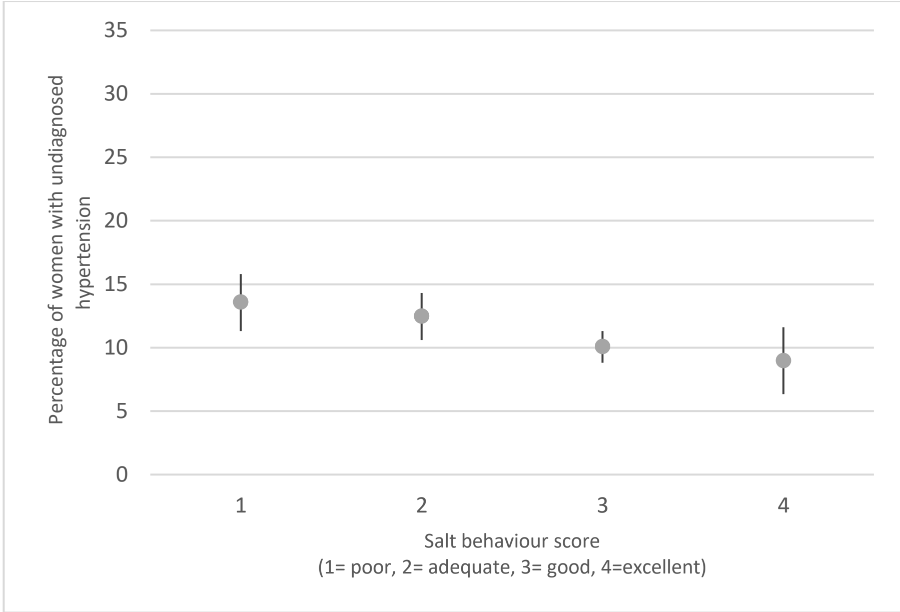


Supplementary figure 2.a. Percentage (95% confidence interval) of men with undiagnosed hypertension, by the self-report of salt behaviour on a seven point scale*

Supplementary figure 2.b. Percentage (95% confidence interval) of women with undiagnosed hypertension, by the self-report of salt behaviour on a seven point scale*

*Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use, tobacco use and waist circumference





Supplementary figure 3.a. Percentage (95% confidence interval) of men with undiagnosed hypertension, by the self-report of salt behaviour on a four-point scale*

Supplementary figure 3.b. Percentage (95% confidence interval) of women with undiagnosed hypertension, by the self-report of salt behaviour on a four-point scale*

*Model adjusted for type of fat and oil used in cooking, age, education, working status, physical activity, alcohol use, tobacco use and waist circumference

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Chapter 5. The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank

5.1 Chapter overview

This chapter provides an analysis of sex differences in dietary intake and the association with the outcomes of all-cause mortality, CVD and dementia in a UK cohort. This chapter used data from the UK given comparable in-depth dietary data and prospectively collected health outcome data is not currently available in LMICs. Given the focus was on the UK, and that the focus was on sex differences, the leading causes of death for women and men in the UK were investigated (dementia and CVD, respectively). This chapter is also formed by a published manuscript.

The study used data from the UK Biobank. The UK Biobank is a large biomedical database funded by the Welcome Trust medical charity, Medical Research Council, Department of Health, Scottish Government and the Northwest Regional Development Agency. The database consists of medical and genetic data from approximately half a million volunteer participants aged between 40 and 69 years at baseline. Baseline data collection was conducted between 2006 and 2010, and participants data is linked to general practitioner data, hospital medical records and death registry data. A 24-hour diet recall was conducted during baseline assessment, with follow-up diet recalls emailed to participants to complete. The 24-hour diet recall used was the "Oxford WebQ" a validated online and self-administered tool developed specifically for the UK context. The study population for the present study was limited to individuals with two or more 24-hour diet recall measures, to get a better estimate of habitual intake. Dietary intake was conceptualised in the form of macronutrient intake and investigated in terms of level of individual macronutrient intake, compliance to dietary recommendations and as a cluster analysis. The cluster analysis was used to define specific groupings of dietary intake, characterising participants based on the composition of their diets in terms of macronutrient intake. This approach considers the fact that macronutrients are not eaten in isolation in a diet (*see the methods section within this chapter for more information on the UK Biobank and the diet methodology used*).

As with the previous chapter (Chapter 4), some sex differences in dietary intake were identified along with some sex differences in the relationship between diet and study outcomes. However, the size of these differences was modest. Instead diets of both women and men need to be improved. It is possible that sex differences identified could become more pronounced if diets are improved. It is also possible that more pronounced sex difference would have been identified if there was more variation in diets within the population studied. Both chapter 4 and chapter 5 highlight the need to improve diets generally, although given the small sex differences identified, sex and gender considerations should still be included in nutrition research and policy setting to ensure that diets are improved equitably.

5.2 Publication details

McKenzie BL, Harris K, Peters SAE, Webster J, Woodward M. The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease, and dementia: findings from 120,963 women and men in the UK Biobank. *British Journal of Nutrition*. 2021 Jul 14:1-24.

5.2.1 Author contributions

As the first author on this publication, I contributed significantly to this piece of work. This piece of work followed on from a publication conducted by MW and SP in 2018, and as such the original research question was posed by MW and SP. I further developed this research question and developed a research plan in consultation with KH. I conducted the statistical analysis in collaboration with KH. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows (and as published): The research question was posed by M. W. and S. P. and was further developed by BLM and K. H. BLM and KH conducted the statistical analyses. BLM wrote the first draft of the manuscript. MW, SP and JW provided critical insights throughout the project. All authors reviewed and approved the final manuscript.

5.3 Manuscript

Abstract

This study aimed to investigate the association between individual, and combinations of, macronutrients with premature death, cardiovascular disease (CVD) and dementia. Sex differences were investigated. Data were utilised from a prospective cohort of 120,963 individuals (57% female) within the UK Biobank, who completed ≥two 24-hour diet recalls. The associations of macronutrients, as percentages of total energy intake, with outcomes were investigated. Combinations of macronutrients were defined using k-means cluster analysis, with clusters explored in association with outcomes. There was a higher risk of death with high carbohydrate intake (Hazard ratios (HRs), 95% confidence intervals (95% CI) upper v lowest third 1.13 (1.03, 1.23)), yet a lower risk with higher intakes of protein (upper v lowest third 0.82 (0.76, 0.89)). There was a lower risk of CVD with moderate intakes (middle v lowest third) of energy and protein (sub distribution HRs (SHR), 0.87 (0.79, 0.97) and (0.87 (0.79, 0.96)) respectively). There was a lower risk of dementia with moderate energy intake (SHR 0.71 (0.52, 0.96)). Sex differences were identified. The dietary cluster characterised by low carbohydrate, low fat and high protein was associated with a lower risk of death (HR 0.84 (0.76, 0.93)) compared to the reference cluster, and a lower risk of CVD for men (SHR 0.83 (0.71, 0.97)). Given that associations were evident, both as single macronutrients and for combinations with other macronutrients for death, and for CVD in men, we suggest that the biggest benefit from diet-related policy and interventions will be when combinations of macronutrients are targeted.

Introduction

In the United Kingdom (UK), the burden of disease due to poor diets is estimated to be 10% of the total disease burden [1]. Previous studies have identified increased risk of non-communicable disease and mortality with high saturated and trans-fat [2-4], high intake of added sugar [5], and decreased risks with higher protein [6, 7] and fibre intake[4, 8]. The vast majority of these studies were observational, with a focus on cardiovascular disease (CVD). Evidence of the relationship between diet and disease has been used to set dietary recommendations for energy and macronutrients, globally and in the UK [9]. These recommended values provide an insight into what a standard diet for a "healthy" individual should be made up of, in terms of energy, carbohydrates, fats and protein. Dietary recommendations generally provide a cut-off for intake of individual macronutrients, for example fat intake should be less than 35% of energy intake a day [9]. However, given that nutrients are not eaten in isolation and many nutrients interact with each other, it becomes difficult to explore the relationship between the individual dietary recommendations and disease outcomes [10].

In order to implement effective food policies and set relevant guidelines, the risk between poor diets and disease needs to be frequently monitored, particularly in relation to diseases contributing the highest burden. In the UK the leading cause of death for men is ischaemic heart disease, for women it is dementia [11]. While it is acknowledged that diet is associated with CVD, the relationship between diet and dementia is less well established [12]. Given there is a vascular component to dementia, it is plausible that disease risk would be influenced by dietary intake in a similar manner to CVD [12]. The treatment options for dementia are currently limited, therefore the identification of modifiable risk factors to prevent dementia are urgently needed.

Participants in the UK Biobank [13] provided data on a range of risk factors, including dietary intake, at baseline and their data are linked to hospital admission data and mortality records. Previously, we utilised these data to explore sex differences in macronutrient intake [14] and identified low compliance to dietary recommendations across the study population, with substantial differences in meeting dietary recommendations between men and women. We hypothesised that such low compliance may relate to health outcomes, with the potential for differing impacts by sex.

Therefore, the aims of the present study were to use the UK Biobank data to investigate (1) the association between individual macronutrients with all-cause mortality, CVD and dementia, (2) the association between combinations of macronutrients with all-cause mortality, CVD and dementia, and (3) any sex differences in the associations of individual macronutrients and combinations of macronutrients with these outcomes.

Methods

Data source

The UK Biobank [15] contains information on over half a million women and men, aged 40-69 years at baseline. Participants volunteered to join the study and completed baseline assessment between 2006 and 2010. Assessments were carried out across 22 research centres in the UK and involved the collection of self-reported (questionnaire) data, physical measurements, and biological samples.

This research has been conducted using the UK Biobank Resource (application No 2495). Permission to use the UK Biobank Resource was approved by the access subcommittee of the UK Biobank Board. All participants provided electronic informed consent. The UK Biobank has obtained Research Tissue Bank approval from its governing research ethics committee, as recommended by the National Research Ethics Service. Additional ethical approval for the present study was gained via the University of New South Wales (HC 20056). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Dietary measures

A web-based 24-hour dietary assessment, "Oxford WebQ", [16, 17] was introduced into the UK Biobank study protocol in 2009. The assessment includes questions on the consumption of 206 types of food and 32 types of drinks and asks about consumption in the previous 24 hours. Participants who completed their baseline assessment during the last year of recruitment completed the 24-hr diet recall survey at the assessment centre. All other participants who provided an email address were invited to complete the 24-hr diet recall survey online, at four points ranging between 2-6 years post baseline data collection. Nutrients from the surveys were calculated based on the frequency, standard portion size, and nutrient composition of the food selected [15, 16]. For the present study, the nutrients of interest were total energy intake, fat intake (total, saturated, polyunsaturated), carbohydrate intake (total, sugar, fibre), and protein intake. In order to estimate habitual energy intake, two or more 24-hour diet recalls are required [18]. It was hypothesised that people who have an event (for example a cardiovascular event or a dementia diagnosis) may change their diet post event [19]. As such, only individuals with two or more 24-hour diet recalls, without an event occurring between measures, were included in this study and the average of their dietary intake values were calculated. Energy intakes more than four standard deviations from the mean were considered implausible and individuals with these extreme measures were excluded from analyses (n=1,034) [20].

Outcome measures

Outcomes analysed were all-cause mortality (death), fatal or non-fatal CVD, and fatal or non-fatal dementia recorded up until 30th of June 2020. Mortality, and cause of death, were identified through linkage to the Office for National Statistics mortality records. Non-fatal CVD and dementia events were determined through linkage to Hospital Episode Statistics for England, Scottish Morbidity Record data for Scotland, and the Patient Episode Database for Wales. Diagnoses were recorded using the International Classification of Diseases (ICD -10) coding system, with CVD defined using I60, I61, I63, I64, I21, I22, I23, I241, I252, comprising stroke (I60, I61, I63, I64) and myocardial infarction (I21, I22, I23, I241, I252). Dementia was comprised of ICD-10 codes A81.0, F00, F01, F02, F03, F05, G30, G31.0, G31.1, G31.8, and

I67.3, with subtype Alzheimer's disease (F00, G30); and vascular dementia (F01, I67.3). Individuals with a self-reported history of CVD or dementia diagnosis at baseline were excluded from all analyses.

Statistical analysis

Dietary intake was assessed as mean energy intake and macronutrients as a percentage of total energy intake (carbohydrate, sugar, fibre, fat, saturated fat, polyunsaturated fat, protein) and split into thirds whereby the lowest intake third was the reference (**supplementary table 1**). The percentage of the population not meeting dietary recommendations was also assessed, in relation to the UK dietary recommendations [9]. In order to define prevalent combinations of macronutrient intakes, cluster analysis was undertaken using the k-means method, which partitions individuals into clusters such that individuals in the same cluster are as similar as possible [21]. Individuals were clustered based on the percentage of total energy intake of carbohydrate, sugar, fibre, total fat, saturated fat, polyunsaturated fat, and protein. Clusters were standardised, and naming and definition of clusters was based on the standardised values, with a greater than 0.5 difference from 0 used to name the clusters as "high" or "low" in a certain macronutrient. The largest cluster was used as the reference in the models. Further details on the approach to identifying and defining the clusters are provided in the **supplementary material**.

For baseline characteristics, categorical variables are presented as number (percentage) and continuous variables are presented as means (standard deviation). Cox proportional hazard models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for all-cause mortality, CVD, and dementia. Dietary intake as an exposure of interest was investigated in three forms: 1) absolute intake of energy and percentage energy intake of macronutrients (in thirds), 2) not meeting vs meeting dietary recommendations, and 3) combinations of macronutrients (standardised cluster variables). Dietary variables were inputted into separate Cox models for each outcome of interest. For the population as a whole, base models adjusted for age, smoking status, sex and socioeconomic status (Townsend deprivation index). Final (multivariable) models were further adjusted for height, weight, physical activity (mean total metabolic equivalents (METs)), mean alcohol intake, systolic blood pressure, diabetes, lipid lowering medication, and anti-hypertensive medication. Competing risk analyses, producing sub-distribution HRs, were conducted for CVD and dementia accounting for all-cause mortality as a competing risk, since death may preclude CVD and dementia from occurring [22]. A sensitivity analysis was conducted, looking at different types of dementia (Alzheimer's disease and vascular dementia, separately). Analyses were also conducted investigating sex interactions with confounders and exposures of interest. For these analyses, the same confounders were used within models with the exception of sex, which was used as an interaction term instead of a confounding variable. Analyses were performed using Stata version 16.0 and R statistical software.

Table 1. Summary characteristics of participants with two or more dietary assessment measures, by sex

Characteristics	Overall	Females	Males
n	120,963	68,927	52,036
Age, years (SD)	55.9 (7.8)	55.5 (7.7)	56.5 (7.9)
Ethnicity, white (%)	116,755 (96.9)	66,510 (96.8)	50,245 (97.0)
Socioeconomic status quintiles (%)			
1st Least deprived	48,335 (40.0)	26,880 (39.0)	21,455 (41.3)
2nd	25,551 (21.1)	14,728 (21.4)	10,823 (20.8)
3rd	18,511 (15.3)	10,693 (15.5)	7,818 (15.0)
4th	15,664 (13.0)	9,214 (13.4)	6,450 (12.4)
5th Most deprived	12,760 (10.6)	7,330 (10.6)	5,430 (10.4)
Smoking status, never smoked (%)	69,940 (57.9)	42,195 (61.3)	27,745 (53.4)
BMI, kg/m^2 (SD)	26.6 (4.6)	26.2 (4.9)	27.2 (4.0)
Overweight or obese (%)	71,985 (59.6)	36,109 (52.5)	35,876 (69.1)
Weight, kg (SD)	76.6 (15.5)	70.2 (13.6)	85.0 (13.7)
Height, cm (SD)	169.3 (9.2)	163.6 (6.2)	176.8 (6.7)
Low physical activity (%)[1]	21,641 (18.9)	12,194 (18.8)	9,447 (18.9)
Systolic blood pressure (mmHg)	136.6 (18.2)	133.7 (18.7)	140.4 (16.9)
Diastolic blood pressure (mmHg)	81.8 (10.0)	80.2 (9.8)	83.9 (9.7)
Blood pressure categories (%)[2]			
Normal	19,978 (16.5)	15,505 (22.5)	4,473 (8.6)
Elevated	16,023 (13.3)	9,709 (14.1)	6,314 (12.1)
Stage 1 hypertension	33,372 (27.6)	18,559 (27.0)	14,813 (28.5)
Stage 2 hypertension	51,499 (42.6)	25,082 (36.4)	26,417 (50.8)
Diabetes (%)	4092 (3.4)	1693 (2.5)	2399 (4.6)
Lipid lowering medication (%)	11,598 (9.6)	4507 (6.5)	7091 (13.6)
Anti-hypertensive medication (%)	14,072 (11.6)	6559 (9.5)	7513 (14.4)
Dietary macronutrient intakes			
Energy (kJ) (SD)	8,819 (2,237)	8,241 (1,981)	9,586 (2,322)
Fats (g)			
Total fat (g) (SD)	78.2 (26.2)	73.5 (23.7)	84.4 (27.8)
% EI	32.5 (5.8)	32.7 (5.8)	32.3 (5.8)
Saturated fat (g)	30.0 (11.4)	28.1 (10.3)	32.5 (12.1)
% EI	12.5 (2.9)	12.5 (2.9)	12.4 (3.0)
Polyunsaturated fat (g)	14.4 (6.1)	13.6 (5.7)	15.4 (6.5)
% EI	6.0 (1.9)	6.1 (1.9)	5.9 (1.9)
Carbohydrates (g)			

Characteristics	Overall	Females	Males
Total carbohydrate (g)	253.2 (74.5)	239.2 (69.2)	271.8 (77.2)
% EI	48.9 (7.6)	49.3 (7.5)	48.3 (7.7)
Total sugar (g)	119.9 (42.5)	115.8 (41.5)	125.3 (45.4)
% EI	23.2 (6.4)	23.9 (6.4)	22.3 (6.2)
Fibre (g)	16.4 (5.8)	16.2 (5.6)	16.7 (6.0)
% EI	1.5 (0.5)	1.6 (0.5)	1.4 (0.5)
Total protein (g)	82.2 (21.3)	78.4 (19.5)	87.1 (22.5)
% EI	16.1 (3.1)	16.4 (3.2)	15.6 (2.9)

Values are as at baseline except for dietary variables which are averaged over all recorded values. Some variables may not sum to the overall numbers due to missingness. [1]low physical activity defined as <600 total MET a week. [2]Blood pressure categories calculated using the American Heart Association's 2017 Hypertension Clinical Guidelines [23]. Normal - SBP <120 mmHg and DBP <80 mmHg, Elevated – SBP 120-129 mmHg and DBP < 80 mmHg, Stage 1 hypertension SBP 130-139 mmHg or DBP 80-89 mmHg, stage 2 hypertension SBP ⩾ 140 mmHg or DBP ⩾90 mmHg. BMI = body mass index, SD = standard deviation, EI = energy intake.

Results

Characteristics

Twenty percent of the UK Biobank population completed two or more 24-hr diet recalls (n=120,963; 57% women). Of these, 45,770 people completed two measures, 40,567 completed three measures, 29,106 completed four measures, and 5,520 completed diet recalls in all five surveys. Their mean age was 56 years (55.5 years for women and 56.5 years for men) at baseline, and 60% (53% of women and 69% of men) were classified as overweight or obese (BMI ≥25 kg/m^2), **table 1.** During a mean of 11.1 years follow-up, there were 2,616 cardiovascular events, 292 dementia diagnoses, and 4,040 deaths.

Compared to the population who did not complete two or more 24-hr diet recalls, this population was more likely to live in the least deprived areas, to have never smoked, and a lower percentage had overweight or obesity (**supplementary table 2**).

Dietary intake

Mean absolute intakes of energy and macronutrients were higher for men than women. However, as a percentage of energy intake, macronutrient intakes were higher for women (**table 1)**. When looking at macronutrient intake in terms of dietary recommendations, 38% of the population exceeded energy intake recommendations. For carbohydrates, 55% did not meet recommendations, while 63% exceeded sugar intake recommendations, and the vast majority (98%) did not meet fibre recommendations. For fat intake, a third of the population (33%) exceeded recommendations, with 69% exceeding saturated fat and 55% not meeting polyunsaturated fat recommendations. Twelve percent of the population did not meet protein recommendations (**supplementary table 3).**

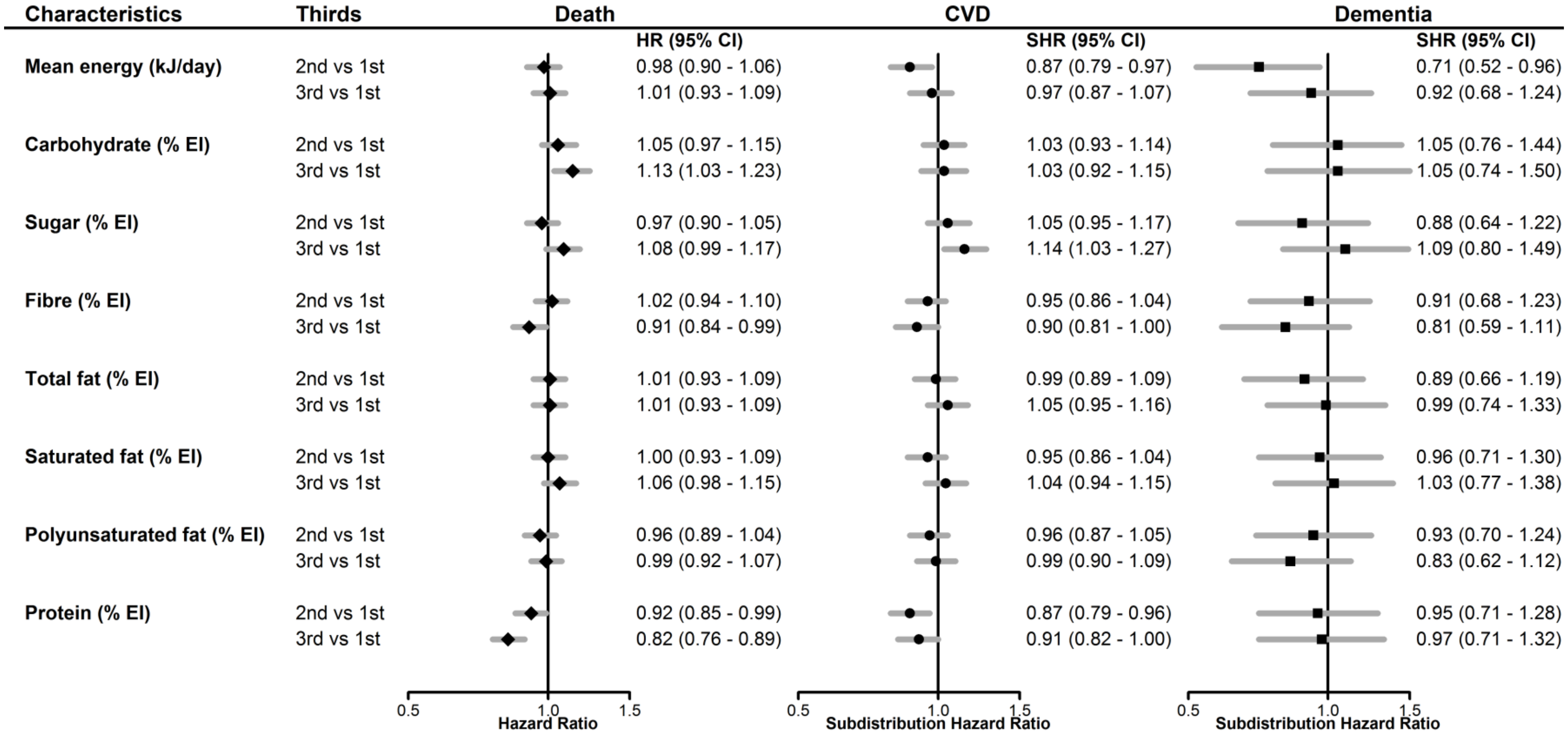

Figure 1. Macronutrient intake (as a percentage of total energy intake, in thirds) and multiple adjusted hazard ratios (HRs) for all-cause mortality, subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) and dementia, with 95% confidence intervals (CIs). Models adjusted for age, smoking, sex, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication (n 114,102)

Association of individual macronutrient intakes with outcomes

In the multivariable models, only carbohydrate and protein intake were associated with all-cause mortality (**figure 1**). The highest third of total carbohydrate intake (as a percentage of total energy intake) was associated with a higher risk of death, compared with the lowest third (HR 1.13, 95% CI 1.03, 1.23). A higher percentage energy intake of protein was associated with a lower risk of death (HR middle v lowest third of intake 0.92, 95% CI 0.85, 0.99, highest v lowest third 0.82, 95% CI 0.76, 0.89). Individuals with the middle third of mean energy intake had a lower risk of CVD (standardised hazard ratio (SHR) middle v lowest third 0.87, 95% CI 0.78, 0.96), individuals with high sugar intake had a higher risk of CVD (SHR highest v lowest third of intake, 1.14, 95% CI 1.03, 1.27) and individuals with the middle third of protein intake had a lower risk of CVD (SHR middle v lowest third 0.87 95% CI 0.79, 0.96). For dementia, individuals with the middle third of mean energy intake had a lower risk (SHR middle v lowest third 0.71, 95% CI 0.52, 0.96). Results from the models adjusted for age, smoking, sex and deprivation are reflective of the findings from the multivariable adjusted model (**supplementary figure 1**). Additionally, for dementia, we investigated the association between energy and macronutrient intake for Alzheimer's disease and vascular dementia, separately, finding no association between variables of interest and outcomes (**supplementary table 4**).

Sex differences in associations between dietary intake and health outcomes were identified, such that, for women those with the highest third of carbohydrate intake had a higher risk of death (HR highest v lowest third of intake, 1.17, 95% CI 1.02, 1.34), whereas for men, those with the highest third of sugar intake had a higher risk of death (HR highest v lowest third of intake, 1.17, 95% CI 1.05, 1.31). Women with the highest third of sugar intake had a lower relative risk of death compared with men (ratio of HRs, RHR, women to men, highest v lowest third of intake, 0.81, 95% CI 0.69, 0.96). Conversely, relative to men, women with moderate total fat intake had a higher risk of death (RHR, women to men, middle v lowest third of intake, 1.20, 95% CI 1.03, 1.41), **supplementary table 5**. For CVD, men with a moderate energy intake had a lower risk (SHR middle v lowest third of intake, 0.83, 95% CI 0.72, 0.95). Men with moderate and high protein intakes also had a lower risk of CVD (HR middle v lowest third of intake, 0.87, 95% CI 0.77, 0.98, highest v lowest third of intake, 0.87, 95% CI 0.77, 0.99). These associations were not identified for women, **supplementary table 6**. For dementia, moderate sugar intake was associated with a lower risk in women (HR middle v lowest third, 0.51, 95% CI 0.30, 0.85), and a lower relative risk compared to men (RHR women compared to men, middle v lowest third of intake 0.40, 95% CI 0.21, 0.77). Additionally, women with the highest third of fibre intake had a lower risk of dementia (HR highest v lowest third of intake, 0.57, 95% CI 0.37, 0.88), and a lower relative risk compared to men (RHR women compared to men, highest v lowest third of intake 0.52, 95% CI 0.28, 0.96). Conversely, women with the highest third of saturated fat intake had a higher risk of dementia (HR highest v lowest third of intake 1.69, 95% CI 1.06, 2.68), and a higher risk relative to men (RHR women compared to men, highest v lowest third of intake 2.49, 95% CI 1.33, 4.63), **supplementary table 7**.

Models investigating the association of compliance to the individual dietary recommendations (not meeting compared to meeting recommendations), produced similar results to the individual macronutrient analysis (**supplementary table 8**).

Cluster analysis

Cluster analysis identified five distinct dietary clusters (**table 2**, **supplementary figure 2**); low polyunsaturated fat and low protein intake (*up*, n=30,231), low carbohydrate, low fat and high protein intake (*cfP*, n= 22,700), high carbohydrate and low fat intake (*Cf*, n= 22,215), low carbohydrate and high fat intake (*cF*, n=23,668), and high polyunsaturated fat intake (*U*, n= 22,149). Sociodemographic characteristics differed by cluster (**figure 2**, **supplementary table 9**), a higher proportion of people within the *up* and *cfP* dietary clusters were men (46.7% and 47.0%, respectively), whereas a higher proportion of people within the *Cf* and *U* were women (64.7% and 61.2%, respectively), compared to the study mean (43% male). A higher proportion of people within the *Cf* dietary cluster had never smoked (62.6%, compared to the study mean, 57.9%).

Table 2. Dietary characteristics of clusters; macronutrients shown as a percentage of total energy intake

Cluster	**Cluster size**	**Energy (kJ/day)**[1]	**Carbohydrate (CHO)**	**Sugar**	**Fibre**	**Fat**	**Saturated fat (SFA)**	**Polyunsaturated fat (PUFA)**	**Protein**
up[2] - low PUFA, low protein	30231	9460.86	52.19	25.96	1.32	32.31	13.66	5.03	14.30
cfP - low CHO low fat, high protein	22700	8173.76	45.06	20.23	1.41	29.47	11.11	5.27	18.61
Cf – high CHO, low fat	22215	7950.70	57.47	30.33	2.01	25.80	9.52	4.96	16.39
cF – low CHO, and high fat	23668	9245.26	40.98	17.52	1.24	39.45	15.77	6.66	16.27
U– high PUFA	22149	9023.98	48.15	21.53	1.72	35.34	11.62	8.37	15.48
Clusters, standardised[3]									
up	30231	NA	0.43	0.43	-0.40	-0.04	0.41	-0.51	-0.58
cfP	22700	NA	-0.50	-0.47	-0.22	-0.53	-0.46	-0.38	0.82
Cf	22215	NA	1.13	1.11	0.98	-1.16	-1.00	-0.54	0.10
cF	23668	NA	-1.04	-0.89	-0.57	1.19	1.13	0.35	0.06
U	22149	NA	-0.10	-0.26	0.40	0.48	-0.28	1.25	-0.20

[1]The mean energy intake per cluster is shown here for reference; since macronutrients were included as a percentage of total energy intake, mean energy intake was not used to determine the dietary clusters. [2]Naming and definition of clusters was based on the standardised values, with a greater than 0.5 difference from 0 used to name the clusters as “high” or “low” in certain macronutrients. [3]Clusters were standardised to aid comparison, the standardised clusters were then used in analyses

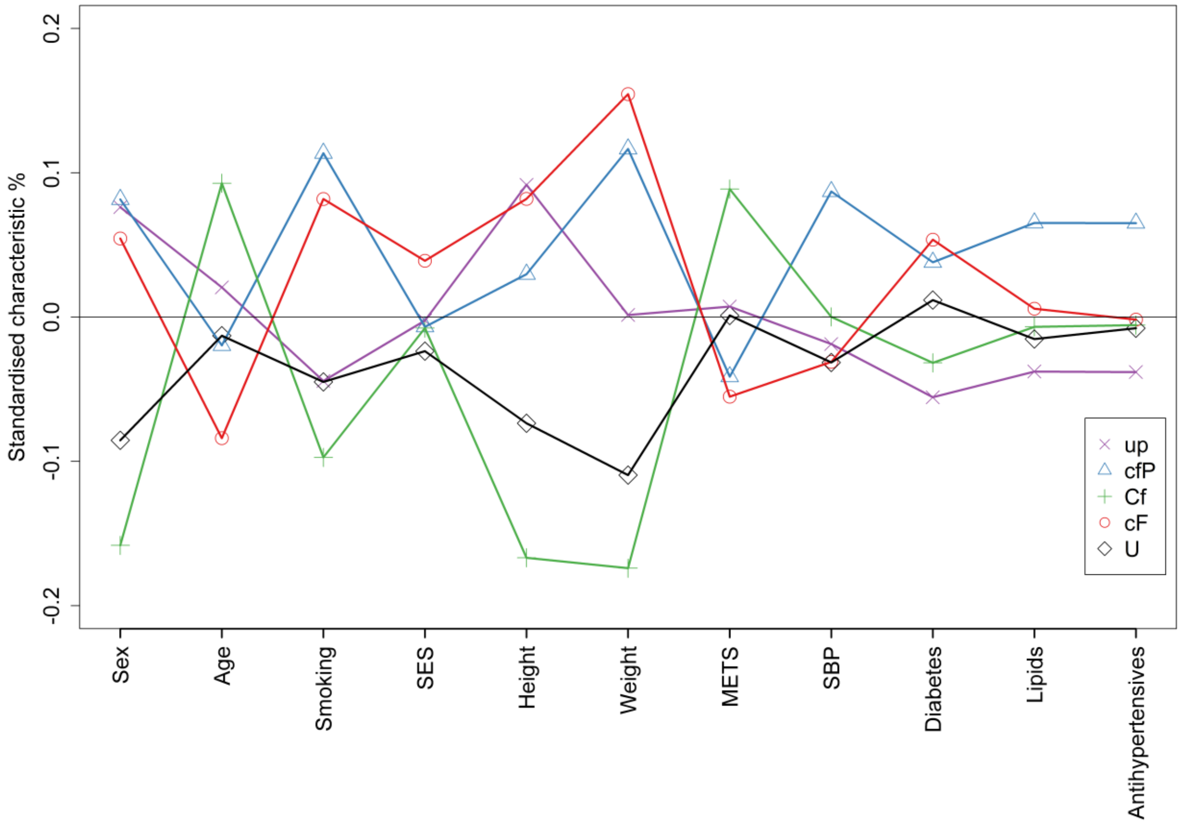

Figure 2. Characteristics of individuals within the identified macronutrient clusters. Macronutrient clusters: up – low polyunsaturated fat, low protein, cfP – low carbohydrate, low fat, high protein, Cf – high carbohydrate, low fat, cF – low carbohydrate and high fat, U– high polyunsaturated fat. Characteristics: SES - socioeconomic status measured by Townsend score, METS -metabolic equivalents, SBP - systolic blood pressure, Lipids - lipid lowering medication. For each characteristic on the graph, negative points imply a higher proportion of women, younger age, a higher proportion having never smoked, higher proportion living with a higher deprivation level, lower height and weight, lower METs, lower SBP, lower proportion with diabetes, lower proportion on lipid lowering medication and lower proportion on antihypertensive medication compared to the study population mean.

Association of combinations of macronutrients with outcomes

From the models for the population as a whole, with multiple adjustments (**figure 3**), the *cfP* dietary cluster was associated with a lower risk of all-cause mortality compared to the *up* (reference) dietary cluster (HR *cfP* v *up* 0.84, 95% CI 0.76, 0.93). There were no associations identified between the dietary clusters with the risk of CVD or dementia. Results from the models adjusted for age, smoking, sex and deprivation are reflective of the findings from the multivariable adjusted model (**supplementary figure 3**).

From the sex-specific models with multiple adjustments, the *cfP* cluster was associated with a lower risk of all-cause mortality for women and men (HR *cfP* vs *up* cluster 0.82, 95% CI 0.70, 0.96 and 0.86, 95% CI 0.75, 0.98, women and men, respectively), **supplementary table 10**. Men within the *cfP* cluster had a lower risk of CVD (SHR *cfP* vs *up* cluster 0.83, 95% CI 0.71, 0.97), **supplementary table 11**. From the model with basic adjustments, relative to men, women within the *U* dietary cluster had a lower relative risk of dementia (ratio of SHR's women to men, *U* vs *up* cluster, 0.40, 95% CI 0.19, 0.84). This association was attenuated in the model with multiple adjustments (ratio of SHR's women to men, *U* vs *up* cluster, 0.49, 95% CI 0.23, 1.05), **supplementary table 12**.

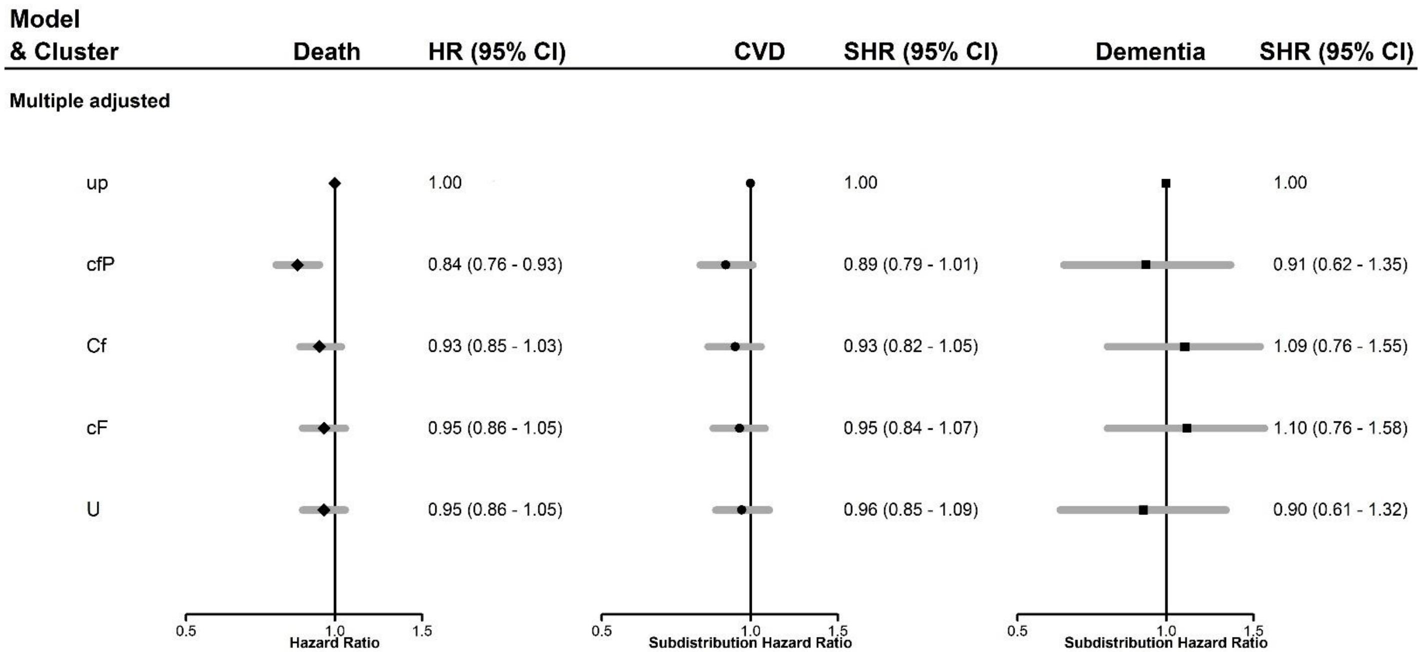

Figure 3. Hazard ratios (HRs) for outcomes of all-cause mortality (death), and subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) and dementia with 95% confidence intervals (CIs), from models adjusted for models adjusted for clusters, age, sex, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication (n 114,102). Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat.

Discussion

In this large prospective study of over 100,000 women and men from the UK Biobank, associations between energy and macronutrient intakes with all-cause mortality, CVD and dementia, were evaluated. We identified a range of associations between individual macronutrients with outcomes. Higher absolute intakes of protein were associated with a decreased risk of all-cause mortality, yet high intakes of carbohydrate were associated with an increased risk of premature death. For CVD and dementia, moderate total energy intake was associated with a decreased risk. Higher sugar intake was associated with an increased risk of CVD whereas moderate protein intake was associated with a decreased risk. When looking at combinations of dietary factors, individuals with diets characterised by low carbohydrate, low fat, and high protein intake had a lower risk of all-cause mortality. Sex differences were identified in the associations between individual macronutrients and outcomes, however, these differences were only reflected in the multiple adjusted cluster analyses for men, where men with diets characterised by low carbohydrate, low fat, and high protein intake also had a lower risk of CVD. Given that risk associations were evident both for single macronutrients and for combinations with other macronutrients for premature death and for CVD in men, our study has highlighted the potential to target dietary interventions at combinations of macronutrients.

Macronutrient intake and all-cause mortality

Previous studies in older aged populations have identified a decreased risk of frailty with increased protein intake, with increased frailty then associated with increased risk of death [6]. Studies have also identified that levels of protein intake higher than recommended add additional protective effect, particularly when combined with physical activity to build muscle mass [7]. While the association between protein intake, frailty, and death may provide a mechanism for the association found in the present study, it is important to note that we have not been able to explore this relationship by protein type. This is a limitation as previous studies have identified a negative association between different animal-based sources of protein with mortality [24]. Conversely, there is a growing body of evidence investigating the health and environmental benefits of consuming plant-based protein. [25, 26] Given the low intakes of fibre in this study, it seems unlikely that consumption of plant-based protein was high, however this is a speculation that warrants further investigation.

High intakes of carbohydrate were associated with an increased risk of death. The risks and benefits of high carbohydrate and protein intakes, respectively, were reflected when we investigated combinations of dietary factors. Individuals who had diets characterised by low carbohydrate intake, low fat intake, yet high protein intake had a decreased risk of death. It is probable that the benefits of higher protein intake are in part due to the displacement of other macronutrients in the diet.

Macronutrient intake and cardiovascular disease and dementia

Dietary risks identified for CVD and dementia were low, and no associations were identified for dietary clusters, with the exception of men with diets characterised by low carbohydrate, low fat, and high protein intake having a lower risk of CVD. Individuals with moderate total energy intake had a lower risk of both dementia and CVD. The mechanism for this is unclear and energy intake on its own has not been strongly related to health outcomes [27]. For CVD, high sugar intake was associated with an increased risk, yet moderate intake of protein was associated with a lower risk. Previous studies have suggested an association between higher consumption of added sugar with CVD and mortality [27, 28]. It has been proposed that the mechanism for this is through increased body weight, adverse glycaemic effects, and lower intake of other essential nutrients with increasing sugar intake, likely increasing the risk of CVD [28, 29]. It should be noted that 63% of the individuals in this study exceeded sugar intake recommendations, and people in the highest third of sugar intake getting 30% of their total daily energy intake from sugar.

Minimal associations were identified for dementia, with the strongest effects identified for women with moderate sugar intake and high fibre intake having an associated decreased risk of dementia. While we were not able to identify the sources of sugar and fibre in the diet, findings from previous studies showed that compliance to a Mediterranean diet characterised by high consumption of fruits, vegetables, legumes and complex carbohydrates, moderate consumption of fish and olive oil, and low consumption of red wine decreased the risk of cognitive impairment and dementia [30-32]. In particular, previous studies found that the type of fat consumed was important, with foods richer in polyunsaturated and monounsaturated fats appearing to either improve cognitive function [32] or delay cognitive decline in high risk groups [33]. While in general we did not find an association between type of fat and dementia outcomes, we did identify that women with diets characterised by high polyunsaturated fat intake had a lower relative risk of dementia compared to men. However, this association was attenuated in the model with multiple adjustments. Given the burden of dementia in the UK is predicted to increase by 57% by 2040 [34], there is a need for further research of modifiable lifestyle risk factors for dementia.

Sex differences in dietary risk

Given previous work that identified sex differences in macronutrient intakes within the UK Biobank population, [14] we hypothesised that differences in intake may be associated with corresponding sex differences in our outcomes of interest. While we identified some sex differences in associations between macronutrients and the outcomes the magnitude of these findings was generally small. Sex differences in the association of individual macronutrients with all-cause mortality were identified. Relative to men, women with the highest third of sugar intake had a lower relative risk of death than those in the lowest third. Conversely, relative to men, women with moderate total fat intake had a higher risk of death than women with a low intake. These observed differences may be due to chance and require confirmation through other studies before firm conclusions can be drawn. However, it is worth noting that sex differences were not evident in the association of dietary clusters with all-cause mortality. For CVD, the individual macronutrient associations that were significant for the population as a whole were only significant for men and not women. This translated into the cluster analysis, where the cluster characterised by low carbohydrate, low fat and high protein intake cluster was associated with a decreased risk of CVD for men. For women, moderate intakes of sugar and high intakes of fibre were associated with a lower risk of dementia, yet high saturated fat was associated with an increased risk of dementia, and relative to men these findings were significant. While it is plausible that different dietary intakes correspond to differing associations with disease outcomes by sex, the inconsistency between our sex specific results looking at macronutrients individually and when looking at clusters of macronutrient intakes for all-cause mortality and dementia warrants further investigation.

Contextualising findings in line with nutrition epidemiology

There is a need to investigate diet quality, for example the source, type, and level of processing, in addition to macronutrient intake when looking at the association with disease outcomes. Recent large-scale studies have identified limited associations between individual macronutrient intake with health outcomes [35-37]. Yet when the same datasets are used to look at dietary quality (for example categorisation of "healthy' or "unhealthy" sources of fat and carbohydrate) stronger associations are seen [35, 37]. Diet quality can also be contextualised in terms of dietary patterns followed. As discussed earlier, a Mediterranean style diet has been associated with a decreased risk of cognitive decline [32], it has also been associated with a lower incidence of major cardiovascular events in comparison to a low fat diet [38], however it is important to note that these associations were identified in populations at high risk of vascular diseases at baseline.

Ho et al [39] previously identified non-linear trends between macronutrient intake with all-cause mortality and CVD in the UK Biobank. The non-linear relationship identified may explain the minimal associations that we found for individual macronutrients with CVD when viewed as thirds of intake. Our findings somewhat echo theirs; however, via cluster analyses, we have further characterised the current dietary patterns of people within the UK Biobank, and estimated the risk that intake of different combinations of macronutrients have for disease outcomes. Given the need for dietary interventions that are sustainable and scalable, we suggest that further investigation of diet quality, dietary patterns and associations with disease outcomes are needed.

Strengths and limitations

A main limitation to the present study is the use of self-reported dietary intake data [40]. Dietary self-report is subject to multiple biases, and studies have shown that people randomly and systematically misreport dietary data, for example with people underreporting foods that they consider "unhealthy" [41]. However, the use of the dietary measure, the Oxford WebQ, has been validated previously [16]. The UK Biobank is a volunteer population and the diet questionnaires were emailed to most participants, with only 20% of the total population completing two or more diet measures. There is also an indication that the group who completed two or more measures were healthier at baseline than those who completed less than two. While this limits generalisability of our findings, the UK Biobank still provides one of the largest cohorts that has comprehensive diet information and disease outcome information collected prospectively. Additionally, only including individuals with two or more completed measures is more likely to provide a reflection of habitual intake, in comparison to those who only have one measure [18, 27]. We also excluded individuals who had cardiovascular events or dementia diagnosis between measures, as this may have influenced eating behaviour.

Nutritional epidemiology is complicated by the fact that macronutrients are not consumed in isolation of each other. There are a range of methods that either account for, or utilise, the compound effects of nutrients. In the present study we utilised cluster analyses to characterise the study population based on macronutrient intake [42]. To the best of our knowledge, this is the largest study to utilise cluster analysis for investigating the association between combinations of macronutrient intake and CVD, dementia and premature death outcomes. In doing this, we have identified combinations of macronutrient intake that could be targeted by food policies. Finally, a number of comparisons were investigated in this study. This means that the risk of type I error will be high, and so significant results should be interpreted with caution.

However, in interpreting the results we mainly focussed on effect sizes, and their confidence intervals, rather than p values.

Conclusion

In conclusion, the present study identified a range of associations between energy and macronutrient intake, and all-cause mortality, cardiovascular disease and dementia, with some differences by sex identified. Dietary intake was characterised based on cluster analysis, finding that individuals with low carbohydrate, low fat and high protein intake had a lower risk of premature all-cause mortality. Further, men with this dietary cluster also had a lower risk of cardiovascular disease. Given that associations were evident, both as single macronutrients and in combination with other macronutrients, we suggest the biggest benefit from diet-related policy and interventions would be when combinations of macronutrients are targeted. Since we identified certain sex differences, which require confirmation, we also suggest that associations between diet and disease by sex continue to be investigated.

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Contributions The research question was posed by MW and SAEP and was further developed by BLM and KH. BLM and KH conducted the statistical analyses. BLM wrote the first draft of the manuscript. MW, SAEP and JW provided critical insights throughout the project. All authors reviewed, and approved, the final manuscript.

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Competing interests MW is a consultant to Amgen, Freeline and Kyowa Kirin. All other authors have not declared any competing interests in relation to this manuscript.

Patient consent Provided

Ethics Generic ethical approval was obtained by UK Biobank from the National Health Service National Research Ethics Service. Approval was gained to use the UK Biobank data for this study (application No 2495). Additional approval via UNSW was gained (HC20056).

5.4 Supplementary material

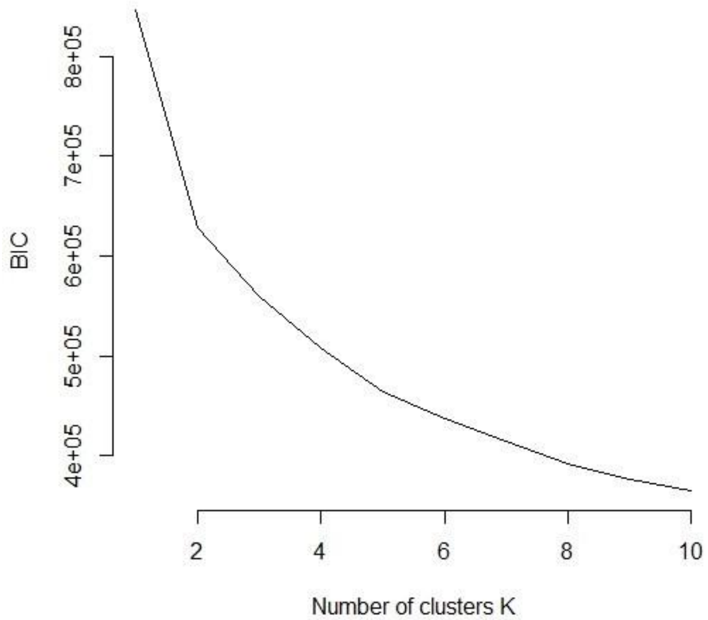
Supplementary methods, cluster analysis

Cluster analysis was undertaken using the k-means method, an unsupervised learning algorithm, to partition individuals into k clusters based on patterns in the data, whereby individuals in the same cluster are as similar as possible. The Individuals are represented by cluster centres (centroid) which corresponds to the mean of points assigned to the cluster. The k-means++ algorithm[43] is used from the ClusterR package in R [44] and is an improved initialisation algorithm to determine the initial cluster centres. A standard initialisation approach, such as the Lloyd algorithm [45], would arbitrarily choose k centres, whereas the k-means++ algorithm selects the first centre randomly and then for subsequent centres chosen from the remaining data points with probability proportional to its squared distance from the point's closest existing cluster centres. After the centres have been selected via the k-means ++ algorithm, the standard k-means approach is applied that partitions data based on local optima and minimises the total within-cluster variation, defined as the sum of squared distances (sum of squared Euclidean distances) between datapoints and the corresponding cluster centre.

Individuals were clustered based on standardised macronutrients data (% Carbohydrate, % Sugar, % Fibre, % Fat, % Saturated fat, % Polyunsaturated fat, % Protein)

The optimum number of clusters was determined using the 'elbow' method based on Bayesian Information Criterion (BIC) calculated over different values of *k* clusters *(k = 2 to 10)*. The elbow (location of a bend) of a function is a point after which the decrease becomes notably smaller. The elbow method to determine the optimum number of clusters is a heuristic approach, since the BIC stop decreasing as much after 5 clusters. Thus the optimum number of clusters was five, based on the elbow method.

Clusters were then described by the characteristics of the macronutrient data. The cluster variable was then inputted as an explanatory variable into separate Cox proportional hazards models for outcomes CVD, Death and Dementia. Two sets of models were fitted to the three outcomes (CVD, Death, Dementia), basic adjusted model adjusting for the cluster variable, age, sex, smoking, Townsend deprivation score, and fully adjusted model additionally adjusting for height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, diabetes, lipid lowering medication, anti-hypertensive medication .



Supplementary table 1 Energy and macronutrient intake ranges, by thirds (mean (min - max))

Intake thirds	Energy intake (mean kJ/day)	Carbohydrate (%EI)	Sugar (%EI)	Fibre (%EI)	Fat (%EI)	Saturated Fat (%EI)	Polyunsaturated fat (%EI)	Protein (%EI)
1	6,572 (1,408 - 7,748)	40.6 (1.0 - 46.0)	16.5 (0.3 - 29.3)	1.0 (0 - 1.3)	26.2 (3.5 -30.1)	9.3 (0.9 - 11.2)	4.0 (0.4 - 5.0)	13.0 (3.5 - 14.6)
2	8,601 (7,748 - 9,508)	49.1 (46.0 - 52.2)	22.9 (20.3 - 25.6)	1.5 (1.3 - 1.7)	32.5 (30.1 - 35.0)	12.4 (11.2 - 13.6)	5.8 (5.0 - 6.7)	15.8 (14.6 - 17.1)
3	11,286 (9,509 - 19,786)	56.9 (52.2 - 89.3)	30.2 (25.6 - 71.1)	2.0 (1.7 - 6.5)	38.8 (35.0 - 66.7)	15.7 (13.6 - 27.8)	8.1 (6.7 - 19.1)	19.5 (17.1 - 50.0)

*%EI= percentage of energy intake

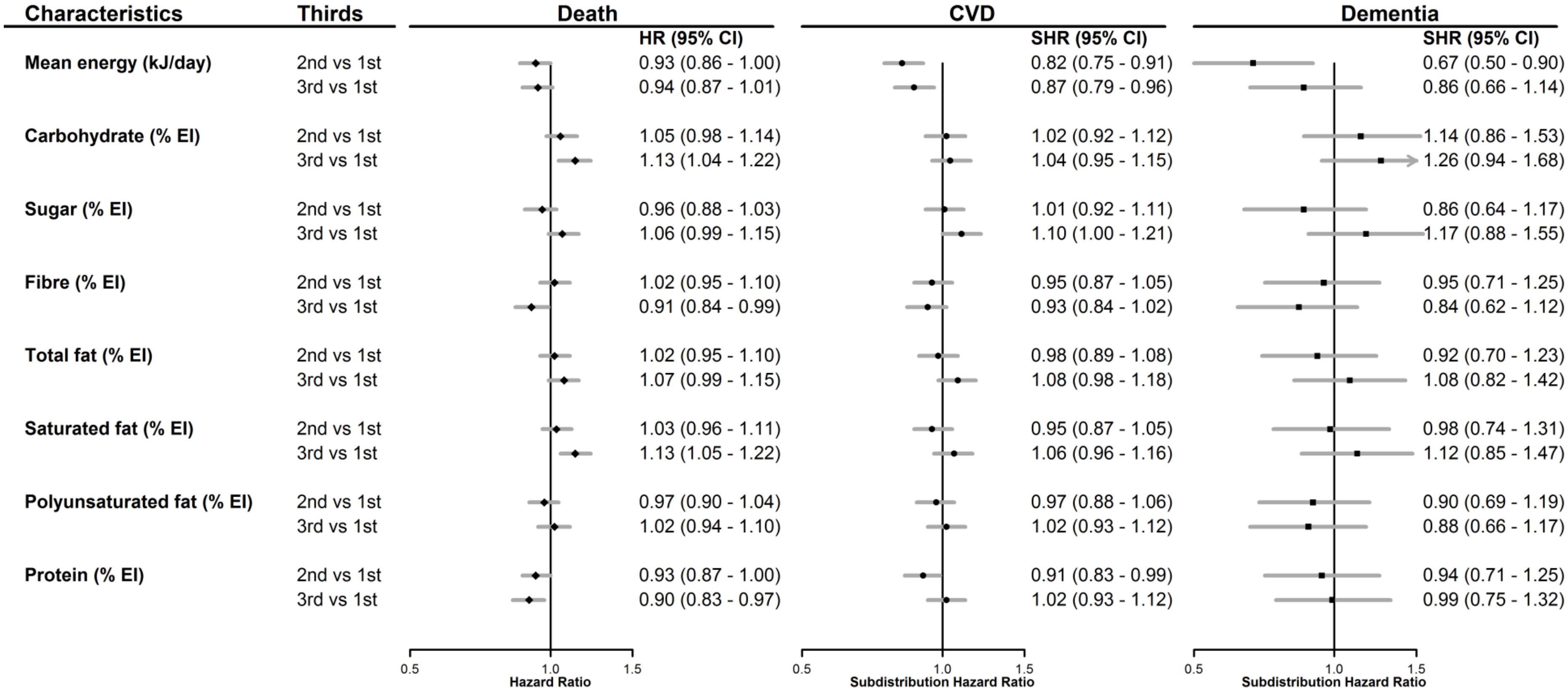
Supplementary table 2. Summary characteristics of participants with two or more dietary assessment measures compared with those without two or more dietary assessment measures, by sex

Characteristics	Women		Men	
	Completed ≥2 24hr diet recalls	Completed <2 24hr diet recalls	Completed ≥2 24hr diet recalls	Completed <2 24hr diet recalls
n	68,927	204,450	52,036	177,079
Age, years (SD)	55.5 (7.7)	56.6 (8.1)	56.5 (7.9)	56.8 (8.3)
Ethnicity, white (%)	66,510 (96.8)	190,921 (93.4)	50,245 (97.0)	165,007 (93.2)
Socioeconomic status quintiles (%)				
1st Least deprived	26,880 (39.0)	74,118 (36.3)	21,455 (41.3)	63,423 (35.8)
2nd	14,728 (21.4)	41,862 (20.5)	10,823 (20.8)	35,357 (20.0)
3rd	10,693 (15.5)	30,553 (14.9)	7,818 (15.0)	25,517 (14.4)
4th	9,214 (13.4)	27,695 (13.5)	6,450 (12.4)	24,006 (13.6)
5th Most deprived	7,330 (10.6)	29,977 (14.7)	5,430 (10.4)	28,540 (16.1)
Smoking status, never smoked (%)	42,195 (61.3)	119,857 (58.6)	27,745 (53.4)	83,720 (47.3)
BMI, kg/m^2 (SD)	26.2 (4.9)	27.4 (5.3)	27.2 (4.0)	280.0 (4.3)
Overweight or obese (%)	36,109 (52.5)	128,070 (62.6)	35,876 (69.1)	134,300 (75.8)
Weight, kg (SD)	70.2 (13.6)	71.9 (14.3)	85.0 (13.7)	86.2 (14.5)
Height, cm (SD)	163.6 (6.2)	162.1 (6.3)	176.8 (6.7)	175.3 (6.9)
Low physical activity (%)[1]	12,194 (18.8)	36,982 (18.1)	9,447 (18.9)	30,575 (17.3)
Systolic blood pressure (mmHg)	133.7 (18.7)	135.9 (19.4)	140.4 (16.9)	141.1 (17.6)
Diastolic blood pressure (mmHg)	80.2 (9.8)	80.9 (10.0)	83.9 (9.7)	84.1 (10.1)
Blood pressure categories (%)[2]				
Normal	15,505 (22.5)	39,827 (19.5)	4,473 (8.6)	15,557 (8.8)
Elevated	9,709 (14.1)	25,866 (12.7)	6,314 (12.1)	19,711 (11.1)
Stage 1 hypertension	18,559 (27.0)	53,507 (26.2)	14,813 (28.5)	47,892 (27.0)
Stage 2 hypertension	25,082 (36.4)	84,551 (41.4)	26,417 (50.8)	93,384 (52.7)

Supplementary table 3. Percentage of the population (n) not meeting the recommended dietary intakes[1]

	Overall	Females	Males
Energy intake (EI)			
≥10,460kJ for men, ≥8,363kJ for women	38.3 (46,324)	43.5 (29,960)	31.5 (16,364)
Carbohydrate intake			
Total carbohydrate <50% EI	54.8 (66,287)	52.4 (36,145)	57.9 (30,142)
Sugar ≥120g for men, ≥90g for women	63.0 (76,145)	72.5 (49,984)	50.3 (26,161)
Fibre <30g	97.7 (118,168)	98.0 (67,565)	97.3 (50,603)
Fat intake			
Total fat ≥35% EI	33.3 (40,267)	34.57 (23,827)	31.6 (16,440)
Saturated fat ≥11% EI	68.5 (82,897)	69.1 (47,652)	67.7 (35,245)
Polyunsaturated fat <6% or >11% EI	55.0 (66,572)	53.6 (36,918)	57.0 (29,654)
Protein intake			
Protein intake <0.75g per kg body weight	12.0 (14,545)	9.9 (6,803)	14.9 (7,742)

[1]UK dietary recommendations [9, 14]



Supplementary figure 1. Macronutrient intake (as a percentage of total energy intake (EI), in thirds) and hazard ratios (HRs) for all-cause mortality (death), subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) and dementia with 95% confidence intervals (CIs).

Models adjusted for age, smoking, sex and Townsend score

Supplementary table 4. Macronutrient intake (as a percentage of total energy intake, in thirds) and subdistribution hazard ratios (SHRs) for Alzheimer's disease and vascular dementia with 95% confidence intervals (CIs)

Intake of macronutrients (%EI)		**Alzheimer's disease SHR**	**Vascular dementia SHR**
Mean energy intake (kJ/day)			
	1		
	2	0.64 (0.38, 1.07)	0.86 (0.42, 1.76)
	3	0.63 (0.37, 1.09)	1.42 (0.72, 2.79)
Carbohydrate intake (% EI)			
	1		
	2	1.19 (0.68, 2.09)	0.82 (0.40, 1.68)
	3	0.90 (0.48, 1.67)	0.94 (0.45, 1.96)
Sugar intake (% EI)			
	1		
	2	0.69 (0.40, 1.20)	0.69 (0.35, 1.37)
	3	0.86 (0.50, 1.46)	0.78 (0.40, 1.54)
Fibre intake (% EI)			
	1		
	2	1.05 (0.61, 1.81)	0.68 (0.34, 1.35)
	3	0.98 (0.56, 1.71)	0.86 (0.44, 1.66)
Total fat intake (% EI)			
	1		
	2	0.85 (0.50, 1.45)	1.16 (0.61, 2.23)
	3	1.02 (0.61, 1.73)	1.07 (0.54, 2.12)
Saturated fat intake (% EI)			
	1		
	2	0.92 (0.54, 1.57)	0.85 (0.45, 1.63)
	3	1.04 (0.62, 1.75)	0.85 (0.44, 1.63)
Polyunsaturated fat intake (% EI)			
	1		
	2	0.98 (0.58, 1.65)	1.09 (0.55, 2.16)
	3	1.04 (0.61, 1.75)	1.42 (0.74, 2.74)
Protein intake (% EI)			
	1		
	2	1.07 (0.64, 1.79)	1.03 (0.55, 1.91)
	3	1.02 (0.59, 1.76)	0.77 (0.38, 1.56)

*% EI, percentage of energy intake

** Adjusted for age, sex, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication

Supplementary table 5. Macronutrient intake (as a percentage of total energy intake, in thirds) and hazard ratios (HRs) for all-cause mortality (death) with 95% confidence intervals (CIs), for females and males and the female to male ratio of HRs (RHRs).

Intake of macronutrients (%EI)		Female HR	Male HR	Female to male RHR
Mean energy intake (kJ/day)				
	1			
	2	0.99 (0.89, 1.11)	0.96 (0.85, 1.08)	1.03 (0.88, 1.21)
	3	1.06 (0.94, 1.21)	0.97 (0.86, 1.09)	1.09 (0.92, 1.30)
Carbohydrate intake (% EI)				
	1			
	2	1.08 (0.95, 1.22)	1.03 (0.92, 1.15)	1.05 (0.89, 1.24)
	3	1.17 (1.02, 1.34)	1.08 (0.95, 1.22)	1.08 (0.90, 1.30)
Sugar intake (% EI)				
	1			
	2	0.88 (0.77, 1.00)	1.03 (0.93, 1.15)	0.85 (0.72, 1.01)
	3	0.95 (0.84, 1.08)	1.17 (1.05, 1.31)	0.81 (0.69, 0.96)
Fibre intake (% EI)				
	1			
	2	1.03 (0.91, 1.17)	1.01 (0.91, 1.11)	1.02 (0.87, 1.20)
	3	0.93 (0.82, 1.06)	0.89 (0.79, 0.99)	1.04 (0.88, 1.24)
Total fat intake (% EI)				
	1			
	2	1.12 (1.00, 1.27)	0.93 (0.84, 1.03)	1.20 (1.03, 1.41)
	3	1.07 (0.95, 1.21)	0.96 (0.86, 1.07)	1.11 (0.95, 1.31)
Saturated fat intake (% EI)				
	1			
	2	0.98 (0.87, 1.11)	1.02 (0.92, 1.13)	0.96 (0.82, 1.13)
	3	1.12 (0.99, 1.26)	1.02 (0.91, 1.14)	1.10 (0.93, 1.30)
Polyunsaturated fat intake (% EI)				
	1			
	2	0.95 (0.85, 1.07)	0.98 (0.88, 1.08)	0.97 (0.83, 1.13)
	3	0.98 (0.87, 1.10)	1.01 (0.91, 1.12)	0.97 (0.83, 1.13)
Protein intake (% EI)				
	1			
	2	0.89 (0.79, 1.00)	0.94 (0.85, 1.04)	0.94 (0.81, 1.11)
	3	0.78 (0.69, 0.88)	0.86 (0.77, 0.96)	0.91 (0.77, 1.07)

*% EI, percentage of energy intake

** Adjusted for age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication

Supplementary table 6. Macronutrient intake (as a percentage of total energy intake, in thirds) and subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) with 95% confidence intervals (CIs), for females and males and the female to male ratio of SHRs (RSHRs).

Intake of macronutrients (%EI)		Female SHR	Male SHR	Female to male RSHR
Mean energy intake (kJ/day)				
	1			
	2	0.94 (0.81, 1.09)	0.83 (0.72, 0.95)	1.13 (0.92, 1.39)
	3	0.96 (0.80, 1.14)	0.94 (0.83, 1.07)	1.02 (0.82, 1.27)
Carbohydrate intake (% EI)				
	1			
	2	1.08 (0.91, 1.28)	1.00 (0.88, 1.13)	1.08 (0.87, 1.33)
	3	1.05 (0.87, 1.26)	1.01 (0.88, 1.17)	1.04 (0.82, 1.31)
Sugar intake (% EI)				
	1			
	2	1.02 (0.85, 1.21)	1.07 (0.95, 1.21)	0.95 (0.77, 1.18)
	3	1.07 (0.90, 1.27)	1.17 (1.02, 1.33)	0.91 (0.74, 1.14)
Fibre intake (% EI)				
	1			
	2	0.88 (0.74, 1.05)	0.99 (0.88, 1.11)	0.89 (0.72, 1.10)
	3	0.94 (0.79, 1.11)	0.87 (0.76, 0.99)	1.08 (0.87, 1.34)
Total fat intake (% EI)				
	1			
	2	1.07 (0.91, 1.26)	0.94 (0.83, 1.06)	1.14 (0.93, 1.40)
	3	1.05 (0.89, 1.24)	1.05 (0.92, 1.18)	1.00 (0.81, 1.23)
Saturated fat intake (% EI)				
	1			
	2	0.93 (0.79, 1.10)	0.95 (0.84, 1.08)	0.98 (0.80, 1.21)
	3	1.00 (0.85, 1.17)	1.06 (0.94, 1.20)	0.94 (0.77, 1.15)
Polyunsaturated fat intake (% EI)				
	1			
	2	0.85 (0.72, 1.01)	1.01 (0.90, 1.14)	0.84 (0.68, 1.03)
	3	1.03 (0.88, 1.21)	0.96 (0.85, 1.09)	1.07 (0.88, 1.31)
Protein intake (% EI)				
	1			
	2	0.89 (0.75, 1.05)	0.87 (0.77, 0.98)	1.02 (0.83, 1.26)
	3	0.96 (0.81, 1.13)	0.87 (0.77, 0.99)	1.10 (0.90, 1.36)

*% EI, percentage of energy intake

** Adjusted for age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication

Supplementary table 7. Macronutrient intake (as a percentage of total energy intake, in thirds) and subdistribution hazard ratios (SHRs) for dementia with 95% confidence intervals (CIs), for females and males and the female to male ratio of SHRs (RSHRs).

Intake of macronutrients (%EI)		Female SHR	Male SHR	Female to male RSHR
Mean energy intake (kJ/day)				
	1			
	2	0.75 (0.50, 1.13)	0.69 (0.43, 1.12)	1.19 (0.58, 2.04)
	3	0.72 (0.44, 1.18)	1.05 (0.68, 1.62)	0.69 (0.36, 1.32)
Carbohydrate intake (% EI)				
	1			
	2	0.82 (0.52, 1.31)	1.27 (0.82, 1.96)	0.65 (0.34, 1.22)
	3	0.76 (0.46, 1.24)	1.38 (0.85, 2.25)	0.55 (0.27, 1.10)
Sugar intake (% EI)				
	1			
	2	0.51 (0.30, 0.85)	1.27 (0.85, 1.89)	0.40 (0.21, 0.77)
	3	0.90 (0.58, 1.40)	1.18 (0.76, 1.83)	0.76 (0.41, 1.42)
Fibre intake (% EI)				
	1			
	2	0.70 (0.45, 1.09)	1.12 (0.75, 1.67)	0.62 (0.34, 1.13)
	3	0.57 (0.37, 0.88)	1.10 (0.71, 1.69)	0.52 (0.28, 0.96)
Total fat intake (% EI)				
	1			
	2	0.94 (0.60, 1.47)	0.86 (0.58, 1.26)	1.09 (0.60, 1.98)
	3	1.17 (0.76, 1.79)	0.86 (0.57, 1.30)	1.36 (0.75, 2.47)
Saturated fat intake (% EI)				
	1			
	2	1.39 (0.86, 2.25)	0.74 (0.50, 1.10)	1.88 (1.01, 3.50)
	3	1.69 (1.06, 2.68)	0.68 (0.45, 1.03)	2.49 (1.33, 4.63)
Polyunsaturated fat intake (% EI)				
	1			
	2	0.82 (0.54, 1.26)	1.04 (0.71, 1.52)	0.79 (0.45, 1.39)
	3	0.75 (0.49, 1.16)	0.90 (0.60, 1.36)	0.83 (0.46, 1.51)
Protein intake (% EI)				
	1			
	2	0.85 (0.54, 1.34)	1.05 (0.71, 1.55)	0.81 (0.44, 1.47)
	3	0.89 (0.57, 1.39)	1.03 (0.66, 1.57)	0.87 (0.47, 1.62)

*% EI, percentage of energy intake

** Adjusted for age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication

Supplementary table 8. Hazard ratios (95%CI) for death, cardiovascular disease (CVD) and dementia for exceeding vs not meeting recommended dietary intakes[1]

	Death, all cause	**CVD**	**Dementia**
Energy intake (EI)			
≥8,363kJ for women, ≥10,460kJ for men	0.99 (0.93, 1.07)	1.01 (0.93, 1.10)	1.03 (0.80, 1.33)
Carbohydrate intake			
Total carbohydrate <50% EI	0.93 (0.86, 0.99)	0.94 (0.86, 1.02)	0.98 (0.75, 1.28)
Sugar ≥90g for women, ≥120g for men	1.01 (0.95, 1.09)	1.04 (0.96, 1.13)	1.15 (0.88, 1.51)
Fibre <30g	0.93 (0.76, 1.14)	1.09 (0.84, 1.42)	0.56 (0.31, 1.01)
Fat intake			
Total fat ≥35% EI	1.00 (0.93, 1.07)	1.06 (0.97, 1.15)	1.06 (0.81, 1.37)
Saturated fat ≥11% EI	1.03 (0.96, 1.11)	0.99 (0.90, 1.08)	0.94 (0.73, 1.23)
Polyunsaturated fat <6% or >11% EI	0.97 (0.91, 1.04)	0.98 (0.90, 1.06)	1.23 (0.96, 1.57)
Protein intake			
Protein intake <0.75g per kg body weight	1.19 (1.08, 1.30)	1.17 (1.04, 1.31)	1.23 (0.83, 1.81)

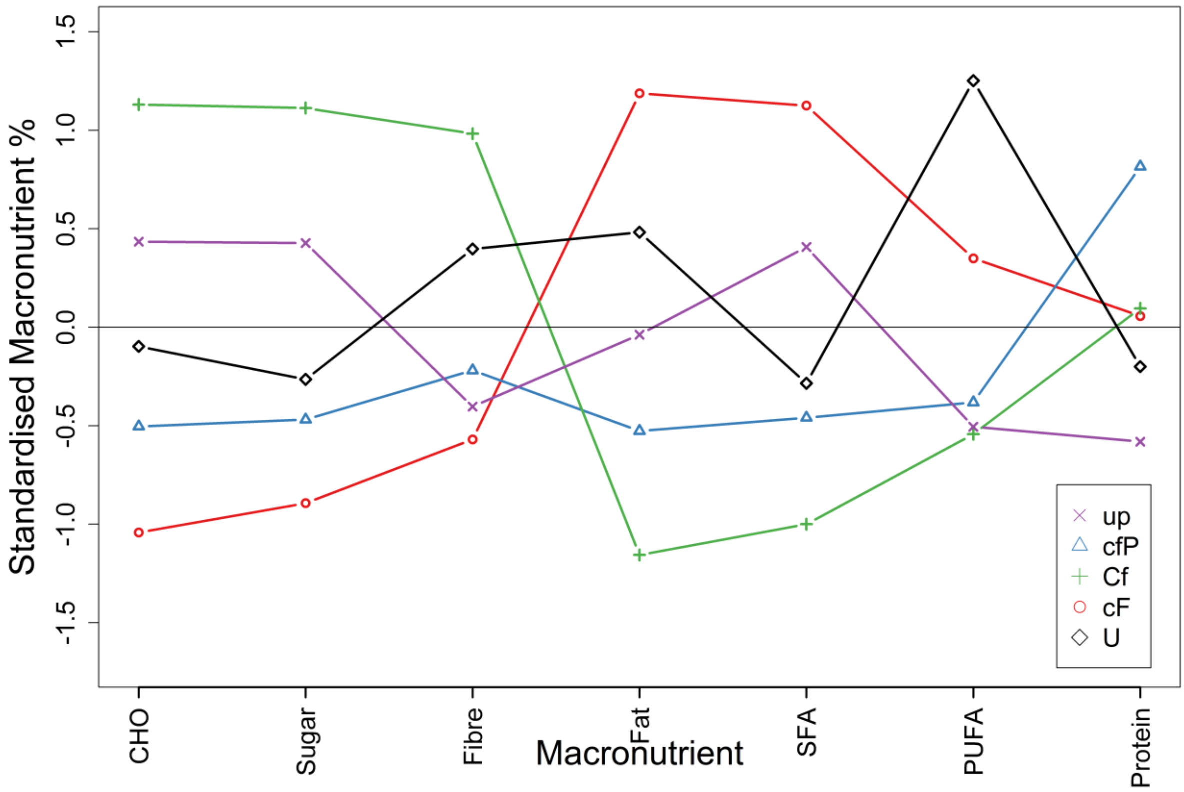
[1]UK dietary recommendations [9, 14]

Models adjusted for age, smoking, sex, height, weight, mean alcohol intake, physical activity (mean total MET), Townsend score, systolic blood pressure, anti-hypertensive medication, diabetes, lipid lowering medication.

Supplementary table 9. Summary characteristics (mean (SD), unless stated) and incidence rates per 10,000 person years (for CVD, Death and Dementia) by clusters

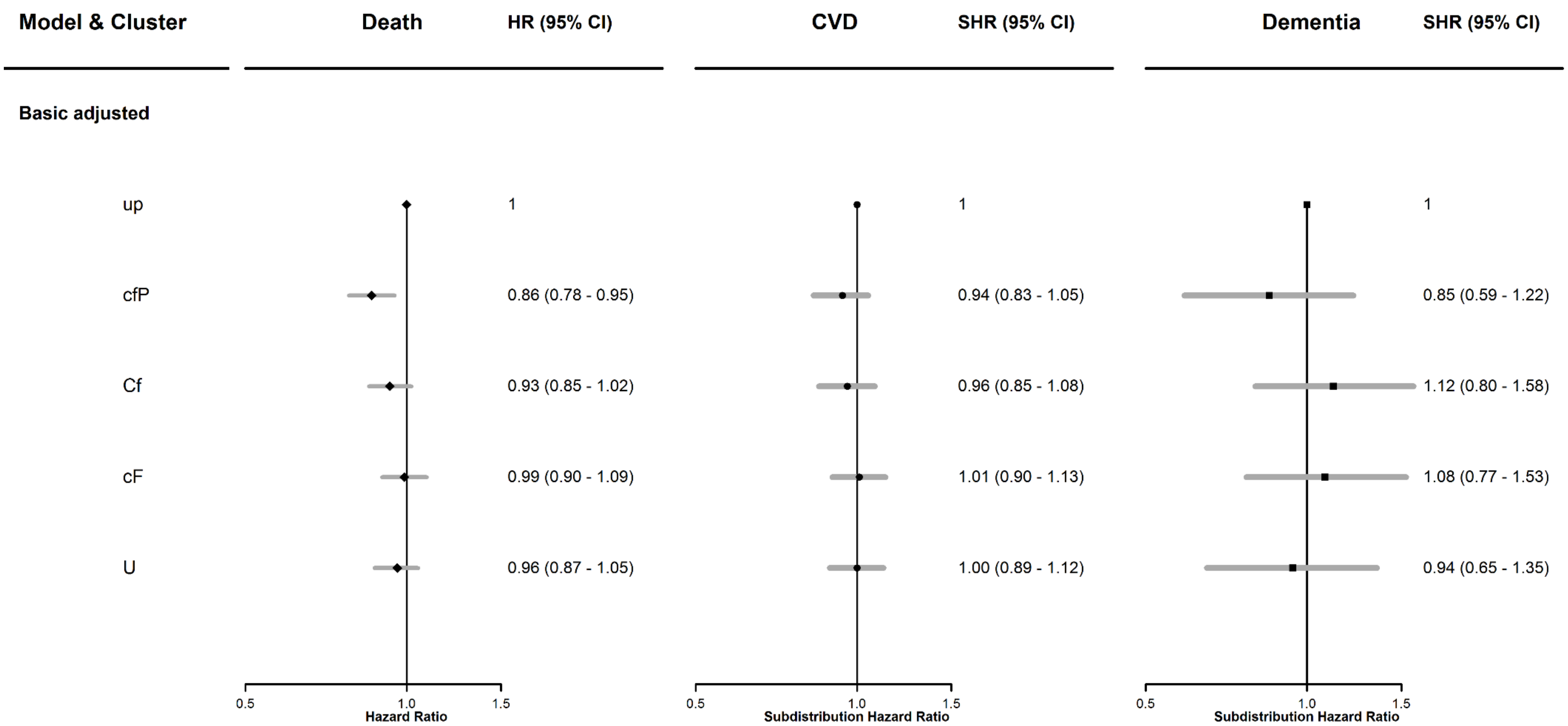
Cluster	***up***	***cfP***	***Cf***	***cF***	***U***
n	30231	22700	22215	23668	22149
Variable					
Sex (% Male)	46.7	47.0	35.3	45.6	38.8
Age (years)	56.1 (7.9)	55.7 (7.8)	56.6 (7.6)	55.3 (7.9)	55.8 (7.8)
Smoking (% never smoking)	60.0	52.2	62.6	53.8	60.1
Townsend	-1.65 (2.84)	-1.67 (2.83)	-1.67 (2.84)	-1.53 (2.86)	-1.70 (2.80)
Height (cm)	170.1 (9.2)	169.5 (8.9)	167.8 (8.9)	170.0 (9.2)	168.6 (9.0)
Weight (Kg)	76.5 (15.2)	78.3 (15.5)	73.9 (14.7)	79 (16.4)	74.9 (14.9)
Metabolic equivalents	2564.32 (3132.22)	2416.96 (2839.10)	2813.39 (3181.61)	2373.45 (2960.96)	2546.34 (2983.40)
SBP (mmHg)	136.2 (18.1)	138.1 (18.3)	136.6 (18.6)	136 (17.9)	136 (18.3)
Diabetes (%)	2.4	4.0	2.8	4.3	3.9
Lipid lowering medication (%)	8.5	11.5	9.4	9.8	9.1
Anti-hypertensives (%)	10.5	13.6	11.5	11.7	11.4
Energy (kJ/day)	9461 (2329)	8174 (1978)	7951 (1952)	9245 (2301)	9024 (2108)
Incidence rates per 10,000 person years (95%CI)					
CVD	20.86 (19.31, 22.41)	19.40 (17.67, 21.13)	18.76 (17.04, 20.48)	19.89 (18.18, 21.61)	19.06 (17.33, 20.79)
Death	32.63 (30.69, 34.56)	27.88 (25.82, 29.45)	29.35 (27.21, 31.49)	31.16 (29.02, 33.30)	29.01 (26.88, 31.15)
Dementia	2.27 (1.76, 2.78)	1.84 (1.31, 2.37)	2.57 (1.93, 3.20)	2.25 (1.68, 2.83)	1.96 (1.41, 2.51)

Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat



Supplementary figure 2. Dietary profile of identified clusters, by (standardised) macronutrient %

Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat



Supplementary figure 3. Hazard ratios (HRs) for outcomes of all-cause mortality (death), and subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) and dementia with 95% confidence intervals (CIs), from models adjusted for clusters, age, smoking, sex and Townsend score. Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat.

Supplementary table 10. Clusters of dietary intake and hazard ratios (HRs) for all-cause mortality (death) with 95% confidence intervals (CIs), for females and males and the female to male ratio of HRs (RHRs). Models adjusted for clusters, age, smoking, and Townsend score (basic adjusted), models adjusted for clusters, age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication (multiple adjusted).

Cluster	**Females, HR (95% CI)**	**Males, HR (95% CI)**	**Female to male RHR**
Basic adjusted			
up	ref	ref	ref
cfP	0.80 (0.68, 0.93)	0.90 (0.80, 1.02)	0.88 (0.73, 1.07)
Cf	0.93 (0.81, 1.07)	0.93 (0.81, 1.06)	1.01 (0.83, 1.22)
cF	0.99 (0.86, 1.14)	0.99 (0.88, 1.12)	1.00 (0.84, 1.21)
U	0.95 (0.83, 1.09)	0.96 (0.84, 1.09)	0.99 (0.82, 1.20)
Multiple adjusted			
up	ref	ref	ref
cfP	0.82 (0.70, 0.96)	0.86 (0.75, 0.98)	0.95 (0.77, 1.18)
Cf	0.91 (0.79, 1.05)	0.95 (0.83, 1.09)	0.96 (0.79, 1.17)
cF	0.98 (0.84, 1.13)	0.94 (0.83, 1.07)	1.04 (0.85, 1.26)
U	0.95 (0.83, 1.10)	0.95 (0.83, 1.08)	1.01 (0.83, 1.23)

Macronutrient clusters: *up* **-** low polyunsaturated fat, low protein, *cfP* **-** low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat

Supplementary table 11. Clusters of dietary intake and subdistribution hazard ratios (SHRs) for cardiovascular disease (CVD) with 95% confidence intervals (CIs), for females and males and the female to male ratio of SHRs (RSHRs) of females to males. Models adjusted for clusters, age, smoking, and Townsend score (basic adjusted), models adjusted for clusters, age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication (multiple adjusted).

Cluster	**Females, SHR (95% CI)**	**Males, SHR (95% CI)**	**Female to male RSHR**
Basic adjusted			
up	ref	ref	ref
cfP	1.06 (0.87, 1.29)	0.88 (0.76, 1.01)	1.21 (0.95, 1.55)
Cf	0.92 (0.76, 1.11)	1.00 (0.86, 1.16)	0.92 (0.72, 1.17)
cF	0.91 (0.74, 1.11)	1.05 (0.92, 1.21)	0.86 (0.67, 1.10)
U	1.08 (0.89, 1.30)	0.94 (0.81, 1.10)	1.14 (0.90, 1.46)
Multiple adjusted			
up	ref	ref	ref
cfP	1.02 (0.83, 1.26)	0.83 (0.71, 0.97)	1.23 (0.95, 1.59)
Cf	0.87 (0.72, 1.06)	0.97 (0.83, 1.14)	0.90 (0.70, 1.15)
cF	0.83 (0.67, 1.03)	1.01 (0.87, 1.17)	0.82 (0.63, 1.07)
U	1.02 (0.84, 1.24)	0.93 (0.79, 1.09)	1.10 (0.85, 1.41)

Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat

Supplementary table 12. Clusters of dietary intake and subdistribution hazard ratios (SHRs) for dementia with 95% confidence intervals (CIs), for females and males and the female to male ratio of SHRs (RSHRs). Models adjusted for clusters, age, smoking, and Townsend score (basic adjusted), models adjusted for clusters, age, smoking, height, weight, mean alcohol intake, physical activity (mean total MET), systolic blood pressure, Townsend score, diabetes, lipid lowering medication, anti-hypertensive medication (multiple adjusted).

Cluster	Females, SHR (95% CI)	Males, SHR (95% CI)	Female to male RSHR
Basic adjusted			
up	ref	ref	ref
cfP	0.72 (0.42, 1.23)	0.98 (0.59, 1.63)	0.73 (0.35, 1.53)
Cf	0.84 (0.52, 1.34)	1.51 (0.94, 2.45)	0.55 (0.28, 1.08)
cF	1.08 (0.68, 1.73)	1.07 (0.65, 1.77)	1.01 (0.51, 2.00)
U	0.57 (0.33, 1.00)	1.43 (0.88, 2.32)	0.40 (0.19, 0.84)
Multiple adjusted			
up	ref	ref	ref
cfP	0.76 (0.41, 1.38)	1.06 (0.63, 1.78)	0.72 (0.32, 1.59)
Cf	0.82 (0.49, 1.35)	1.43 (0.87, 2.34)	0.57 (0.28, 1.16)
cF	1.17 (0.71, 1.95)	1.04 (0.62, 1.77)	1.12 (0.54, 2.33)
U	0.61 (0.34, 1.08)	1.25 (0.75, 2.08)	0.49 (0.23, 1.05)

Macronutrient clusters: *up* - low polyunsaturated fat, low protein, *cfP* - low carbohydrate, low fat, high protein, *Cf* – high carbohydrate, low fat, *cF* – low carbohydrate, and high fat, *U*– high polyunsaturated fat

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Chapter 6. Incorporating a gender lens into nutrition and health-related policies in Fiji: a policy analysis

6.1 Chapter overview

This chapter consists of a policy landscape analysis approached through a gender lens, to understand how gender considerations are included in nutrition and health- related policies in Fiji. This chapter consists of a manuscript submitted for publication.

As established in the thesis methods section (Chapter 2), Fiji was focused on for the second thesis aim, to conduct in-depth qualitative work in a country where there are ongoing programs to strengthen food policy interventions, to curb the high rates of cardiometabolic disease in the region. Fiji is classified as a middle-income country, and is one of the larger Pacific Island Nations, with a population of approximately 900,000 people. A nutrition transition has occurred in Fiji, with a move away from a diet high in seafood and locally sourced fruits and vegetables to an increasing reliance on processed packaged foods.

The policy landscape analysis consisted of three steps: an analysis of policy content (analysing 11 nutrition and health- related policies), assessment of policies via the WHO gender analysis framework, and stakeholder interviews with 18 key informants to understand perceptions on including gender considerations within policies or nutrition related programs. The WHO gender analysis framework was used to assess the extent to which the policies were gender responsive, or conversely, gender blind. Only one policy was identified as gender responsive, and while other policies stated goals related to gender (such as broad gender equality goals), there was no information on how these goals could be achieved. Further, while key informants identified gender differences in roles and responsibilities related to nutrition, and identified differences in cardiometabolic disease burden by gender, there was an ambivalence towards a change in the status quo in terms of gender consideration or inclusion in policies. This study highlights the need for strengthening of gender considerations in nutrition and health- related policies in Fiji and concludes with suggestions of four actions for policy strengthening in this regard.

6.2 Publication details

McKenzie BL, Waqa G, Mounsey S, Johnson C, Woodward M, Buse K, Thow AM, McLean R, Webster J. Incorporating a gender lens into nutrition and health-related policies in Fiji: a policy analysis. Submitted to *International Journal for Equity in Health*, on the 10th of November 2021.

6.2.1 Author contributions

As the first author on this publication, I contributed significantly to this piece of work. I was responsible for developing the research question and developing the research plan in collaboration with senior authors on the paper. I led data extraction from the policy documents, I conducted 15 of the 18 interviews with key informants and led analysis of both the policy content and interview transcripts, with insights from co-authors when appropriate. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors. All authors have approved for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows: BLM, MW and JW conceived the research question. BLM, GW, RM and JW developed the research protocol. BLM, SM, AMT, and GW identified documents for the policy document review and identified the key informants. BLM and SM conducted the key informant interviews with support from GW. BLM conducted the analysis of the policy documents and the interviews with support from GW and SM. KB, AMT and JW provided expert advice on policy analysis. All authors provided feedback on the manuscript and approved the final version.

6.3 Manuscript

Abstract

Background

Gender equality, zero hunger and healthy lives and well-being for all, are three of the Sustainable Development Goals (SDGs) that underpin Fiji's National Development Plan. Work towards these goals contributes to the reduction of non-communicable diseases (NCDs). There are gender differences in NCD burden in Fiji. However, it is unclear whether a gender lens could be more effectively included in nutrition and health-related policies.

Methods

This study consisted of three components: (i) a policy content analysis of gender inclusion in nutrition and health-related policies (n =11); (ii) policy analysis using the WHO Gender Analysis tool to identify opportunities for strengthening; and (iii) informant interviews (n=18), to understand perceptions of the prospects for gender considerations in future policies.

Results

Gender equality was a goal in seven policies (64%); however, most focused on women of reproductive age. One of the policies was ranked as gender responsive. Discussions with informants covered perceptions on: 1) a needs-based approach for the focus on specific population groups in policies; 2) gender-related roles and responsibilities around nutrition and health; 3) what is considered "equitable" when it comes to gender, nutrition, and health; 4) current considerations of gender in policies and ideas for further gender inclusion; and 5) barriers and enablers to the inclusion of gender considerations in policies. Informants acknowledged gender differences in the burden of diet-related NCDs. However, most did not identify a need for stronger inclusion of gender considerations within policies.

Conclusions

There is considerable scope for strengthening the inclusion of gender in nutrition and health-related policies in Fiji. This could be done by: 1) framing gender considerations in ways that are actionable and inclusive of a range of gender identities; 2) undertaking advocacy through actor networks to highlight the need for gender-responsive nutrition and health-related policies for key stakeholder groups; 3) ensuring that data collected to monitor policy implementation is inclusive of and disaggregated by sex and genders; and 4) promoting equitable participation in nutrition related issues at both a community and governance level. Action on these four areas are likely critical enablers to gender equitable NCD reduction in Fiji.

Background

Diet-related non-communicable diseases (NCDs) are the leading causes of death globally [1]. The burden of NCDs is increasing among women and increasing disproportionately among women in low- and middle-income countries (LMICs) compared to women in high-income countries [2]. The Pacific Island nations experience some of the highest risks and burdens of NCDs, including a high prevalence of malnutrition [3]. Therefore, the implementation of effective policies to address the burden of diet-related disease is a priority for governments in the region [4].

Fiji is one of the larger Pacific Island Nations, with a population of approximately 900,000 people, and is classified as a middle income country [5]. Within this population, 42% of women and 22% of men live with obesity [6]. In 2011, Fijian women were found to be more likely than men to have three or more of five key NCD risk factors: current smoking, consuming less than five servings of fruit and vegetables per day; low level of physical activity; overweight; and/or raised blood pressure [6]. Further, a high prevalence of iron deficiency anaemia, particularly in women, was identified in the 2014 National Nutrition Survey [7].

There are both biological (sex) and social (gender) reasons for differences in dietary intake, and diet-related disease risk between women and men. At a biological level there are some sex differences in nutrient requirements. Women of reproductive age, or who are pregnant, have different requirements for some micronutrients to men. Men generally require a higher intake of energy (and corresponding macronutrients) due to their higher lean body mass than women [8]. Previous research has illustrated how gender roles and responsibilities can influence food provision and the health of families [9-11]. In many countries, including Fiji, women tend to be responsible for the bulk of the reproductive labour and care defined as childrearing, cooking, cleaning, and community work [12]. This means that women can act as the "gate keepers" for food provision. Therefore, gendered norms and practices (including marketing and promotion) concerning nutrition ought to be considered in food policy formulation and implementation [13].

Despite evidence of gender differences in dietary intake and diet-related disease risk, it is unclear how comprehensively gender has been included in nutrition and health related policies in Fiji. Gender- based analyses acknowledge gender-based inequalities and focus on assessing policies or programs so that they can be designed to address these inequalities [14].Therefore, responding to gender issues in nutrition and health-related policies could also contribute towards more effective implementation of the Sustainable Development Goals 2, "Zero hunger", 3, "Good Health and Well-being" and 5, "Gender Equality" [15]. The aims of this study were to assess: to what extent nutrition and health related policies in Fiji incorporate gender considerations and; key stakeholders' perceptions on the importance and feasibility of, and opportunities for, incorporating gender-responsive measures into future polices.

Methods

This study was designed and conducted with support from researchers in Fiji to ensure that it was contextually relevant and appropriate. The approach is based broadly on the ideas of feminist theory, as we aimed to assess the inclusion of gender as a construct in nutrition related policy, and ultimately, the ability of these policies to contribute towards gender equity (by reducing diet-related disease risk in a gender equitable manner) [16].We adapted the World Health Organization's (WHO) Gender Assessment Tool [17] and the Food and Agriculture Organization's (FAO) gender mainstreaming framework [18] (**table 1**), drawing on the guidance on policy analysis in the Gender-Based Analysis Plus tool (GBA+) [14].

Given the aims of our paper, we use the term "gender" throughout. However, we often discuss gender in a binary way (women and men). This is because this is how gender is referred to in most of the policies reviewed, and how gender was identified and discussed by informants. We do, however, acknowledge that gender is non-binary. Further, where policies referred to sex instead of gender, we have used the term "sex", as defined in the included policies.

Table 1. Coding framework and the grouping of codes into overarching themes

	Codes	**Alignment of codes with overarching themes**
Deductive codes, based on the World Health Organization gender assessment tool [17] and the Food and Agriculture Organization gender mainstreaming framework [19]	Nutrition and the life cycle	1. Perceptions on gender, health and nutrition – a needs-based approach for the focus on specific groups in nutrition and health policy
	Obesity and nutrition	
	Income generating activities and spending income on nutrition	2. Perceptions on gender-related roles and responsibilities around nutrition and health
	Local (food) culture and gender	
	Rights-based perspective related to gender and nutrition	3. Perceptions on what is considered "equitable" when it comes to gender, nutrition and health
	Targeting in nutrition	4. Perceptions of current considerations of gender in nutrition and health related policies and ideas for further gender inclusion
Inductive codes, identified during thematic analysis of the transcripts	Gender specific needs and disease risk	1. Perceptions on gender, health and nutrition – a needs-based approach for the focus on specific groups in nutrition and health policy
	The need to focus on other 'vulnerable' groups	3. Perceptions on what is considered "equitable" when it comes to gender, nutrition and health
	Current considerations of gender in policy	4. Perceptions of current considerations of gender in nutrition and health related policies and ideas for further gender inclusion
	Barriers to the inclusion of gender	5. Enablers and barriers to the inclusion of gender in nutrition and health related policy
	Enablers to the inclusion of gender	

We conducted a qualitative policy analysis of: (1) existing policy content; (2) current policy strengths and opportunities; and (3) stakeholder perceptions around gender inclusion in policies as follows:

1. The inclusion of gender in existing policy content

A desk-based review of policy content was conducted between March and October 2020 (**supplementary table 1**). We identified nutrition and health-related policies through: (1) online searches of Government and relevant within-country organization websites; (2) snowballing of relevant information from the initial search (for example, referenced guidelines, strategies, policies and action plans); and (3) direct requests to government ministries (ministries of health, industry and trade, agriculture, women, children and poverty alleviation, education and economy).

Whether, and how, gender or sex was included in the policies, in terms of policy goals and activities, representation of women and men (that is in terms of population beneficiary group), and consideration of evidence that includes gender or sex-disaggregated data, was extracted into a matrix. Information on each policy's objectives and overarching activities was also included.

2. Analysis of current policy content - opportunities for strengthening

We analysed the gender inclusions with reference to global "best practice". To do this, we utilised a gender matrix, building on ideas from the World Health Organization's Gender Assessment Tool [17, 19] (**supplementary table 2**). This tool is based on an assessment of policy content, including how terminology is used, along with the extent to which the content is gender sensitive, specific or transformative, or conversely the extent to which the content is gender-blind or gender-unequal [17]. We extracted relevant data related to each criterion, in order to identify where opportunities and strengths are within the policy. We also identified common opportunities for strengthening gender-responsiveness across the assessed policies, to inform future efforts at enabling more gender-responsive nutrition-related policy.

3. Stakeholder analysis

Semi-structured interviews were conducted with 18 informants in Fiji, between May and August 2020, via Zoom. The informants consisted of six government, five development partners, four private sector and three civil society representatives. Eight men and 10 women were interviewed. Interviews were led by BM or SM, with support from GW, and all interviews were conducted in English. Questions relating to gender, and the incorporation of gender into food and nutrition-related policy formed one section of the interview tool for a related study on strengthening the implementation of food- and nutrition-related policies in Fiji [20]. The interview tool for the broader study was informed by Shiffman's theory [21] and Kingdon's theory [22].

The key informants approached to take part in this study were identified via the policy documents, defined as '*actors who have an interest in the issue under consideration, who are affected by the issue or – because of their position – have or could have an influence on the decision-making and implementation processes'[23].* Given our aims, the focus was specifically on nutrition and NCD- related informants who have, or could have, an influence on nutrition and NCD-related decision making, as advised by local collaborators. The initial sample commenced with: 1) government agencies with responsibilities related to fiscal policy and/or nutrition (e.g. Ministries of Women and Poverty Alleviation, Finance, Industry/Commerce, Trade, Health, Agriculture); 2) food industry actors; 3) civil society actors with an interest in health and/or food; and 4) the media. Recruitment of interviewees was through formal (written) approaches to the heads of relevant agencies. Once approval was obtained, relevant departments were contacted to request interviews. At the end of each interview, we asked interviewees to identify further relevant interviewees (within and/or outside of their policy area).

A thematic analysis was conducted focusing on the perceived consideration/inclusion of gender in current nutrition and health related polices, the perceived need to have a stronger and/or different focus on gender in policies, and the enablers and barriers to such inclusion. Perceptions were also analyzed based on the participants' organizational category (e.g. government agency, NGO, industry) and by gender. This analysis followed inductive coding (i.e. the coding of text that related to our research aims), along with deductive coding, based on the WHO gender assessment tool [24] and the FAO gender mainstreaming framework [18]. Codes were then mapped to overarching themes (**table 1**). SM extracted high level gender-related codes (pulling gender-related information into broad gender codes), BM validated this coding and then conducted in-depth inductive and deductive analysis of the transcripts. The coding framework was discussed with GW, RM and JW with a particular focus on ensuring local cultural knowledge was prioritized. Inductive codes were discussed with GW, RM and JW as they were identified. NVivo software was used for transcribing the audio files (which were then validated). It was also used for analysis of the transcripts and data management.

Findings were discussed by the research team and informed recommendations regarding the integration of gender responsive measures into nutrition and health related policy in Fiji.

Ethics approval was granted by the University of New South Wales (HC200055) and Fiji National University (CHREC ID 184.20).

Results

1. The inclusion of gender in existing policy content

Eleven policy documents were reviewed (**table 2, supplementary table 1**). Seven policy documents explicitly mentioned gender considerations within the policy goals or objectives. These included the National Development Plan [25], the Strategic Plan [26], the draft Food and Nutrition Security policy [27], the Wellness Policy [28], the Fijian Trade Policy Framework [29], the Supplement to the Budget [30, 31], and the National Gender Policy [32]. Of these seven policies, two had explicit gender considerations that were broader than a focus on women. Specifically, the Wellness Policy stated “The policy will ensure that men, women, boys and girls are considered equally in the planning and implementation processes of all Wellness initiatives and programs” [28]. Also, the National Gender Policy stated “The overall goal of this policy is to promote gender equity, equality, social justice and sustainable development in the Republic of Fiji. The Government of Fiji is committed to removing gender inequality in Fiji”

[32]). In general, across policies, men and women were represented collectively. One exception was the classification of pregnant women as a vulnerable group in the Strategic Plan [26]. Five of the policies that had explicit gender considerations also referenced gender-related and/or specific evidence (generally as background to the formation of explicit gender goals or activities) [25-27, 29, 32]. In terms of policy development, four of these documents provided information on the consultation process. However, gender of participants in the consultation process was not defined.

2. Analysis of current policy content

Figure 1 shows the assessment of the 11 nutrition and health-related policies against the WHO Gender Assessment Tool, with rationale for categorisation provided in **supplementary table 2**. Of the six policies that had explicit consideration and commitment to promoting or achieving gender equality, the Fiji National Gender Policy stated that programs or activities should include sex as a selection criterion for target populations and purposely include both women and men [32]. Only the Gender Policy clearly defined what was meant by the terms “sex” and “gender”.

Most policies did not include considerations of life conditions and opportunities for women and men, nor did they reflect on family and household dynamics, opportunities, resource allocation or decision-making power within households, that might impact on attainment of policy goals across population groups. Exceptions to this included the National Development Plan, which stated that *"These reforms provide a platform for equality where both men and women can enjoy the benefits of employment and conditions conducive to productivity and prosperity for all*" and “*It is expected that home duties in caring for children and household work will be shared by the spouse or partner”* [25]. Conversely, six policies did have considerations related to women’s practical and strategic needs. For example, the Agriculture Sector Policy included an objective to create an investment fund for "retirees, women, and youth", to help attract these groups to the farming industry [33]. The NCD Strategic Plan [34], the draft Food and Nutrition Security Policy [27] and the Gender Policy [32], clearly stated that both women and men had been involved in policy development, and that both men and women would be involved in policy implementation, monitoring and evaluation.

Table 2. Description of gender inclusion in policies

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Economy
Included policies	5-Year & 20-Year National Development Plan. Main author(s): Ministry of Economy Dates: 2017 - 2036 [25]	Non-Communicable Diseases Strategic Plan. Main author(s): Ministry of Health, Australian Aid, C-POND Dates: 2015-2019 [34]	Strategic Plan Main author(s): Ministry of Health Dates: 2020 – 2025 [26]	Draft Fiji Policy on Food and Nutrition Security (FPFNS) Main author(s): Ministry of Health, Ministry of Agriculture Dates: 2018-2022 (Note, not endorsed) [27]	Wellness Policy Main author(s): Ministry of Health Dates: 2015 [28]	Fijian Trade Policy Framework Main author(s): Ministry of Industry, Trade and Tourism Dates: 2015-2025 [29]	Fiji 2020 Agriculture Sector Policy Agenda Main author(s): Ministry of Agriculture, and FAO Dates: 2014-2020 [33]	Fiji National Gender Policy Main author(s): Ministry for Social Welfare, Women & Poverty Alleviation Dates: 2014 (to be reviewed every 4 years) [32]	Fiji School Health Policy Main author(s): Ministry of Health and Ministry of Education, Heritage & Arts Dates: 2016 (reviewed every 2 years) [35]	Policy on Food and School Canteens Main author(s): Ministry of Education, Heritage & Arts Dates: 2017 [36]	Economic and Fiscal Update - Supplement to the 2019-2020 budget address Main author(s): Ministry of Economy Dates: 2019-2020 [30, 31]
Explicit consideration of gender in policy goals and activities?	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes
How are men, women and other groups represented?	Collectively	Collectively	Pregnant women are mentioned as a "vulnerable" group	Collectively	Collectively	Not differentiated	Not differentiated	Collectively, although specific aims focus on different groups of women and men, girls and boys.	Not differentiated	Not differentiated	Not differentiated
Is there consideration of evidence that includes gender?	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No
Information on consultation process and gender of participants?	Not covered	Outline of the consultation process; the workshop summary gives a list of names with females represent approximately 50% of the participants.	Consultation process described, but details based on gender not provided.	Not covered	The consultation process is described in the Annex, and the contributing senior officials were named. (but gender not defined)	Not covered	Not covered	The consultation process is described. 37 out of the 55 stakeholders consulted on the policy were female (71%)	Not covered	Not covered	Not covered

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Fiscal
WHO Gender Analysis Tool [17]	5-Year & 20-Year National Development Plan [25]	Non-Communicable Diseases Strategic Plan [34]	Strategic Plan [26]	DRAFT Fiji Policy on Food and Nutrition Security [27]	Wellness Policy [28]	Fijian Trade Policy Framework [29]	Fiji 2020 Agriculture Sector Policy Agenda [33]	Fiji National Gender Policy [32]	Fiji School Health Policy [35]	Policy on Food and School Canteens [36]	Fiscal Policy (Budget) [30, 31]
Do the vision, goals or principles have an explicit commitment to promoting or achieving gender equality?											
Does the policy or programme include sex as a selection criterion for the target population?											
Does the policy or programme clearly understand the difference between sex and gender?											
Does the target population purposely include both women and men?											
Have women and men participated in the following stages? Design Implementation Monitoring and evaluation											
Do both male and female team members have an equal role in decision-making?											
Does the policy or programme consider life conditions and opportunities of women and men?											
Does the policy or programme consider and include women's practical and strategic needs?											
Have the methods or tools been piloted with both sexes?				NA							
Does the policy or programme consider family or household dynamics, including different effects and opportunities for individual members, such as the allocation of resources or decision-making power within the household?											

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Fiscal
WHO Gender Analysis Tool [17]	5-Year & 20-Year National Development Plan [25]	Non-Communicable Diseases Strategic Plan [34]	Strategic Plan [26]	DRAFT Fiji Policy on Food and Nutrition Security [27]	Wellness Policy [28]	Fijian Trade Policy Framework [29]	Fiji 2020 Agriculture Sector Policy Agenda [33]	Fiji National Gender Policy [32]	Fiji School Health Policy [35]	Policy on Food and School Canteens [36]	Fiscal Policy (Budget) [30, 31]
Does the policy or programme include a range of stakeholders with gender expertise as partners, such as government affiliated bodies, national or international non governmental organizations or community organizations?											
Does the policy or programme collect and report evidence by sex?											
Is the evidence generated by or informing the policy or programme based on gender analysis?											
Does the policy or programme consider different health needs for women and men?											
Does the policy or programme include quantitative and qualitative indicators to monitor women's and men's participation?											
Does the policy or programme consider gender-based divisions of labour (paid versus unpaid and productive versus reproductive)?											
Does the policy or programme address gender norms, roles and relations?											
Does the policy or programme exclude (intentionally or not) one sex but assume that the conclusions apply to both sexes?											
Does the policy or programme exclude one sex in areas that are traditionally thought of as relevant only for the other sex, such as maternal health or occupational health?											
Does the policy or programme treat women and men as homogeneous groups when there are foreseeable, different outcomes for subgroups, such as low-income versus high-income											

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Fiscal
WHO Gender Analysis Tool [17]	5-Year & 20-Year National Development Plan [25]	Non-Communicable Diseases Strategic Plan [34]	Strategic Plan [26]	DRAFT Fiji Policy on Food and Nutrition Security [27]	Wellness Policy [28]	Fijian Trade Policy Framework [29]	Fiji 2020 Agriculture Sector Policy Agenda [33]	Fiji National Gender Policy [32]	Fiji School Health Policy [35]	Policy on Food and School Canteens [36]	Fiscal Policy (Budget) [30, 31]
women or employed versus unemployed men?											
Do materials or publications portray men and women based on gender-based stereotypes?		NA	NA	NA	NA	NA	NA			NA	NA
Does the language exclude or privilege one sex?											

Figure Key:

Policy met criteria
Minimal consideration/abides in some respects
Insufficient information provided to make an assessment
Opportunity for strengthening
NA - not applicable

Figure 1. Gender analysis of diet related policies in Fiji, using the World Health Organization Gender Analysis Tool

According to this review, the most gender responsive policy was the Fiji National Gender Policy [32]. The Strategic Plan [26] and the Fijian Trade Policy Framework [29] both referred to the National Gender Policy. However, how various elements of the gender policy would be incorporated into the subsequent action plans was not specified.

3. Stakeholder perceptions

Key themes and illustrative quotes are presented in **supplementary table 3**. The main themes identified from the WHO and FAO frameworks included: income-generating activities and spending income on nutrition; local (food) culture and gender; nutrition and the lifecycle; obesity and nutrition; rights-based perspective related to gender and nutrition; and targeting in nutrition. Themes identified inductively, during the coding process included: barriers and enablers to having gender considerations in health and nutrition-related policies; gender-specific needs and disease risk; current considerations of gender in policy; and the need to focus on other 'vulnerable' groups (rather than women, or gender considerations more broadly). These themes were grouped in overarching themes to aid interpretation: see **table 1**.

1. Perceptions on gender, health, and nutrition – a needs-based approach for the focus on specific groups in nutrition and health related policy:

Gender-specific needs and disease risk. Most of the discussion on gender-specific needs and disease risk focused on women of reproductive age and iron deficiency anaemia. However, there was acknowledgement of a higher incidence of premature death due to NCDs in men in Fiji.

"Yeah, I think anaemia is towards women more than men. Women outlive men in Fiji. Men die more earlier to NCDs - high blood pressure is also on women. Also obesity in children" – Government, W.

Nutrition and the lifecycle. Any discussion around nutritional needs and the lifecycle was exclusively focused on women of reproductive age, including women who were pregnant or breastfeeding. In general, this discussion also focused on iron-deficiency anaemia, and the higher risk that women of reproductive age have for this condition.

Obesity and nutrition. There was a consensus that, while obesity was prevalent across genders in Fiji, there was a higher prevalence of women living with overweight and obesity (supported by the most recent WHO STEPs survey [6]). How to address this gender difference was not discussed in depth. Interviewees suggested that the burden of obesity in the region needed to be addressed more generally, not by a gender- or sex-specific response.

"There is clear evidence that, one, in terms of overweight and obesity, then one is bigger than the other. But in terms of policy, we need to talk more about that instead of if we need to be more gende-r specific…" – Government, M.

2. Perceptions on gender-related roles and responsibilities around nutrition and health:

Income-generating activities and spending income on nutrition. Interviewees reflected that there are increasing numbers of women in the formal paid workforce, particularly in the urban region of Suva. They reflected that this shift has corresponded with increased consumption of convenience foods, highlighting that women maintain responsibility for their family's nutritional needs.

"And so people are working longer hours than women who, like my mom, was a housewife. And so most of the wives now are no longer the housewives. They are all part of the mad rat race and so getting home to cook the food, and when I say cook the food, it's not only woman, it's also men who ought to cook the food" – Private sector, M.

Food culture and gender. There was a lot of discussion around culture, gender, and food in Fiji. Interviewees reflected on a strong sense of culture in Fiji, and how there are traditional gender roles around food, although it was highlighted that the gender roles and expectations around food were changing.

"We engineer the thought process [where] women are the nurturers, the feeders, and sometimes they give everything and there's nothing left for them." – Civil society, W.

Interviewees did not, however, uniformly think that the relationship between culture and food would necessarily have an impact on diet quality. Additionally, most did not see the social and cultural norms around food being related to gender inequality.

"I think that the diets, whether it's Indo-Fijian [or Fijian], they're similar, the families eat together. It's a very important ritual, the family meal … there are similar challenges across the board for both men and women and children as such, because … everyone does eat."– Private sector, M.

3. Perceptions on what is considered "equitable" when it comes to gender, nutrition, and health:

Rights-based perspectives related to gender and nutrition. A range of rights-based perspectives on gender and nutrition were identified. Some interviewees suggested that, if they were to focus on gender, it could risk being at the expense of other "vulnerable" groups, such as children, or may lead to identification of relatively unimportant differences.

"Because if we were to demarcate to between men and women, I mean, already we are pre-empting and we are differentiating... 'This is the emphasis that we place on men and this is the emphasis that we place on women'" – Government, W.

It was acknowledged that, traditionally, women prepare the food for the household, yet are often the last to eat, highlighting a cultural aspect that translates into gender inequality. Interviewees also highlighted a need to move on from putting all the responsibility of nutrition, health, and wellbeing of the family on women.

"… No, I am trying also to get away from the idea that women should be responsible for their own health issues, but also for their kids health. Because then we place the whole responsibility of nutrition on women, which I feel that is very unfair." – Development partner, W.

4. Perceptions of current considerations of gender in nutrition and health-related policies and ideas for further gender inclusion:

Current considerations of gender in policy. There were a range of views on the current considerations of gender in policies. Some interviewees stated that policies had more general aims, but that they did include programs focused specifically on women. Others suggested that gender was considered within the "vulnerable" groups' category. There was also a perception that "vulnerability" should be a focus in policies, and that this may not always mean a focus on gender (women), but rather a focus on those with highest need, dependent on the policy focus.

"I think it's addressed in the policy. There's this area around the, you know, the needs of the vulnerable groups in the population, so it's addressed in the nutrition policy." – Development partner, W.

Targeting nutrition. Most interviewees acknowledged that there were gender differences in diet- related disease risk, and or needs. However, views on the need to target nutrition-related policies or interventions were mixed, and there was a general lack of acknowledgement that people of a certain gender(s) may be overlooked when developing nutrition and health-related policy.

"I think no. I mean... the priority should be both genders. Why only one?" – Civil society, W.

"Yes, because the requirement for a woman is different than compared to men. So, I believe that when making these policies, both genders could be considered." – Private sector, W.

5. Enablers and barriers to the inclusion of gender in nutrition- and health-related policy. For interviewees who agreed that gender considerations should be evident in health and nutrition related policies, a range of barriers and potential enablers to their inclusion were identified. Key barriers included a lack of: (i) awareness around the need for gender considerations (broader than women's reproductive health); (ii) collaborative and multisectoral platforms; and (iii) disaggregated data for the identification and monitoring of gender-related needs. Further inclusion of the National Gender Policy in health and nutrition-related policies, multisectoral engagement (for example, building on expertise from the Ministry of Women), and making it standard practice to collect and make available gender-disaggregated data, were identified as key enablers.

"… if you want to include gender into their [policies] we need to create that environment first… So that they'll be able to accept it and be able to go out and work on gender." – Development partner, W.

Discussion

Progress towards, and achievement of, the SDGs are central to Fiji's whole-of-government National Development Plan [25]. Given marked differences by sex and gender in diet-related disease risk and burden, there is a need for sex and gender considerations to be included across policies and sectors that deal with health-related issues. From our analysis, we found that, while gender was considered in a number of the policies, only one policy was assessed as gender responsive, and this was the National Gender Policy [37]. Most informants acknowledged that there are sex and gender differences in the diet related disease burden in Fiji, however, there was a general acceptance of the "status quo" in relation to the inclusion of gender considerations with policies, and roles and responsibilities of women in Fiji.

The Government of Fiji has demonstrated a commitment to gender equality, through its National Gender Policy. This policy is led by the Ministry of Women, Children and Poverty Alleviation, but with the aim to be cross cutting, applying to all government ministries, and with the overall goal to "promote gender equity, equality, social justice and sustainable development in the Republic of Fiji" [32]. The Policy, and achievements towards the policy goal, are reviewed every four years in line with the review process for the Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW) [38]. Whilst the National Gender Policy was the only policy found to be gender responsive, it is encouraging that a number of the other policies refer to it, and key informants were aware of the policy. However, our analysis showed that there is a lack of detail in most policies concerning how the goal of gender equity could be achieved in terms of diet and related NCD burden. Training within government ministries could aid the tailoring of programs to ensure they are gender responsive, and to ensure that they include actionable steps towards the broader gender-related goals. Whilst there are related costs, research shows that the degree of budgetary commitment drives successful policy implementation, highlighting the need for advocacy targeted towards the Treasury and the Ministry of Economy [39].

Some informants identified differences by gender in the prevalence of obesity and the burden of premature NCD death in Fiji, yet they did not think that these differences would require more targeted programs. Most also did not link these differences with gender-related roles and/or responsibilities around nutrition, a consideration also lacking in the majority of the reviewed policies. There was an impression, from both women and men, that including gender considerations in policies could distract from other population groups with "higher needs". Informants also identified actor-related barriers to the inclusion of gender considerations, including a lack of awareness around the need for gender considerations (broader than women's reproductive health) and collaborative and multisectoral platforms. Globally, women are more likely to be affected by malnutrition (both under and over nutrition), and to be food-insecure [40]. Given the importance of gender in relation to the health of all people in Fiji, it is important for policy implementors to recognize that gender is a cross-cutting determinant of health [41]. There are key actors in this space in Fiji, including the Ministries of Women and Children and Poverty Alleviation, who lead the National Gender Policy, International Organizations including FAO and the Pacific Community, and NGOs including Diverse Voices, Action for Equality, FemLINKpacific and the Fiji Women's Rights Movement. Evidence from both gender and nutrition-policy research shows that effective nutrition actor networks, spanning different sectors, can generate government commitment to issues [39, 42]. In the Pacific, evidence from regional policy forums on nutrition issues reflect the need for multi-sectoral response [43]. There are multi-sectoral working groups in Fiji that focus on specific nutrition issues (for example food labelling) or more broadly on NCD risk reduction. Therefore, there are opportunities to further strengthen the commitment to the inclusion of gender-related considerations in nutrition and health- related policies through pre-existing nutrition focused multi-sectoral platforms, with advocacy and awareness raising of nutrition-related stakeholders from key gender actors.

Several informants reflected on the changing work culture in Fiji, and its impacts on the roles and responsibilities of women. They reported a shift to more women working within the formal (paid) workforce, particularly in urban areas of Fiji. They suggested that these shifts have likely played a role in the changing burden of diet-related disease, with a reliance on convenience foods which are generally highly processed, of low nutritional value, yet high in fat, salt and sugar [44]. This observation highlights that, even with more women in the workforce, women retain the responsibility for preparing food for their families. While the importance of addressing gender inequities in roles and responsibilities (including those relevant to nutrition) are highlighted in the National Development Plan, there are no identified mechanisms for addressing the negative implications [25]. An increasing proportion of women in the formal work force and changes in nutritional status of populations is not a new concept, nor is it unique to Fiji [45, 46]. Mkandawire et al [19] conducted a gender assessment of Malawi's National Nutrition Policy and Strategic Plan in 2016. While they identified that the policy was gender responsive, based on the WHO gender assessment and FAO tools, they proposed that there was a need to develop an environment that promoted boy's and men's participation in nutrition, including shopping, preparing and cooking food [19]. Informants in the present study similarly argued that nutrition should be viewed as a responsibility of men as well as women.

Across the policies reviewed (including the National Gender Policy), gender is referred to in binary terms, and there is no acknowledgement that gender is non-binary. Further, only a limited number of policies defined what they meant by "sex" or "gender". There is a danger in referring to gender solely in binary terms, as this groups by femineity and masculinity, which can deepen existing stereotypes and corresponding roles and responsibilities [41]. Gender is about everyone; gender equality is everyone's responsibility, and everyone benefits from gender equality. Yet, informants often responded to questions about gender and health only in terms of the implications for women of reproductive age, despite some acknowledgement that men should have a role in nutrition. Further, globally there have been calls to ensure that data is collected in a gender sensitive manner, and with the ability to disaggregate data by sex [42]. The availability of sex and gender data following policy implementation in Fiji will be crucial to understanding the influence of gender on policy implementation going forward.

A finding that underlies most of the above discussion points is that many of the informants interviewed were satisfied with the level of gender inclusion in nutrition and health-related policies in Fiji. We have discussed some factors related to this. However, there is a need to better understand why this is the case. It is possible that better evidence on the difference that gender sensitive policies can have on health outcomes is needed. It is also possible that there is a broader resistance to changing gender roles. As in most cultures, there are cultural norms and practices that define the role of women and men regarding food and nutrition in Fiji. For example, in iTaukei (Indigenous Fijian) culture, ideas around femininity and masculinity are largely based on Christian ideals of women being caring and nurturing and men being strong and being the head of the family [47]. While culture needs to be respected, it should not be at the expense of work towards gender equality [38]. It is possible that action in this area could stem from advocacy and mobilisation by feminist groups working towards gender equality more broadly, and that such action could trickle down to nutrition-related policy.

Considerable work is being done around women's empowerment in Fiji. In 2019, the FAO in collaboration with the Pacific Community, conducted a country gender assessment of agriculture and the rural sector [48]. Key recommendations echo those of the present study, but focus specifically on women in rural settings. There is also extensive research around gender and fisheries in Fiji, with programs for women's empowerment [49]. Gender-based work in agriculture and fisheries highlights the need for the representation of women in governance structures. This need was reflected by our policy review and interviews with informants. In 2020, representation of women in Parliament was 22% [50]. While this is positive, and is an increase on previous years, it shows that there is still scope for improvement. Globally, an initiative called "Global Food 50/50" has been introduced [51], which highlights how gender is reflected, or not, in the policies and practices of leading global food organisations. It aims to provide an accountability system for organizations to ensure gender-responsive programming, gender-equitable institutions and diversity of leadership within organizations [51]. Such tools could be used or adapted for the Fiji context.

Strengths and limitations

To our knowledge, this is the first study to focus on gender considerations in nutrition-related policies in the Pacific Island region. We gained a range of insights and expertise from interviewees. However, some informants whose insights would likely have been beneficial, did not respond to requests for interviews. We were able to triangulate our findings from the different sections of our analysis and from different data sources which, in line with the literature discussed, informed our recommendations. The first author on this paper, who led the study and wrote the first draft of the article, is not from Fiji [52], but input from in-country co-authors and collaborators was sought throughout the research process. Another limitation is that the questions on gender considerations made up a very small part of the overall interview guide. The interviews overall focused on nutrition and health related policy and opportunities for scaling-up these policies, informed by Shiffman's theory [21] and Kingdon's theory [22]. We propose that interviews focused specifically on gender considerations in policies could be conducted to gain more in-depth information particularly in relation to explanations for the lack of inclusion of gender considerations in policies. Further, we focused specifically on gender, but there are other factors that could be assessed in relation to informing equitable nutrition policy in Fiji, and that likely intersect with gender, including socioeconomic status, ethnicity, and region (urban compared to rural). It will be important to explore this further in future analyses.

Conclusion

Gender equality is a stated goal in several nutrition and health related policies in Fiji, however, based on the WHO Gender analysis tool only one policy was ranked as gender responsive. The gender responsive policy, The National Gender Policy, aims to be cross-cutting across all government ministries. While this is a key strength in terms of accountability for monitoring progress towards gender equality in Fiji, we have identified opportunities to further strengthen gender considerations across nutrition and health related policies. We suggest: 1) framing gender considerations in policies so that they are actionable and more inclusive of a range of gender identities; 2) undertaking advocacy through actor networks to highlight the need for gender-responsive health and nutrition- related policies across key stakeholder groups (including government, industry, civil society and development partners); 3) ensuring that data collected to monitor policy implementation is disaggregated by sex, and inclusive of gender identities; and 4) promoting equitable participation in nutrition-related issues at both a community and governance level. We propose that these steps will be crucial in the development of gender-responsive policies. However, future monitoring and evaluation of policy implementation will be needed to identify corresponding changes in practice.

Declarations

Ethics approval and consent to participate

Ethics approval was granted by the University of New South Wales (HC200055) and Fiji National University (CHREC ID 184.20). Informed consent was provided by each key informant prior to the interview.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

BLM, MW and JW conceived the research question. BLM, GW, RM and JW developed the research protocol. BLM, SM, AMT, and GW identified documents for the policy document review and identified the key informants. BLM and SM conducted the key informant interviews with support from GW. BLM conducted the analysis of the policy documents and the interviews with support from GW and SM. KB, AMT and JW provided expert advice on policy analysis. All authors provided feedback on the manuscript and approved the final version.

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6.4 Supplementary material

Supplementary table 1. Included policy documents, description of policies, and stated policy objectives

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Economy
	5-Year & 20-Year National Development Plan [25]	**Non-Communicable Diseases Strategic Plan [34]**	**Strategic Plan [26]**	**DRAFT Fiji Policy on Food and Nutrition Security [27]**	**Wellness Policy [28]**	**Fijian Trade Policy Framework [29]**	**Fiji 2020 Agriculture Sector Policy Agenda [33]**	**Fiji National Gender Policy [32]**	**Fiji School Health Policy [35]**	**Policy on Food and School Canteens [36]**	**Fiscal Policy (Budget) [30, 31]**
Year endorsed and timeframe for policy	2017 - 2021 (5-year) and 2017 - 2036 (20-year)	2015-2019	2020 - 2025	2018-2022 *Note - this policy is not yet endorsed. The policy used for the content analysis is the draft from 2018.*	2015 - current	2015-2025	2014 - 2020	2014 (to be reviewed every 4 years)	2016 (to be reviewed every two years)	2017 - current	2019 - 2020
Type of policy document	Strategic short- and long-term plan	Strategic plan	Strategic Plan	Policy	Policy	Framework	Sector policy agenda	Policy	Policy	Policy	Supplement to the 2019-2020 Budget Address
Main policy objectives/focus of policy	The 20-year long-term national development plan, supported by Fiji's strengths and an enabling national environment, is translated into individual sector development plans to be implemented over the 5-year blocks.	Objectives focusing on reducing the burden of NCDs through improving diets (e.g., reducing salt intake, increasing fruit and vegetable intake), decreasing prevalence of overweight and obesity, increasing physical activity, decreasing smoking prevalence, decreasing alcohol consumption and to reduce rates of	Goal: Universal Health Coverage Three strategic goals (page 19): Strategic Priority 1: Reform public health services to provide a population-based approach for diseases and the climate crisis Strategic Priority 2: Increase access to quality, safe and patient-focused clinical services Strategic Priority 3: Drive efficient and effective	Ten main goals, focused on: 1. multisector leadership, 2. promotion of sustainable, diversified and resilient food systems, 3. investment in nutrition sensitive value chains, 4. improvements in food safety, 5. enhancements in maternal, infant and	Focus is on establishing a national "Wellness" strategic plan that will include a multisectoral wellness team to implement the program of work. There is also an aim to conduct and support research to determine population "wellness".	The overall goal is to "To transform Fiji into a vibrant, diversified and internationally competitive export-led growth-oriented economy" Objectives to achieve this goal include facilitating growth of micro, small and medium enterprises, improving trade related infrastructure, and	Five key objectives, including 1. building modern agriculture in Fiji, 2. developing integrated production, processing, energy, and transport system, 3. improving delivery of services, 4. enhance capabilities to generate funding via foreign investment, public private partnerships,	Overall goal "Improve the quality of life of men, women, boys and girls, at all levels of society through the promotion of gender equity and equality." With objectives focusing on gender mainstreaming in all sectors and within civil society.	Overall goal to implement wellness activities in all schools through the school curriculum. Also focuses on strengthening multi-sectoral collaboration and co-ordination of wellness activities.	Overall goal to promote healthy eating practices, healthy living, well-being and the safety of all students in school.	Overall goal "achieving inclusive economic growth and fiscal sustainability"

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Economy
	5-Year & 20-Year National Development Plan [25]	**Non-Communicable Diseases Strategic Plan [34]**	**Strategic Plan [26]**	**DRAFT Fiji Policy on Food and Nutrition Security [27]**	**Wellness Policy [28]**	**Fijian Trade Policy Framework [29]**	**Fiji 2020 Agriculture Sector Policy Agenda [33]**	**Fiji National Gender Policy [32]**	**Fiji School Health Policy [35]**	**Policy on Food and School Canteens [36]**	**Fiscal Policy (Budget) [30, 31]**
		suicide, violence and injury.	management of the health system	child nutrition, 6. support for healthier school environments, 7. Promotion of healthy diets and lifestyles to reduce NCDs, 8. Adequate micronutrient intake, 9. programs for social protection, and 10. Scaling up of evidence-based actions for food and nutrition insecurity.		facilitating capacity building in all priority sectors. (see pg. 12)	and other business arrangements, 5. improving project implementation.				
Ministry responsible	Ministry of Economy	Ministry of Health	Ministry of Health	National Food and Nutrition Centre (also called the Wellness Division).	Ministry of Health	Ministry for Industry, Trade & Tourism	Ministry of Agriculture	Ministry of Social Welfare, Women and Poverty Alleviation	Ministry of Health Public Health Division to take the lead role and the Ministry of Education will be responsible for the monitoring (Corporate Services Section).	Ministry of Health & Ministry of Education	Ministry of Economy

	Whole of Government Plan	Health				Trade	Agriculture	Gender	Education		Economy
	5-Year & 20-Year National Development Plan [25]	**Non-Communicable Diseases Strategic Plan [34]**	**Strategic Plan [26]**	**DRAFT Fiji Policy on Food and Nutrition Security [27]**	**Wellness Policy [28]**	**Fijian Trade Policy Framework [29]**	**Fiji 2020 Agriculture Sector Policy Agenda [33]**	**Fiji National Gender Policy [32]**	**Fiji School Health Policy [35]**	**Policy on Food and School Canteens [36]**	**Fiscal Policy (Budget) [30, 31]**
Other Ministries named	Ministry of Labour; Ministry of iTaukei Affairs, Ministry of Agriculture, Ministry of Rural Affairs; Ministry of Health; Ministry of Education	MIT; Ministry of Information and Communications , NFNC, Wellness Unit, Ministry of Education, Ministry of iTaukei Affairs, Ministry of Women; Ministry of Industry and Trade; Ministry of Primary Industries	None.	The multisectoral policy acknowledges the equal and collective input to the objectives and actions contained within it to be from six key ministries: Agriculture, Health, Women, Children and Poverty Alleviation, Industry, Trade and Tourism, Youth and Sports, and Education Heritage and Arts.	"Whole of Government" approach	"Whole of Government" approach	FAO Technical Assistance; Ministry of Strategic Planning, National Development and Statistics, The Asian Development Bank; EU, SPC	Ministry of Labour; Ministry of iTaukei Affairs, Ministry of Agriculture, Ministry of Rural Affairs	None.	None.	The Budget report was compiled by the Ministry of Economy in consultation with Government ministries, the Fiji Revenue and Customs Service, the Reserve Bank of Fiji and other Government agencies.

Supplementary table 2. Gender analysis of diet related policies in Fiji, using the World Health Organization Gender Analysis Tool

WHO Gender Analysis Tool [17]	5-Year & 20-Year National Development Plan [25]	Non-Communicable Diseases Strategic Plan [34]	Strategic Plan [26]	DRAFT Fiji Policy on Food and Nutrition Security [27]	Wellness Policy [28]	Fijian Trade Policy Framework [29]	Fiji 2020 Agriculture Sector Policy Agenda [33]	Fiji National Gender Policy [32]	Fiji School Health Policy [35]	Policy on Food and School Canteens [36]	Fiscal Policy (Budget) [30, 31]
Do the vision, goals or principles have an explicit commitment to promoting or achieving gender equality?	Yes. Vision: "Transform Fiji towards an even more progressive, vibrant, and inclusive society" One specific goal is "empowering women to reach their full development potential", within this gender equality and SDG 5 are discussed/highlighted. Gender equality is also highlighted under the "Social Development" goal Gender equality is also highlighted in the forward as a "critical cross cutting issue"	No. Goal of strategy: "To contribute to the overall goal of a healthier Fiji, and specifically to achieve a 25% reduction in premature mortality from the four key NCDs by 2025"	No, However, they make reference to gender equality being a cross-cutting policy, that has the aim to achieve gender equality. They do have a strategic priority that included an objective specific to women: "Improve the physical and mental well-being of all citizens with particular emphasis on women, children and young people through prevention measures."	No. Not an explicit commitment, however they do say that "Reducing the triple burden of malnutrition is a huge challenge that cuts across multiple sectors, including health, agriculture and food systems, water and sanitation, education, gender and trade." they also acknowledge that women are the main food producers in LMICs, but generally have less resource and less control of money.	Yes, one of the guiding policy principles: "Gender equity – the policy will ensure that men, women, boys and girls are considered equally in the planning and implementation processes of all Wellness initiatives and programs."	Yes, although is focused on referencing/mainstreaming the broader gender policy. Pg 11. Policy objectives: "To facilitate the mainstreaming of gender, environmental protection and other related policies to ensure coordination and policy coherence."	No.	Yes. The overall goal of this policy is to promote gender equity, equality, social justice and sustainable development in the Republic of Fiji.	No	No	Not within the goals h/e in terms of activities, a range of gender equality focused activities are listed (PwC Budget report, pg 36)

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Does the policy or programme include sex as a selection criterion for the target population?	No. The plan is targeted at the Fiji population as a whole, although for some of the goal's women are highlighted as the target population.	No. The policy is targeted at the Fiji population.	No. The policy is targeted at the Fiji population.	No. The policy is targeted at the Fiji population.	No. The policy is targeted at the Fiji population.	Unclear. Pg. 49 states: "In order to enhance the mainstreaming of gender policy into the Trade Policy Framework, preparation for a mid-term review of the Trade Policy Framework will take into account gender aspects when analysing the performance of current trade agreements, i.e MSG."	No. The policy is targeted at the Fiji population.	Yes. "Promoting an approach that is grounded in research, based on age and sex disaggregated data collection, and a gender analysis of roles and social relations of women and men"	Not stated.	Not stated.	Not stated.
Does the policy or programme clearly understand the difference between sex and gender?	No. Definitions of terms used are not stated. "Women" and "females" used interchangeably; term "men" used.	No.	No. Note, only the term gender, women and men are used in the plan	No. Definitions of terms used are not stated. "Women" and "females" and "men" and "males" used interchangeably.	No. Note, only the term gender, women and men are used in the policy	Unclear. Only gender is used	Not stated (only women referred to)	Yes, although in general throughout the policy gender is referred to in binary term (e.g., "women" and "men")	Not stated.	Not stated.	Not stated (only women referred to)
Does the target population purposely include both women and men?	Covers women and men (all of the Fiji population). For some of the specific goals i.e., social development and empowering women, women are a target population.	Covers the whole population (not purposely women and men)	Not purposely.	Not purposely, however as the vision for the policy is "to ensure every Fijian has access to safe, sufficient nutritious foods…" both women and men are within the target population.	Not purposely. Specifies that benefits will be for all the population.	Unclear.	No.	Yes, all women and men within Fiji are (explicitly) the target population for this policy.	Not stated (includes children, broadly)	Not stated (includes children, broadly)	Not stated (only women referred to)

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Have women and men participated in the following stages? Design, implementation, monitoring, and evaluation.	Unclear	Some indication that women were involved in the consultation process for the development of the plan. The workshop gives a list of names with Mr, Ms, Dr. etc. Of the Mr & Mrs, females represent approximately 50% of the participants.	Unclear (information not provided).	Yes, both women and men have been involved in the design of the policy, and the steering committee includes both women and men. However, the gender of people who participated in the consultation process is not known. Note, only the design phase is relevant for this policy.	Evident that women and men participated in the design of the policy (from the annex on the consultation process), however, not possible to quantify this involvement.	Unclear. Although in terms of implementation it states: "Ensure representation of the Department of Women in the NTDC subcommittees" (pg 55)	Mainly men have participated in policy development (per stakeholder and consultation list, counting "Mr" vs "Mrs/Ms"	Yes. Design: 37 out of the 55 stakeholders consulted on the policy were female (i.e. 71%) - Appendix 1	Unclear	Unclear	Unclear
Do both male and female team members have an equal role in decision-making?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear

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Does the policy or programme consider life conditions and opportunities of women and men?	For women, there is a strong focus on reproductive health, working opportunities (and general social development), and reducing physical/sexual violence against women (and children). Conditions and opportunities are less clear for men, however in the way that women's opportunities are discussed it seems men are used as the reference "normal" comparator. E.g., "The intelligence and capability of women will be further realised, and they will be encouraged to choose from a variety of occupations, many of which were previously the domain of men."	No. Some gender differences are mentioned in the background, but these have not been incorporated into the strategy.	Yes. Discussion on gender equity in the workforce, having a particular emphasis on women in health prevention measures, and the encouragement of men in seeking health advice.	Unclear	No	Life conditions/the disadvantage of women are considered in section 9.15. Also included in terms of the reference to the National Gender Policy (pg. 49)	No	Yes. Particularly in the sections regarding family roles and responsibilities, and employment.	No	No	Yes, to some extent (through the activities funded)

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Does the policy or programme consider and include women's practical and strategic needs?	Yes. (as highlighted, through specific goals within the social development and women's empowerment goals)	No.	Yes, (Outcome 1.2. "Reduced the number of inpatients presenting symptoms of CDs and NCDs, especially women, children and young people.")	Women's practical and strategic needs are considered in the background. The high rates of anaemia are also reflected on. Policy actions: Provide select women groups training on simple farming techniques and skills to establish home gardens and produce consistent supply of nutritious food for home consumption and sale. Strengthen micronutrient supplementation programme through the use of a practical tool for monitoring compliance among school children, pregnant and non-pregnant women	No	Yes (focus of page 49)	To some extent - there is an aim to set up an investment fund for "retirees, women, and youth" to aid attraction to the farming industry. (pg 13)	Yes, covered under each sub-section (i.e., 5.1 - 5.19)	No	No	To some extent (through the activities funded)
Have the methods or tools been piloted with both sexes?	Unclear	Unclear	Unclear	Not applicable (draft policy).	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear

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Does the policy or programme consider family or household dynamics, including different effects and opportunities for individual members, such as the allocation of resources or decision-making power within the household?	Yest, as covered in the below quotes: "It is expected that home duties in caring for children and household work will be shared by the spouse or partner." "Promotion of traditional handicrafts, natural body products, local ceramic ware, and exotic herbs and spices will be nurtured and expanded, offering more opportunities for women to use their traditional skills to expand opportunities for economic empowerment." "These reforms provide a platform for equality where both men and women can enjoy the benefits of employment and conditions conducive to productivity and prosperity for all."	No	No	Yes. In the background: "Globally, it has been estimated that if women were given the same access to resources as men, they can increase food production and economic growth by 20-30% and undernutrition could decline by 12- 17% (FAO, 2011). Research shows that resources and income flows that women control have positive impacts on nutrition because they are more likely to be directed towards food, education, health and care (FAO, 2017)"	No	Minimal considerations - reference the National Gender Policy	No	Some consideration (see section 5.6 Families) however, gender differences in decision-making power isn't a strong focus, or explicitly stated.	No	No	To some extent (through the activities funded)

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Does the policy or programme include a range of stakeholders with gender expertise?	Unclear, specific strategies do state that work should be conducted between relevant ministries (i.e Ministry of Women & Children and Poverty Alleviation) and NGOs, but the exact NGOs are not highlighted.	Ministry of Social Welfare, Women and Poverty Alleviation and Women's Crisis Centre are included.	Not enough information provided. States that they will do the following: "We will focus on ensuring better collaboration with other government departments on key health-related and SDG issues, including the Ministry of Education, Ministry of Women, Children and Poverty Alleviation, Ministry of Agriculture, Ministry of Rural Development, Ministry of Youth and Sports, and Police Force, to name a few."	Stakeholders with gender related remits: -Ministry of Women, Children and Poverty Alleviation -FAO	Yes.	No. H/e does state to "Ensure representation of the Department of Women in the NTDC subcommittees"	No	Yes, a range of stakeholders are included. However, monitoring meetings (with stakeholders invited) are only held every 4 years.	Unclear, states: "Both the MoHMS and MoEHA need to develop a collaborative approach with other stakeholders to ensure that the health and wellness of children is given prominence. "	Unclear	Unclear
Does the policy or programme collect and report evidence by sex?	The intention is set is to collect and report sex (and age) disaggregated data.	Only specified for cancer: "Incidence of cancer, total and disaggregated by type and sex" Note, they do say that WHO STEPs	Unclear	Unclear. Data related to this policy is yet to be collected. Evidence used to inform the policy (and quoted in the policy) includes sex specific data.	Unclear	Unclear	Unclear	States that data should be collected and reported by sex	Unclear	Unclear	Unclear

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		surveys will be used for monitoring, and these surveys disaggregate data.									
Is the evidence generated by or informing the policy or programme based on gender analysis?	Gender analysis is not stated, although some gender specific results have been quoted (e.g., women and men with anaemia, and numbers of women in parliament)	Unclear	Yes, and references the National Gender Policy.	Unclear	Unclear	To some extent. E.g., informed by the 2013 Global Gender Gap Report 2013 (pg 49)	Unclear	Yes. Stated that policy is informed by gender-based analyses (however, these are not referenced)	Unclear	Unclear	Unclear
Does the policy or programme consider different health needs for women and men?	Yes, a range of gender specific needs are covered.	No	Yes. Discussion on gender equity in the workforce, having a particular emphasis on women in health prevention measures, and the encouragement of men in seeking health advice.	Policy reflects on the requirements of women of childbearing age (specifically micronutrient requirements) - no further health needs/differences are highlighted.	No	Reference the National Gender Policy	No	Yes. Particularly through section 5.12 Access to Health Services	No	No	To some extent (e.g., domestic violence)

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Does the policy or programme include quantitative and qualitative indicators to monitor women's and men's participation?	Unclear, but the plan seems to be based on quantitative data.	No	No	No	Unclear	Unclear	No	Unclear	No	No	Unclear
Does the policy or programme consider gender-based divisions of labour (paid versus unpaid and productive versus reproductive)?	To some extent: "It is expected that home duties in caring for children and household work will be shared by the spouse or partner."	No	No	Unclear	No	Reference the National Gender Policy	No	Yes. Particularly through section 5.6 Families.	No	No	No

WHO Gender Analysis Tool [17]	5-Year & 20-Year National Development Plan [25]	Non-Communicable Diseases Strategic Plan [34]	Strategic Plan [26]	DRAFT Fiji Policy on Food and Nutrition Security [27]	Wellness Policy [28]	Fijian Trade Policy Framework [29]	Fiji 2020 Agriculture Sector Policy Agenda [33]	Fiji National Gender Policy [32]	Fiji School Health Policy [35]	Policy on Food and School Canteens [36]	Fiscal Policy (Budget) [30, 31]
Does the policy or programme address gender norms, roles and relations?	It acknowledges and aims to address some gender norms/roles/relations e.g., "Support for women's health and decisions regarding family planning and sexual and reproductive health will be shared and respected... Women will be included and consulted in all planning for future development projects, and their input will be translated into tangible project outcomes. This includes adaptation planning at the community level, where women can be key agents to change unsustainable production and consumption practices within the family and community."	No	No	No. Some gender norms/roles/relations are highlighted in the background, these are not addressed in the policy actions (e.g., discussion re resource allocation and power in the background, not carried through to the strategy actions)	No	Reference the National Gender Policy	No	Yes (section 5.6), however, addressing differences in responsibilities/decision making power isn't a clear focus.	No	No	No
Does the policy or programme exclude (intentionally or not) one sex but assume that the conclusions apply to both sexes?	No	To some extent	Unclear The policy is broad, assumes coverage of all Fijians.	To some extent	To some extent	No	Unclear	No	Unclear	Unclear	No

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Does the policy or programme exclude one sex in areas that are traditionally thought of as relevant only for the other sex, such as maternal health or occupational health?	Yes. Men seem to be excluded from the aims to reduce sexual violence (i.e., the focus is on women being subjected to sexual violence). Reproductive health almost exclusively focuses on women, although there is acknowledgement that decision making and roles and responsibilities around childcare should be shared.	In some areas	Yes, maternal/infant health is focused specifically on women	Yes. In action 5 "Enhance maternal, infant, young child and adolescent nutrition" only pregnant/non-pregnant women are referred to	In some areas. Note, this seems to be a very general/high level document.	No	Yes, women are largely excluded from the policy actions.	No. There is some focus on including men in reproductive health (e.g., father's involvement in pre-natal, birthing and post-natal activities), however the focus of responsibility is still on females.	Unclear	Unclear	Unclear
Does the policy or programme treat women and men as homogeneous groups when there are foreseeable, different outcomes for subgroups?	Different groups with potential different inequalities are considered separately to women/men.	Yes	Yes	Yes	Yes	To some extent, although does state on pg. 49 "The interests of women (as well as other disadvantaged groups) will be taken into account in trade policy formulation and trade negotiations."	Yes	No, there is a focus on intersectionality	Yes	Yes	Unclear

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Do materials or publications portray men and women based on gender-based stereotypes?	Yes/to some extent e.g. within the publication plan women and men are depicted in the following ways: Women: in field, holding a child, as a nurse, working in a computer lab, women soldiers, selling food at a market, weaving, (girls at school) Men: in tractor, (boys at school), male soldiers, on a bus, fishing, performing cultural dance	NA	NA	NA	NA	NA	NA	No. Stated strategy: "Promoting a balanced and non-stereotyped portrayal of women in the media through training."	Yes. Images of boys only.	NA	NA
Does the language exclude or privilege one sex?	No	No	No	No	No	The focus (particularly within the gender specific sections) seems to refer to women as the "other" i.e. the gender section only focuses on the disadvantage of women.	No	No	No	No	No

Supplementary table 3. Stakeholder perspectives on gender considerations in nutrition and health related policy

		Example 1	*Example 2*
Themes, deductive	Income generating activities and spending income on nutrition	It's the availability of processed foods. That's the problem now and so the Fijian is now becoming like the Australians of the past, the Americans of the past where everything is go, go, go, go. And so people are working longer hours than women who, like my mom, was a housewife. And so most of the wives now are no longer the housewives, they are all part of the mad rat race and so getting home to cook the food and when I say cook the food, it's not only woman it's also men who ought to cook the food. (Private sector, M)	Oh, yes. Well, yes. We are having an increase in number of women who are now working. For our food preparation culture is definitely changing. For example, for that time I'm really targeting workplace policies, because more of our women are working and we need to go into the workplace and talk to them about healthy workplace. That's a labor plan. Ministry of Education need to go in so that our children are informed. That's a sector. We need to bring it in. Then Ministry of Agriculture. And particularly Ministry of Trade, because I think that is the biggest..... (Govt, M)
	Local (food) culture and gender	Yeah. It'll be that, it also be on the misconceptions of culture, about women and also the access which is a big issues of women as well; so access to money to buy food, and I would say communication again. We engineer the thought process was it's like women are the nurturers, the feeders and sometimes they give everything and there's nothing left for them. (Civial Society, W)	Look, I don't think so. I think that the diets, whether it's Indo, Fijian. they're similar, the families eat together. It's a very important ritual, the family meal and that meal time. So there are similar challenges across the board for both men and women and children as such, because they everyone does eat. But the community and the community feel around meals is very important to Fijians. (Industry, M)
	Nutrition and the life cycle	Yeah, I think in terms of what we've said, we need to be what kind of food that we might need. Nutrition labelling on packaged food. I think to talk about women and their lifecycle, their needs to be more awareness on why women need more iron than men, and in the culture, where men eat fist then women. And how can we actually address, you know, the anaemia around child bearing age. Can we promote local, local food that can actually be used in like in hospital instead of tablets. It could be a substitute instead of taking iron tablets (Govt, W)	Well, I mean, with anaemia, you know, supplementation is generally only run for a certain population groups that have a high prevalence, which is set out in the Ministry of Health plan, but it's based on burden and of course, the burden tends to follow population subgroups but it's essentially about burden so you're and then for fortification, of course, when you're deciding fortification levels, then it's primarily around, you know, making sure that, you know, overdosing anybody and trying not to under dose anybody. But that's kind of part of the technical assessment rather than being stated directly in the policy. That's just how you assess fortification levels. So I guess it's the hidden subtext, but it's not an it's it's all related to burden and demanded intake rather than targeting gender specifically. (Development Partner, W)

	Obesity and nutrition	There is clear evidence that, one, in terms of overweight and obesity, then one is bigger than the other. But in terms of policy, we need to talk more about that instead of if we need to be more gender specific because there's a clear difference in the gender. (Govt, M)	Obesity is also across genders, but it isn't just more prevalent in females. Definitely because of low physical activity and other factors and because obesity is more prevalent in females, they are pretty good chances that if we start screening and see through the population, that will be lowered by a steps survey because physical activity is low, consumption is high. Definitely. Prevalence would be different in both the sexes. (Govt, W)
	Rights-based perspective related to gender and nutrition	Maybe yes. They may not, I'd say it ought to be whatever it is, it ought to be family centered or community centered so that everyone in the community or everyone in the household gets to benefit from. From this policies or this plan. Because if we were to demarcate to between men and women, I mean, already we are pre-empting and we are differentiating that deal. This is the emphasis that we place on men and this is the emphasis that we place on women. I'd like to think that we need to -because we are exposed to the similar environment - I would think that we ought to be treated the same way as well. If there is a particular section of the society that we ought to place prominence on, I'd say you would have to be the children. Specifically, the children under five. We need to work on that specific cohort. We need to work on them to allow that healthy transition throughout the life span. (Govt, W)	No, I am trying also to get away from the idea that women should be responsible for their own health issues, but also from their kids health. Because then we place the whole responsibility of nutrition on women, which I feel that is very unfair. (Development Partner, W)
	Targeting in nutrition	Yes, because the requirement for a woman is different than compared to men. So I believe that when making these policies, both genders could be considered. (Private Sector, W)	I think it's important to have a gender aspect to it. Gender and also with children should be mentioned specifically because Fiji is very rich in its culture. So I think if you generalize, then it just falls through but there should be opportunities or women and opportunities for children. I know it's no different in what you eat, but it's actually the provision of the activities or the services that's available. (Development Partner, W)
Themes, inductive	Gender specific needs and disease risk	Yeah, I think anaemia is towards women more than men. Women outlive men in Fiji. Men die more earlier to NCDs - high blood pressure is also on women. Also obesity in children. (Govt, W)	For some of the NCDs it's across, and I think maybe where there is a difference between men and the ladies is cancer. Yeah. Ladies having cervical cancer, breast cancer. Well, it's men having prostate cancers is the only difference, but otherwise generally I feel it's the same across both. (Govt, M)
	Current considerations of gender in policy	Yes, I think the policy of having fortified iron in the products that we produce like flour that was mainly focused for our women because of the high rate of anaemia and in the past years and it is still increasing. So I think that was considered for the females. (Private Sector, W)	I think the policies that we have - it's more general. Even though, like I will say with the strategic development plan, we have some programs in there that looks at women, but overall policies are more general. (Development Partner, W)

	Targeting not needed (women and men have the same needs)	I think no. I mean, priority on nutrition should be like, you know, the priority should be both genders. Why only one? (Civil Society, W)	Yeah well, I'd like to think men are always healthier, but with our anaemia stats, men are also becoming anaemic. So I think that we'd be equally affected both males and females, because the environment is the same and even in households we would be consuming the same meal. I would say that the factors affecting nutritional status, both male and females would be subjected to this same environmental factors, dietary intake, consumption patterns, purchasing power. (Govt, W)
	The need to focus on other 'vulnerable' groups	Not particularly. I mean, I think the diets are broadly similar in both genders, in adults. I mean, I think what we're generally seeing is, you know, in young children, there's still quite significant issues of undernutrition and we're still seeing, you know, hospital admissions from malnutrition and that's never really gone away. We also see, you know, continuous problems of anaemia and things like that. But it's not particularly related to, you know, that small age group related and subgroup related like women during pregnancy, more might be anaemic, et cetera. But the dietary patterns, I think, you know, are slightly different between the two genders in adulthood. But it's not something that is huge in terms of impacting on nutritional status. (Development Partner, W)	Yes, this is target the sectors of the population that children under 5 and women of childbearing age. But then each stem of the policy talks to a different targeted sector of the population. So there is already that inclusion into the draft policy. But we'd like to, as I had mentioned, I'd like to see more of these interventions as family centered. Working on the entire family, that will rub off positively on the entire community. If we can work on the entire family into the interventions to benefit the entire family, that these families become success stories for the entire community. And the community is what that builds the entire nation. (Govt, W)
	Barriers to the inclusion of gender	I think it will be collaborative effort. Like just safe agriculture wants it, it should work with the ministry of women. We tried to do it with agriculture. We worked with [*organisation name removed*] because there was report put out on gender, the key results were put out. The biggest challenge that I see amongst ministries because they see gender as a 'women' thing, hence the need for awareness and understanding. (Development Partner, W)	I'm not quite sure how you would do that. I mean, of course, generally one when one's doing kind of the communication and social mobilization and so on, that very much considers gender roles and so on, but not so much at the policy level. No, it's more of a community outreach level. (Development Partner, W)
	Enablers to the inclusion of gender	Engaging community groups to getting an understanding of what the needs are. I know the food and Nutrition Centre have done quite a bit of work in the communities with their kitchen garden projects. But I guess it's important to do more. It's not to say with a women's group, but also with the men - they have a part to play. (Development Partner, W)	In terms of acknowledgement and in terms of visibility, we would hope that we are going to be able to make more evident that the role that women are playing and the different roles, of course, also the difference in terms of access, which is so key, access to formal employment or access to the different agricultural inputs, access to land, which is so key for the agricultural sector. (Development Partner, W)

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Chapter 7. Perceptions on healthy eating among iTaukei women and men in Viti Levu, Fiji: an intersectional interpretation

7.1 Chapter overview

This chapter further addresses the second thesis aim and focuses on understanding perceptions of women and men in Fiji on their ability to eat a healthy diet. Given findings from previous chapters, in that minimal sex differences were identified in the relationship between diet intake and behaviours and cardiometabolic outcomes and given the relatively low priority that gender considerations were given by policy makers in Chapter 6, this chapter took an intersectional approach to understanding perceptions on healthy eating. An intersectional approach was taken given such an approach acknowledges, and aims to explore, the interaction of demographic characteristics, social identities, and environmental factors. This is done by examining the layers of influence or power, for example, individuals' unique circumstances/identity, aspects of identity (for example, sex, gender, age), different types of discrimination or attitudes that impact identity (for example, perceptions of masculinity or femineity based on heteronormative values), and finally larger forces or structures (for example, development, politics, economy). This chapter consists of a manuscript submitted for publication.

This study explored perceptions of women and men through focus group discussions conducted in 2019 in Viti Levu, Fiji. The study identified embedded traditional perceptions on gendered roles related to nutrition and identified that these perceptions have become misaligned with other societal and environmental changes, which collectively impacted on participants' perceived ability to eat a healthy diet. For example, women and men reported that it is the "duty" of women to prepare foods for their families, conversely men reported planting and growing less foods due to the negative impacts of climate change. This study highlights the need to address the upstream determinants of poor diets in Fiji. Further, this study acts as an example of using an intersectionality framework to understand equity issues inclusive of gender; in this case, focusing on perceptions around the ability to have a healthy diet in Fiji. Such an understanding can help inform food policy development and nutrition interventions.

7.2 Publication details

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7.2.1 Author contributions

As the first author on this publication, I contributed significantly to this piece of work. I conceptualised the study in consultation with GW and JW. GW led the focus group discussions, and I supported and contributed to the discussions when appropriate. I led the analysis of the focus group transcripts, with ACH acting as the second coder. Themes identified during analysis were discussed with GW and JW. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors. All authors have approved for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows: BLM, GW and JW conceptualised the study. BLM and GW conducted the focus group discussions. BLM and ACH analysed the data in consultation with GW and JW. All authors provided critical insights to the interpretation of the results. BLM drafted the first draft of the manuscript. All authors provided critical insights on the manuscript and approved the final version of the manuscript.

7.3 Manuscript

Abstract

Objective: To investigate perceptions of iTaukei Fijian women and men around diet and the ability to consume a healthy diet.

Design: Six focus groups conducted with women and men, separately. Six to 10 women and men participated in each group. Discussions were recorded, transcribed, translated, and thematically analysed. Themes were mapped to an intersectionality framework to aid interpretation.

Setting: Four villages in Viti Levu, Fiji.

Participants: Twenty-two women and 24 men.

Results: Seven overarching themes were identified, including generational changes in food behaviour, strong gendered beliefs around food and food provision, cultural and religious obligations around food, the impact of environment change on ability to consume a healthy diet, perceptions of the importance of food, food preferences and knowledge around food. Participants across focus groups identified that it was the "duty" of women to prepare food for their families. However, some women reflected on this responsibility being unbalanced with many women now in the formal workforce. Changes between generations in food preferences and practices were highlighted, with a perception that previous generations were healthier. Power dynamics and external factors, such as environmental changes, were identified by women and men as crucial influences on their ability to eat a healthy diet.

Conclusion: Embedded traditional perceptions of gendered roles related to nutrition were misaligned with other societal and environmental changes. Given factors other than gender, such as power dynamics and environmental factors were identified as influencing diet, viewing nutrition-related issues through an intersectional lens is important to inform equitable food policy in Fiji.

Keywords: Diet, disease, Fiji, nutrition interventions, food policy, gender, intersectionality

Introduction

Globally, non-communicable diseases (NCDs) are the leading causes of death and are predicted to retain this position for the foreseeable future [1, 2]. There is a dietary risk component to many NCDs, with diets high in salt, saturated and trans-fats, sugar and ultra-processed foods associated with increased risks of hypertension, cardiovascular disease, obesity, diabetes and some cancers [3]. Pacific Island countries experience some of the highest rates of NCDs [1]. It is hypothesised that this NCD burden is in part due to a transition from more traditional plant- and seafood-based diets to westernised diets characterised by high fat, salt, and sugar intakes [4, 5].

Fiji is an upper middle -income country and has a population of approximately 900,000 people, spanning around 100 islands [6]. Approximately half of the population lives in urban areas [7]. Fiji has two main ethnic groups, Indigenous iTaukei Fijians and Indo-Fijians or Fijians with Indian origin. The burden of disease differs by ethnic group and by sex [8]. iTaukei Fijian men have a higher risk of dying from cardiovascular disease than iTaukei women, Indo-Fijian women and Indo-Fijian men [8, 9]. However, in the overall Fijian population, almost twice the number of women compared to men live with obesity [10]. The prevalence of obesity is highest for iTaukei women, compared to iTaukei men and compared to Indo-Fijian women and men [10, 11]. Additionally, the proportion of type two diabetes attributable to high body mass index is greater in the iTaukei Fijian population than in the Indo-Fijian population [11].

Gendered roles and responsibilities can influence food provision and the health of individuals and families [12-14]. In many countries, including in Fiji, women tend to be responsible for the bulk of the childrearing and household work [15]. Additionally, in traditional iTaukei culture ideas around femininity and masculinity, largely based on Christian ideals, may influence roles around food, with women as carers and nurturers being responsible for food preparing and cooking, while men have the role of head of the family and, therefore, having the first serve of meals [16]. It is important to understand the different gendered roles and responsibilities around food, along with understanding what these roles are influenced by (including culture, social systems, and religion), in order to establish effective diet interventions and food policy in Fiji [17, 18]. An intersectionality framework can be used to aid understanding of the interaction of demographic characteristics, social identities, and environmental factors [17, 18]. Given a new Food and Nutrition Security Policy is due to be endorsed in Fiji in 2022, we propose that this research will help inform the type of interventions and support needed to effectively implement the policy.

There is a need to hear the voices of community members to understand their interpretation of healthy eating and how gender roles and responsibilities and other equity factors are implicit in this. Therefore, the aim of this study was to investigate perceptions around diet and the ability to consume a healthy diet with an intersectional interpretation. Given the differing prevalence of diet-related disease risk factors between the main ethnic groups in Fiji, the focus for this study was within the iTaukei population.

Methods

Terminology

We hypothesised that societal and environmental factors would have a greater influence on healthy eating knowledge, attitudes, and behaviours, rather than biological (sex) factors. Therefore, the term "gender" has been used throughout this study. However, we acknowledge that gender is not binary, and that we have focused on only two gender identities within this study (women and men). We did not recruit people with other gender identities, and as such we cannot conflate our findings to a broader spectrum of gender identities.

Participants and procedure

Six focus groups were conducted with women and men, separately, across four villages in the Central Division of Viti Levu, Fiji. A convenience sample of villages in rural (n=2) and peri-urban (n=2) settings were selected based on the local social and geographic knowledge and experience of Fijian members of the research team. Village leaders were approached a week before the planned focus group discussion to seek permission to visit the village and conduct research. On an agreed day and time in early December 2019, two researchers went to the village, where a I sevusevu (a gift) was presented to the village chief or official representative seeking their consent to conduct research in their village. Six to 10 women and men were randomly approached to participate in each village. This number of participants per focus group was sought to ensure both diversity of lived experience and productive group discussion [19]. In one peri-urban village, men were not available for a focus group during the study period, and therefore a fourth village, in a rural setting, was approached to participate. Potential participants were identified by village health care workers and were eligible to participate if they were aged 18 years or older and lived in the village visited. Participants self-selected which group they participated in (women's focus group or men's focus group).

Discussions were held in either English, Fijian, or a mixture of both, depending on the preference of the group. Focus groups were conducted in village halls and were attended by two researchers: one researcher facilitated and moderated the group discussions while the other made notes and monitored the process. The researcher who facilitated the discussions is an experienced qualitative researcher based in Fiji, having conducted her PhD via a range of qualitative methods. Before beginning the discussion, information was collected on each participant's age, gender and the number of people that lived in their household. At the end of the discussion participants were provided with a voucher for staple foods such as fruits, vegetables, and grains, from a nearby supermarket, to the value of twenty Fijian dollars. Focus group duration ranged from 45-75 minutes and discussions were audio-recorded.

Discussion guide

Discussions were guided by a pre-defined, semi-structured discussion guide (**supplementary table 1**). Questions were based on knowledge, attitudes and behaviours towards food and healthy eating; additional questions on perceptions of the food environment were asked. The discussion guide was written in English, translated into Fijian and back translated into English to check accuracy. The discussion guide was piloted in English and Fijian, with minor amendments made prior to finalisation.

Data analysis

The recorded discussions were transcribed manually in Fijian and then translated into English. Each transcript was cross-checked for accuracy. NVivo12 was used for data storage and coding. An inductive, thematic approach was used to code the data. Transcripts were independently coded by two researchers, who then compared and discussed identified themes in consultation with other research team members. A coding framework was used to consolidate themes, which was adapted as transcripts were analysed. The identified themes were mapped, inductively, to an intersectionality framework, with reference to the World Health Organisation toolkit on the incorporation of intersectional gender analyses into research [18], and visually depicted based on the Canadian Research Institute for the Advancement of Women, Intersectionality Wheel [20] (**Figure 1** shows an interpretation of the Intersectionality Wheel in reference to our study findings). These intersectional factors, viewed in the intersectionality wheel, are either proximal or distal to the individual (represented by the different circles of the wheel, with circles closer to the centre representing more to the individual), representing that there are many different "levels" or "power dynamics" that influence participants perceived ability to eat a healthy diet. Specifically, the innermost circle represents the individuals unique circumstances/identity, the second circle represents aspects of identity (for example, sex, gender, age), the third circle represents different types of discrimination or attitudes that impact identity (for example, perceptions of masculinity or femineity based on heteronormative values), and finally the outermost circle represents larger forces or structures (for example, development, politics, economy) [20]. The themes, mapped to the intersectionality framework were used to assess where, and how, diet interventions could be targeted to have the greatest impact on individuals' ability to eat a healthy diet.

Table 1. Characteristics of focus group participants

	Peri-urban			Rural			Overall
	Women	**Men**	**All**	**Women**	**Men**	**All**	
Number of participants	14	10	24	8	14	22	46
Age (years)*	48 (24, 67)	25 (18, 42)	39 (18, 67)	51 (28, 69)	58 (40, 76)	55 (28,76)	47 (18, 76)
Number of people in household*	6 (2, 13)	6 (3, 9)	6 (2, 13)	6 (3, 9)	5 (3, 8)	5 (3, 9)	6 (2, 13)

*** Mean (range)**

Table 2. Themes and sub-themes identified from the focus group discussions

Overarching themes	**Sub-themes identified in the analysis**
1. Behaviours around food and reflections on generational changes in food behaviours	Food behaviours Actions to improve diets Generational changes in behaviours
2. Beliefs around food, and gendered beliefs	Food beliefs Gendered beliefs
3. Cultural and religious obligations and influences around food	Food preparation Food purchasing Religious practices involving food
4. Environmental factors impacting on the ability to achieve a healthy diet	Availability Access Environmental context Importance of being able to grow own food Impacts of development
5. Perceptions around the importance of food and health	Importance of food Perceptions of health Perceptions of healthy food
6. Food preferences and attitudes, and generational changes in preferences	Food preferences and attitudes Generational changes in preferences
7. Knowledge around food, dietary requirements and the relationship between food and disease	Knowledge of food and disease Sources of health information Dietary requirements

Results

Twenty-two women (14 peri-urban, 8 rural) and 24 men (10 peri-urban, 14 rural) participated in the focus group discussions. The mean age of women who participated was 49 years (48 for the peri-urban and 51 for the rural focus groups) and for men it was 44 years (25 for the peri-urban and 58 for the rural focus groups). Women and men had an average of six people in their households (6 for peri-urban and 5 for rural households), **table 1**.

Seven overarching themes were identified from across the six focus group discussions (**table 2**). Each theme spanned the four levels of the intersectionality wheel (**figure 1, supplementary table 2**), representing the many levels and corresponding power dynamics that influenced the themes and the participants' perceived ability to eat a healthy diet.

1. Behaviours around food and reflections on generational changes in food behaviours

Discussion around food behaviours focused on individual and family/friends' food behaviours, individual actions to improve diets and generational changes in behaviours. Generational changes in behaviour were reflected on by both rural and peri-urban participants, and by women and men, as being key to negative changes in the health of participants and their families. There was discussion around changes in lifestyle, with more women working in the formal (paid) workforce, and that this was changing what their families were eating (i.e. an increased reliance on processed packaged foods). Women in the rural and peri-urban focus groups also reflected that men were drinking more kava (a herbal depressant) and alcohol, which was impacting how they worked and contributed to the family.

Just do your plantations and plant vegetables, root crops and there is the sea, streams and rivers where we can get our food (instead) there is too much grog and sleep. –W, FG1, Rural

Sometimes we will fight because I always stop him from drinking grog. I have a lot of uncles here, most of the time, they are coming to have grog with him. –W, FG1, Rural

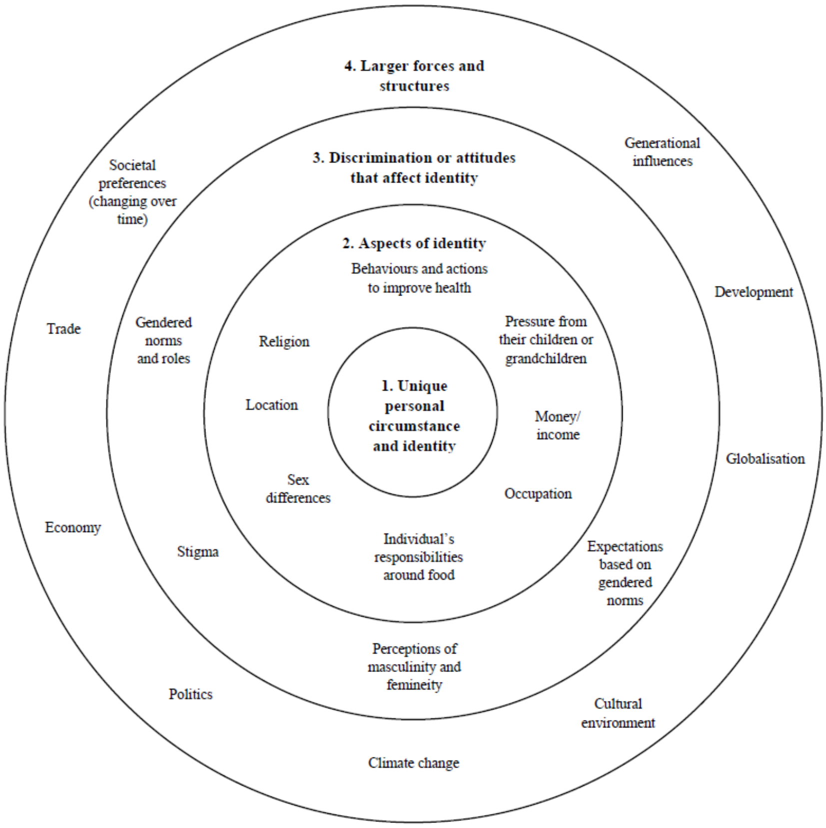

Figure 1. Factors identified within thematic analysis, mapped to the four levels of the intersectionality wheel [18, 20]

In the rural focus group, women reflected that men were less often planting crops (for food) or fishing. Instead, they were choosing to purchase food from the local shop when needed. The rural men discussed two key barriers to growing and catching their own foods; 1) that it was now harder to grow the foods that their forefathers used to grow, due to changes in the soil and raising sea levels, and 2) that they perceived themselves and others in their village to be less hardworking than previous generations.

I think one of the causes of the problem as well is that, during this time, the people are not like before - they were hardworking. These days, they wake up at eight or nine o'clock, whereas the elders will work first before breakfast. But people are used to having easy life; wake up in the morning at eight or nine, run to the shop, get one packet of biscuit, and have tea. – M, FG 2, Rural

This theme covered factors of individual identity (intersectionality (IS) level 1) including individual actions and behaviours around food, aspects of identity (IS level 2) including the living arrangement and influence of family members, and external forces (IS level 4) including social factors stemming into societal pressure and generational change, and the impact of development/globalisation and climate change (**figure 1, supplementary table 2**).

2. Beliefs around food, and gendered beliefs

Strong gendered beliefs around food and food and alcohol-related practices were identified. Women highlighted the transition of men towards unhealthy food and dietary practices. Both women and men said that it was the role or "*duty*" of women to prepare food, as well as to look after the health of the family in general.

Our ancestors didn't consume kava and grog [alcohol] *excessively and now, most of our women are widows because their husbands do not listen to the advice of a woman (their better half). They don't realise that we (women) are created to assist with providing food from the farm/garden.- W, FG 3, Peri-urban*

The gendered beliefs around meal decisions and food preparation were also shown in terms of relationships. Men, particularly in the rural focus group, reflected that when wives prepare food for the family it is a way of them showing their love and care for their husband and family.

When the food is being prepared nicely by the wife, it will be felt by the man.- M, FG 2,Rural

Participants also reflected on the fact that men eat first and that women often eat what is leftover, once the rest of the family has served themselves. While there was a consensus across the focus groups that women *should* prepare food, the women's focus groups agreed that men should no longer get "*all the best food*" – they reflected that women work just as hard as the men, so there should not be a difference for women and men.

But our culture is that, Men should have more food and us Women, we will eat what is left… But now, for me at home, I will be very honest, my husband and I will eat the same amount of food. Sometimes, I will eat more food than him and he will say "hey, you have more" and I will tell him, "I am doing more work than you". W, FG 1, Rural

This theme covered aspects of an individual's identity (IS level 2) including their gender, religion, and perceived household roles, it also included aspects of discrimination and attitudes that impact on identity (IS level 3), such gendered norms and roles around food based on perceptions of masculinity and femineity.

3. Cultural and religious obligations and influences around food

Strong cultural and religious factors that influenced both food choice and gendered perceptions around food and health were identified. Every focus group discussed their eating practices on a Sunday, a day on which it is common for extended families to come together and share food after church. This is an important part of iTaukei culture, however several of the focus group participants discussed that the food provided at these occasions is unhealthy, and that a lot of food is provided with corresponding large portion sizes. Participants said that leftover food is then re-fried and eaten in the days following.

"… one issue that I see which can cause sickness is the amount of fried foods that we are eating…, over here, we do not have a lot of rootcrops. For us, on Sundays, we always have a lot of rootcrops and I always keep the left-over foods. I can fry it today, sometimes I will put it in the container and place it in the Deep and will heat it again. Sometimes, I fry it so that it can be kept for longer period. I know that this will cause sickness but since it is not happening, I keep on doing it." W, FG 1, Rural

I know that I'm diabetic and I usually separate my food, but on Sundays I can't… I'm always afraid of eating at home. When they prepare chicken curry… I'm always afraid to eat it so I choose what to cook to eat... I'm afraid to die – W, FG 3, Peri-urban

This theme spanned aspects of an individual's identity (IS level 2) including their gender, religion, income, and role within the household, it also included aspects of discrimination and attitudes that impact on identity (IS level 3).

4. Environmental factors impacting on the ability to achieve a healthy diet

Key themes around individuals' environments, including food availability, food access, environmental context (climate change), impacts of development, and the importance of being able to grow their own food, were identified.

Rural participants identified an increase in availability of and access to processed packaged foods, and a decrease in access to traditional and/or home-grown foods. Reasons identified included infrastructure developments (e.g. roads, electricity, shops), climate change with more frequent storms, cyclones and rising sea levels that are impacting people's ability to grow the foods that their forefathers used to grow, along with more women and men working in the city (Suva).

…. like the electricity that we have on our roads. Before, our forefathers cross the river using their own lights, but now the electricity is on the road, as well as inside the buses. Before, our forefathers, when they are hungry, they eat from their plantations, what they eat is always

healthy. But for us, when there is left over cassava, we put it in the fridge and then we fry it so that we can make use of it. That is not so good. W, FG 1, Rural

All participants said that people need to focus more on growing their own foods and fishing to provide food for their families. However, men in one of the peri-urban villages discussed how they were concerned about the pollution and chemicals around the foods that they were growing, and that home-grown foods may not be healthy because of that pollution.

We do not get a lot of food from the land because there is a lot of chemicals there to make it grow quickly which is not suitable for our body so that we can live longer. That means everything that they do is just to get our lives shorter because there is a lot of chemicals in our food. We should do something like not to put manure on the food and make it grow by itself so that it meets the requirement that our body needs. - M, FG 5, Peri-urban

Finally, women and men in the rural village focus groups, and women in one of the peri-urban focus group discussions, said that they were worried about sugary snacks available in or around their children's schools and kindergartens (Kindy). In the rural focus groups, participants said that some of the teachers were selling sugary snacks in the school, and that their children or grandchildren would ask their parents for money to take to school for this.

I have a grandchild and he is having toothache every night but, in the morning, we still give him the money because we want the child to go to school. We want to say something to the teachers not to sell those sweets, but we cannot. So that's it. - W, FG 1, Rural

It's the teachers that are selling there, especially to the Kindy; beans, sweets, lollies, chewing gums, those things. – W, FG 1, Rural

The women in the peri-urban focus group, said that the food in the schools was healthy, but that people were selling sweets around the schools.

I have a grandchild that attends [school] *and by the time they finish school, those (food hawkers) that sell by the school roadside sell a lot of lollies – W, FG 3, Peri-urban*

These three groups each discussed how this was impacting negatively on their children/grandchildren and that a lot of their children/grandchildren now have dental issues.

Environmental factors impacting on the ability to eat a healthy diet spanned aspects of an individual's identity (IS level 2) namely their income influencing how/where they accessed food and where they live influencing what food are available. However, the focus was mainly on external forces (IS level 4) that in general were perceived to have negative impacts on the access and availability to healthy foods, including: development and globalisation, climate change, politics, economy, and trade influences.

5. Perceptions around the importance of food and health

Food was perceived as important for both cultural reasons (bringing people together, particularly for religious events), and for providing the body with strength for work. Perceptions on health and how a healthy person would look varied across groups. However, what was consistent was that the signs of good health were much broader than just physical markers like body weight. Both women and men reflected that a "healthy woman" was someone who had a healthy and happy family, who presented herself well and was happy. Women reflected that a healthy man was a man who didn't drink too much alcohol, who was able to look after himself, and who actively provided for his family. Men reflected that you could tell if a man was healthy through how he presented himself and how he took care of his family.

It will be seen where he lives, his looks, his way of preparing things. How he mixes with people, how he takes care of things in his home, his environment, his family, his children, and grandchildren. – M, FG2, Rural

Healthy foods were identified as fresh foods that were cooked using traditional methods, for example, most participants said that if they were having a healthy meal, it would be fish cooked in lolo (coconut milk), with vegetables like dalo (Fijian taro). Most stated that unhealthy foods included foods that were fried, were packaged, or came from the shops. Although, most of the focus groups discussed that they worried about their children and/or grandchildren as they felt they preferred unhealthy foods.

For me at home, when we eat a lot of oily food, I always tell them "cut down on oily foods". When there is a lot of lolo [coconut milk] *foods, I tell them "boil it". We show the people at home how to prevent sickness that is caused by abusing these foods. - M, FG2, Rural*

Perceptions around the importance of food and health were influenced by education (IS level 2), perceptions of masculinity and femineity (IS level 3) and the cultural environment/societal values (IS level 4).

6. Generational changes in food preferences and attitudes

Across the focus groups, participants said that they preferred locally sourced traditional foods. However, individual preferences were not a strong focus of discussions. Instead, participants focused on the changing food preferences across generations, including that their children and grandchildren would not eat traditional healthy foods when they are prepared.

We take it upon ourselves for the children to have foods from the three food groups when they have their lunch in school and the teachers will make sure that the children bring fruits every day, as they are not allowed to eat sweets in school. The children have changed so quickly to have lollies and bongos. When moca (bhajia) is cooked with egg or sausage, the egg or sausage will be eaten and the moca (bhajia) will be left there. They have changed and not like last year. I see that there is a change in terms of the eating pattern, most of the time, children see what the other families are eating and it is not eaten in our house, so they want to eat that food too. That is a big change that I see in our family regarding the quality of food. – W, FG 1, Rural

This theme of generational changes in food preferences and attitudes included factors of individual identity (IS level 1), gendered norms and roles (IS level 3), values of the society as a collective, development and globalisation and generational influences/changes more broadly (IS level 4).

7. Knowledge around food, dietary requirements and the relationship between food and disease

There was consistently a high level of knowledge around food and what would consist of a healthy diet and healthy food behaviour. Participants reflected on the risk of having a poor diet with diseases like diabetes and heart disease and poor dentition. Participants also knew about the increased nutritional needs for women of reproductive age, and the risk of iron deficiency. Women across focus groups reflected on either themselves or others in their village being widowed, with their husbands dying early from NCDs. They discussed that they had support and information from the Ministry of Health and community nurses, and information on healthy eating from television and radio. Both women and men across the settings discussed how they knew what they needed to do to eat healthily, however, it was not always possible to do the right thing.

For me, when I look at the health of my family, sometimes we eat healthy food which contains everything, we will eat cassava, vegetables and meat. Sometimes, there is nothing at all. – W, FG 1, Rural

Sometimes we eat healthy food and sometimes we eat whatever we can afford – M, FG 6, Rural

Knowledge around food, dietary requirements and the relationship between food and disease was influenced by aspects of an individual’s identity, such as education, physical environment, occupation, and sex (IS level 2). It was also influenced by perceptions of masculinity and femineity (IS level 3) and generational changes/influence (IS level 4).

Discussion

This is the first study to explore the relationship between gender and diet in a Fijian population using a qualitative approach with an intersectional interpretation. Our findings highlight important gender-related inequities and gendered roles and responsibilities around food among iTaukei Fijians. However, broader power dynamics and external factors, such as environmental change, were identified by both women and men as factors impacting their ability to achieve a healthy diet. The identified influences from external factors (viewed by different levels of the intersectionality wheel) will be helpful when considering the implementation of food related policies in Fiji.

There were strongly identified gendered roles and responsibilities around food across focus group discussions. Women and men identified that it is the "role" or "duty" of women to cook for their families. Gendered roles and responsibilities were related to religious beliefs and practices, for example the role of women in preparing food for their extended families on Sundays (to be eaten after attending Church), and practices that dictate men eat first and women eat last as a form of showing respect. Previous studies have discussed at length the role of women in food provision, and how women tend to be the gatekeepers of nutrition for their families [12-14, 21]. Globally, research shows that women spend substantially more time preparing food, cooking, cleaning, and childcaring/rearing than men [22, 23]. In Fiji, and in many other countries around the world, the proportion of women working in the formal (paid) workforce is increasing [24], and literature has shown a shift to convenience foods that are often highly processed, energy dense but nutrient poor [21, 25]. Inequities in terms of gendered roles and responsibilities for food provision are therefore misaligned with other societal changes, and can have an impact on the health of populations [25]. However, this does not mean that women should be "kept" as gate keepers of nutrition. Instead, it highlights the need for nutrition related responsibilities to be shared within households and for environments to be conducive to healthy eating, meaning the most convenient options are the healthiest options. For this to occur, there likely needs to be grass-root approaches, including advocacy within and by community groups and feminist organizations, along with the formation of gender responsive food policy.

A high level of nutrition related knowledge was evident across focus groups and this level of knowledge did not appear to differ by gender. However, while participants knew how to eat healthily, and knew about the relationship between diet and disease, they reflected that it is not always possible to eat healthily, instead, they eat what they can afford. Fiji's dietary guidelines focus on three key groups [26]: body-building foods (for example protein rich foods like meat and dairy products), energy foods (for example carbohydrate rich foods like rice and bread) and health foods (fruits and vegetables). We found that there was a focus on making sure that families had body-building and energy foods (for example carbohydrate rich foods like rice and bread), and that leftover money was then spent on health foods (fruits and vegetables). Previous studies have also shown a relationship between self-reported food insecurity and low diet quality, particularly lower consumption levels of fruits and vegetables [27, 28]. There have been efforts to improve food security and to increase the consumption of fruits and vegetables in Fiji, with support from the Government and Development Partners in providing plant seeds and gardening equipment for people to use in their home gardens [29]. Additionally, Leweniqila and Vunibola have published key recommendations for improving food security in Fiji by utilising Indigenous knowledge and traditional practices [30]. However, we did identify some conflicting ideas about the safety of eating home-grown foods, with men in one of the peri-urban focus groups concerned about the pollution of home-grown foods, including chemicals from the soil, while solutions for this were identified within the group, by using different/natural products on soil.

Generational changes were also evident, and these generational changes had relevance to gender equity. Firstly, both women and men across focus groups reflected that men are no longer planting and harvesting crops for food or fishing as much as their forefathers used to. Three reasons for this were provided: environmental change (climate change) making it harder to plant and grow foods, a lack of motivation to grow/catch food given foods can be purchased from a shop, and because of the negative impacts of alcohol consumption. Kava is a traditional Fijian drink, often used during formal ceremonies and used for celebrations [31]. Kava, consumed on its own and in moderation, is thought to pose a minimal risk to human health [32]. However, women in the discussions reflected that men are now drinking alcohol along with kava and that they are drinking alcohol in excess. The negative health effects of consuming alcohol and kava collectively are highlighted by the Fijian Ministry of Health [33]. Our findings also highlight the negative social impacts, and potential impacts on food security, of this practice, and emphasise the need for the consumption of alcohol and kava (collectively) to be addressed by health policy.

Participants' relationship with their environments, and implications of climate change, were emphasised. Pacific Island countries are very minor contributors to greenhouse emissions, however, are bearing the brunt of the climate crisis with rising sea levels, and an increase in frequency of storms and tropical cyclones [34]. Climate change was provided as another reason for the change in eating practices in comparison to participants' forefathers, with a corresponding increased reliance on processed packaged foods. Previous research has depicted how women and men are, and will be, impacted differently by climate change [35, 36]. Women, globally, are more at risk of being food insecure and of having malnutrition, and this is being exacerbated by climate change [37]**.** Climate change is a political priority for the Fijian Government [38], however, climate change and the burden of poor diets are often viewed as a separate issue, and therefore feature separately on political agenda [39, 40]. There is a need to consider the overlapping relationship between climate change, food (particularly food security) and gender equity, both within Fiji and globally. These three factors and the cross-over between them are also central to the achievement of the Sustainable Development Goals in Fiji [41].

The school environment was also identified as a key area of concern to participants. Both women and men in the rural focus groups reflected that confectionary was being sold in schools and kindergartens, by the teachers. Women in one of the peri-urban focus groups said that confectionary and sugary or salty snacks were being sold around their children's' schools by food hawkers. The parents and grandparents who raised these concerns reported feeling powerless; they felt that they did not have the power to tell the teachers to stop, and that they had to give their children or grandchildren money to buy confectionary otherwise they would refuse to go to school. Similar concerns have been raised in Samoa, where a key barrier to the implementation of their school food policy was the high prevalence of unhealthy food sold around schools [42]. Fiji has policies in this space, for example the Fiji School Health Policy [43] and the Policy on Food and School Canteens [44], however, our findings highlight the need for more strongly implemented, and monitored, policies both in and around schools.

Strengths and limitations

This is the first study to explore perceptions around healthy eating using an intersectional lens in Fiji. There are several limitations to our approach; firstly, we had a small convenience sample from four villages within the central district of Fiji. We visited villages during the working day, and in one of the villages not enough men were available to participate, so a different village was approached where men were able to participate. The sample size of our study also limits the generalisability of our findings. Given the size of the study we were only able to focus on two gender identities within one ethnicity, and it is likely that people with other gender identities and other ethnicities, have different perspectives of their food environment, which should be a focus of future research. There are also a number of important strengths to our study, we selected villages in rural and peri-urban locations to get an idea of different perspectives based on location. We took an intersectional approach for the interpretation of this work, which we believe is useful in this study to frame gender-related factors in a broader equity framework. We have identified several issues that may be considered the upstream causes or influences of gender-related inequities around nutrition and health in Fiji and propose these findings should be considered for policy formation going forward.

Conclusion

Use of an intersectional framework aided the understanding of perceptions around healthy eating of iTaukei women and men in rural and semi-urban Suva, Fiji. Embedded traditional perceptions of gendered roles, responsibilities and beliefs around food and food provision were identified, along with important generational changes in food preferences and practices, and in experiencing the impacts of climate change. These findings highlight that food policy in Fiji needs to consider a range of different factors, both proximal and distal to individuals in-order to improve diets equitably.

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Authorship: BLM, GW and JW conceptualised the study. BLM and GW conducted the focus group discussions. BLM and ACH analysed the data in consultation with GW and JW. All authors provided critical insights to the interpretation of the results. BLM drafted the first draft of the manuscript. All authors provided critical insights on the manuscript and approved the final version of the manuscript.

Ethical Standards Disclosure: This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the University of New South Wales Human Research Ethics Committee (#180959), and Fiji National University (#111.19). All focus group participants provided written informed consent and agreed for the discussion to be audio recorded. Data were collected between the 3rd and the 8th of December 2019.

7.4 Supplementary material

Supplementary table 1. Discussion topics used in the focus groups (and translation to Fijian)

Area of enquiry	Question/topic to discuss
Attitudes	How important is the food you eat to you? *NA CAVA MADA NA YAGA NI KAKANA KO DAU KANIA ENA VEISIGA?*
	What do you think about the quality of the food that you usually eat? *NA CAVA NOMU NANUMA BALETA NA I VAKATAGEDEGEDE NI KAKANA KO KANIA ENA VEISIGA?*
	Do you think your overall diet is different to what your grandparents ate when they were your age? *NA CAVA NA KENA DUIDUI NI KAKANA KO DAU KANIA KEI NA KENA ERA DAU KANIA NA TUKADA SE O IRA NA NODA BUBU/NAU ENA GAUNA E LIU?*
Behaviours	What foods do you like eating? *NA KAKANA CAVA SARA MADA KO DAU TALEITAKA MO KANIA?*
	In your households, who normally sources/purchases the food? *ENA NOMUDOU VUVALE, O CEI E DAU KAUTA MAI SE VOLIA NA KEMUDOU KAKANA?*
	In your household, who normally prepares the meals? *ENA NOMUDOU VUVALE, O CEI E DAU VAKARAUTAKA SE VAKASAQA NA KEMUDOU KAKANA?*
	If you were to make a meal for your family, what would you make? *KEVAKA MO VAKARAUTAKA SE VAKASAQARA NA KEMUDOU KAKANA, NA KAKANA CAVA KO NA VAKARAUTAKA?*
	If you were to cook that meal but had the goal of making it "healthier" how would you do this? *KEVAKA MO VAKASAQA SE VAKARAUTAKA NA KAKANA KO NANUMA TIKO MO VAKARAUTAKA, IA ME BULABULA CAKE MAI NA KENA VAKARAUTAKI ENA VEISIGA, O NA VEISAUTAKA BEKA VAKACAVA?*
	What do you think about the food that members of your household eat? *NA CAVA NOMU NANUMA ENA KAKANA KO DOU KANIA VAKAVUVALE ENA VEISIGA?*
Environment	What do you think about the food in your community?

	NA CAVA NOMU NANUMA ME BALETA NA KAKANA ENA NOMUDOU I TIKOTIKO SE KORO?
	What are your thoughts on the types of foods being sold around schools? *NA CAVA NOMU NANUMA ENA MATAQALI KAKANA KA RA DAU VOLITAKI E KORONIVULI SE NA KENA ERA DAU VOLITAKI VOLEKATA NA KORONIVULI?*
	Can you get the foods that you wish to get when you want them? *E RAWA BEKA NI KO NA KANIA SE KAUTA MAI NA KAKANA KO DAU GADREVA SE TATADRATAKA ENA GAUNA KO VINAKATA KINA?*
	How available is fresh food in your community? *E TU VAKA RAWARAWA BEKA NA KAKANA KA SEGA NI VOLI MAI NA SITOA (FRESH) ME VAKA NA VUATA, DRAUNIKAU, LEWE NI MANUMANU SE SASALU NI WAITUI?*
Knowledge	What do you see as the main health risks to yourself and your family? *NA CAVA KO NANUMA NI RAWA NI TOKONA SE VAKAVU TAUVIMATE VEI IKO KEI RATOU NA LEWE NI NOMU VUVALE?*
	As a (woman or man, depending on the group) do you have any additional or different health concerns? *E TIKO TALE BEKA E DUA NA KA KO NANUMA NI RAWA NI TOKONA NA TAUVIMATE ENA NOMUDOU VUVALE ENA NOMU RAI VAKA MARAMA (SE TURAGA)?*
	How would you describe a "healthy" body shape for a man? V*AKAMACALATAKA MADA NAI RAIRAI SE TUVAKI NI DUA NA TURAGA BULABULA VINAKA?*
	How would you describe a "healthy" body shape for a woman? *VAKAMACALATAKA MADA NAI RAIRAI SE TUVAKI NI DUA NA MARAMA BULABULA VINAKA?*
	What role do you think diet (what you eat) has in your health? *NA CAVA NA I TAVI NI KAKANA (KO DOU KANIA ENA VEISIGA) KINA NOMU BULA?*
	What specific health issues can be addressed through the food that you eat? *NA MATAQALI MATE CAVA SARA MADA KO NANUMA NI RAWA NI WALI ENA KAKANA EDA KANIA?*

	Where do you find information on the food that you eat? *E VEI KO RAWA NI VULICA SE KILA KINA NA I TUKUTUKU NI KAKANA KO KANIA?*
	As a (women or man, depending on the group), do you have any additional or different diet/nutrition requirements? *E DUIDUI BEKA NA KAKANA SE NA NUTRIENTS E GADREVA E DUA NA TURAGA (SE MARAMA)?*

Supplementary table 2. Themes identified from the focus group discussions, and mapping to intersectional factors

Overarching themes	**Sub themes identified in the analysis**	**Mapping to intersectional factors [18, 20]**	**Intersectionality wheel, level [18, 20]**
1. Behaviours around food and reflections on generational changes in food behaviours	Food behaviours	Individual behaviour	1 – personal circumstance/identity
		Societal pressure (influencing food behaviour)	4 – larger forces/structures 2 – aspects of identity
	Actions to improve diets	Individual actions, actions to improve diets of those around them	1- personal circumstance/identity
	Generational changes in behaviours	Societal pressure/preferences (changing over time)	4 – larger forces/structures
		Generational influences (in both directions)	4 – larger forces/structures
		Pressure from children/grandchildren	2 – aspects of identity
		Development/globalisation	4 – larger forces/structures
2. Beliefs around food, and gendered beliefs	Food beliefs	Perceptions of masculinity and femineity	3 – discrimination or attitudes that affect identity
		Gendered norms and roles	3 – discrimination or attitudes that affect identity
		Responsibilities around food	2 – aspects of identity
		Religion	2 - aspects of identity
	Gendered beliefs	Stigma	3 – discrimination or attitudes that affect identity
		Perceptions of masculinity and femineity	3 – discrimination or attitudes that affect identity
		Gendered norms and roles	3 – discrimination or attitudes that affect identity
		Responsibilities around food	2 – aspects of identity
		Religion	2 – aspects of identity
3. Cultural and religious obligations and influences around food	Food preparation	Perceptions of masculinity and femineity	3 – discrimination or attitudes that affect identity
		Gender norms and roles	3 – discrimination or attitudes that affect identity
		Responsibilities around food	2 – aspects of identity
	Food purchasing	Gendered norms and roles	3 – discrimination or attitudes that affect identity
		Responsibilities around food	2 – aspects of identity
		Money	2 – aspects of identity

Overarching themes	Sub themes identified in the analysis	Mapping to intersectional factors [18, 20]	Intersectionality wheel, level [18, 20]
	Religious practices involving food	Religion	2 – aspects of identity
		Expectations based on gendered norms	3 discrimination or attitudes that affect identity
		Perceptions of masculinity and femineity	3 discrimination or attitudes that affect identity
4. Environmental factors impacting on the ability to achieve a healthy diet	Availability	Development/globalisation	4 – larger forces/structures
		Geographical location, i.e. immediate surrounds	2 - aspects of identity
		Climate change	4 – larger forces/structures
		Money	2 - aspects of identity
	Access	Development/globalisation	4 - larger forces/structures
		Geographical location, i.e. immediate surrounds	2 - aspects of identity
		Money	2 - aspects of identity
	Environmental context	Geographical location	2 - aspects of identity
		Climate change	4 - larger forces/structures
	Importance of being able to grow own food	Geographical location, i.e. immediate surrounds	2 - aspects of identity
		Climate change	4 - larger forces/structures
	Impacts of development	Development/globalisation	4 - larger forces/structures
		Money	2 - aspects of identity
		Politics	4 - larger forces/structures
		Economy	4 - larger forces/structures
		Trade	4 - larger forces/structures
5. Perceptions around the importance of food and health	Importance of food	Cultural environment	4 - larger forces/structures
	Perceptions of health	Societal values	4 - larger forces/structures
		Perceptions of masculinity and femineity	3 - discrimination or attitudes that affect identity
	Perceptions of healthy food	Cultural environment	4 - larger forces/structures
		Education	2 - aspects of identity

Overarching themes	**Sub themes identified in the analysis**	**Mapping to intersectional factors [18, 20]**	**Intersectionality wheel, level [18, 20]**
6. Food preferences and attitudes, and generational changes in preferences	Food preferences and attitudes	Gender norms and roles	3 - discrimination or attitudes that affect identity
		Societal pressure/preferences (changing over time)	4 - larger forces/structures
	Generational changes in preferences	Generational influences (in both directions)	4 - larger forces/structures
		Development/globalisation	4 - larger forces/structures
		Societal pressure/preferences (changing over time)	4 - larger forces/structures
7. Knowledge around food, dietary requirements and the relationship between food and disease	Knowledge of food and disease	Education	2 - aspects of identity
		Environment	2 - aspects of identity
		Generational influences (in both directions)	4 - larger forces/structures
	Sources of health information	Education	2 - aspects of identity
		Environment	2 - aspects of identity
	Dietary requirements	Sex differences	2 - aspects of identity
		Occupation	2 - aspects of identity
		Perceptions of masculinity and femineity	3 - discrimination or attitudes that affect identity

7.5 References

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Chapter 8. Discussion and conclusions

8.1 Chapter overview

This chapter summarises how the thesis aims of exploring sex and gender differences in the relationship between dietary intake, behaviour, and cardiometabolic outcomes, and the policy implications of this relationship, were addressed. Five distinct studies were conducted to explore these aims, each utilising different methodologies and different study populations. While each study (chapter 3 through to chapter 7) can act as a standalone piece, this chapter summarises how the findings interlink, and draws on relevant global literature, to provide a narrative on the relationship between sex and gender, dietary intake and behaviours and disease outcomes, along with a discussion about what this means for food policy. This chapter also summarises the strengths and limitations of the thesis and proposes future directions based on findings.

8.2 Synthesis of thesis findings

To address the first thesis aim (to identify if there are differences between women and men in diet and associated cardiometabolic disease), it was important to establish whether there are sex differences in the accuracy of diet assessment methods. Two previous systematic reviews, that assessed studies qualitatively, stated that women were more likely to under-estimate their energy intake in comparison to men [1, 2]. However, in chapter 3 (a systematic review and meta-analysis), sex differences in the accuracy of energy intake estimation were not evident, with the degree of underestimation by sex being the same [3]. This finding was important for interpreting results from the other quantitative studies in the thesis, as it suggests that it is less likely that the subsequent results are due to a sex bias in reporting. The following quantitative studies (chapter 4 and 5) identified some sex differences in dietary behaviours, dietary intake, and the association with cardiometabolic risk factors and outcomes [4, 5]. In chapter 4, across nationally representative surveys conducted in seven LMICs (24,332 people), it was found that women reported more positive salt use behaviours (that is, actions and behaviours to reduce their salt intake) than men. Additionally, women who reported positive salt use behaviour were less likely to have undiagnosed hypertension, a relationship not seen for men [4]. Sex differences were also found in a UK cohort (120,963 people). In this study men with diets characterised by lower carbohydrate, lower fat, and higher protein intakes (compared to the rest of the study population) had an associated lower risk of CVD [5], a relationship not seen for women. Both studies suggest that there are some differences in dietary behaviours and intake between women and men, and that these differences are associated with cardiometabolic risk factors and outcomes. However, the magnitude of the differences was small. Chapters 4 and 5 identified that poor dietary behaviours [4] and dietary intake [5] were prevalent across study populations (and across sexes). The limited variation in dietary behaviour and dietary intake between sexes, corresponded with the modest interactions of sex on the association between diet and disease outcomes. While the sex differences identified were small, it is possible that the differences would become more pronounced if diets change. This highlights the need to continue to consider the interaction of sex with the diet and cardiometabolic disease relationship through further research.

Whilst the systematic review and quantitative studies addressed the first aim; to address the second aim (to assess whether policies to improve diets are inclusive of gender considerations), an in-depth qualitative approach was required. Fiji was selected, because of the pronounced burden of diet-related disease, along with substantial differences in disease burden by sex within the country. A further motivation to undertake this part of the study in Fiji was the established connections with researchers at Fiji National University, via a National Health and Medical Research Council grant focused on scaling up food policy interventions in the region [6]. This meant that findings from the research (chapter 6 and 7) could be incorporated into future interventions. Both the policy analysis (particularly the interviews with stakeholders) and the community focus groups demonstrated strong gendered beliefs of roles and responsibilities around food, and these gendered beliefs and gendered roles and responsibilities, were misaligned with other societal and health beliefs. However, community members did not identify a need for this to change. Gender was also viewed as a relatively minor factor influencing the nutritional health of themselves and their families. Instead, community members discussed the impacts of development (including infrastructure developments, changes in working practices and the access to imported processed packaged foods), socioeconomic status (particularly income level) and climate change on their ability to eat a healthy diet. In terms of nutrition and health- related policies, only one policy was identified as being gender responsive. However, most policy stakeholders in Fiji did not identify a need to have stronger gender considerations in nutrition and health related policies, despite an acknowledgement of gender differences in roles and responsibilities and sex differences in the burden of cardiometabolic diseases. Both studies described in chapter 6 and 7 provide context-specific findings to aid understanding of the role of gender in relation to food and nutrition and the potential for policy strengthening. While this work was conducted in Fiji, and provides context specific findings for Fiji, other countries around the world, including other Pacific Island Nations, have experienced, or are experiencing, similar shifts in socio-cultural practices. It is possible that some of the identified upstream factors, that influence people's ability to eat a healthy diet in conjunction with gendered roles and responsibilities, would be relevant across other settings. Therefore, the exploration in Fiji acts as an example of an in-depth qualitative analysis that could be conducted in other countries or regions to identify opportunities for the strengthening of gender inclusion in nutrition and health- related policy, along with important contextual factors impacting people's ability to have a healthy diet.

The following sections of this discussion set out what these findings mean for nutrition research and food policy development. Further, these findings contribute to a broader narrative on including equity considerations, inclusive of sex and gender, when assessing and developing policies to address the burden of diet-related cardiometabolic disease.

8.3 The importance of sex and gender considerations in nutrition research and policy formulation

Findings from this thesis show that significant investment is needed to improve diets across populations, irrespective of sex and gender. However, the findings also highlight the need to continue to monitor sex differences in the diet disease relationship to assess if differential impacts by sex are evidenced when diets change or improve within populations. Further, gender needs to be a factor in nutrition research and nutrition related policy development, to ensure that sex and gender disaggregated data is collected within studies, and that policies are gender responsive and contribute towards gender equity in health outcomes.

8.3.1 Sex differences in nutrition research

There is a growing recognition of the need to include sex and gender considerations in health research. Most of these calls for action draw on evidence of sex differences in the prevalence, treatment, and control of CVD [7, 8]. Given diet is an important modifiable risk factor for CVD, the hypothesis for this thesis (chapter 4 and 5, in particular) was that there may be sex differences in dietary intake, which may be associated with sex differences in the burden of cardiometabolic disease. The findings show that this hypothesis cannot be rejected. However, the sex differences identified were small and the direction of identified interactions was not consistent (for example, there was not consistently more or less risk of the investigated outcomes for women compared to men), particularly in the analysis of the UK cohort data [5].

The datasets used to produce these findings were large, with 24,332 people across seven LMICs [4], and 120,963 people in the UK cohort [5], analysed. As such, there was a sufficient sample to investigate the research questions. It is not clear why such small sex differences were identified. While there is still the possibility that these results were chance findings, another hypothesis is that the small differences were due to poor diets across both sexes. For example, across seven LMICs only 13% of women and 15% of men met fruit and vegetable intake recommendations [4]. In the UK cohort, 73% of women and 50% of men exceeded dietary recommendations for sugar, and 98% of women and 97% of men did not meet dietary fibre recommendations [5]. These findings tie into public health nutrition epidemiology showing the high prevalence of poor diets globally [9], and to the number of studies that highlight overweight and obesity (and therefore unhealthy food environments) as an increasingly important contributor to cardiometabolic disease prevalence globally [9-12].

As established in the introduction (chapter 1) it is likely that poor diets, contributing to metabolic risk factors, are a key contributor to the slowing in the decline of CVD mortality in HICs [13, 14], increasing incidence of CVD mortality in LMICs, and increasing prevalence of diabetes globally [15]. As such, significant investment is needed to improve population diets in LMICs as well as HICs. Whilst the sex differences found were small, the size of the differences may change as diets change, and there is a need to continue to monitor if there are differential impacts of changing diets on health outcomes, by sex.

8.3.2 Gender considerations in food policy formulation

Food is a basic requirement for survival, with access to sufficient safe and nutritious food being a human right [16]. Food is also central to many cultural and social practices, and for many people is a source of enjoyment. Gender as a construct varies by culture, society, time, and place [17]. Gender roles and responsibilities around food can therefore reflect cultural and societal norms. Previous research has hypothesised that such gender roles perpetuate inequality [18-20]. Further, “gender equality” and “healthy lives and well-being for all” are two of the Sustainable Development Goals and are intrinsically linked [16, 21]. Progress towards both goals has been slow, with the COVID-19 pandemic likely to further slow progress [22, 23].

In the quantitative studies (chapters 3 to 5), sex differences were discussed, as the data variable was sex (categorised as female/woman or male/man in datasets used). While there are some biological (sex) reasons for differences in dietary intake, there is also an overlap with gender [17]. As established in the introduction (chapter 1), it was hypothesised that differences identified in dietary intake or behaviours between women and men would be more related to gender (social/cultural) reasons than sex (biological) reasons. While it was not possible to explore gender related reasons for the findings of the quantitative studies in chapters 3 to 5, because of the limitations in the data available, they were explored in the qualitative chapters (6 and 7).

In Fiji there were evident differences in gender roles and responsibilities around food. There were also marked gender differences in the burden of diet-related cardiometabolic diseases (as set out in chapters 6 and 7). While society is changing in Fiji (for example, more women are now working in the formal [paid] workforce) both community members and policy stakeholders did not identify an issue with food preparation and the nutritional wellbeing of the family being "women's work". It has long been hypothesised that a transition of women into the formal (paid) workforce would correspond to an increased reliance on "convenience foods" [24], which in many cases are ultra-processed foods that are energy dense, yet nutrient poor [25]. In turn, the increasing availability of ultra-processed foods has occurred in parallel to increasing rates of obesity [11, 12]. This relationship demonstrates that gendered roles and responsibilities can be resistant to change, and that unequal expectations are placed on people due to their gender identity.

From both the discussion with policy stakeholders and the community focus groups in Fiji, there was a consensus that the "status quo" in terms of gender related roles and responsibilities and how gender is included within nutrition and health policies was sufficient. Rather than singling out gender, participants discussed the need to change either external factors (such as accessibility and affordability of healthy foods) or focus on other "vulnerable" groups (such as children or older people). Using an intersectionality framework to interpret the findings of the focus group study (chapter 7), demonstrated that gendered beliefs, roles, and responsibilities were related to heteronormative relationships and perceptions of femininity and masculinity, along with Christian ideals of women being caring and nurturing and men being strong and being the head of the family [26]. It is possible that such factors/ideals contribute to a broader resistance to changing gender roles, even when there is political commitment to the achievement of gender equality [20, 27], as is the case in Fiji with the National Gender Policy [28].

There has been progress in the space of monitoring and evaluating how gender is included within food systems. The Global Food 50/50 initiative was launched in 2021[18]. This initiative highlights how gender is reflected, or not, in the policies and practices of leading global food organisations. It aims to provide an accountability system for organizations to ensure gender-responsive programming, gender-equitable institutions and diversity of leadership within organizations. The authors state that "gender inequalities are both a cause and an outcome of inequitable food systems that contribute to unjust food access, production, and consumption" [18]. Across 52 global food system organizations they identified a high commitment to gender equality, however actual action towards gender equality was limited. The policy landscape analysis conducted in Fiji (chapter 6) reflects findings from this global report. Most nutrition and health-related policies in Fiji stated a commitment to gender equality in nutrition and health related matters, but no actionable/measurable steps nor budget were provided to achieve gender equality goals (chapter 6). This study, in particular, highlights the need to include gender considerations in nutrition and health-related policies, in an actionable format, to ensure that there is an accountability system for gender equity.

While this thesis has not identified a strong need to tailor or target dietary interventions by sex or gender to reduce the diet-related burden of cardiometabolic diseases, findings do highlight the importance of having gender responsive policies, with actionable steps towards gender equality in disease risk reduction. Policies need to be gender responsive to overcome resistant social norms and gendered stereotypes around food provision and preparation. However, at the same time it is important to address gender as part of a range of equity issues, as discussed in the following section.

8.4 Implications for equitable food policy formulation

8.4.1 Developments in food policy

In the last decade, much of the focus for food policy has been on issues such as population salt reduction, reducing sugar sweetened beverage intake, and implementing front-of-pack nutrition labelling to aid consumers to make healthier food choices. However, many democratic governments of HICs are adopting voluntary regulations rather than mandatory regulations, even though such methods show limited success [29]. In many ways, LMICs are showing greater leadership in terms of food policy development and implementation. For example, Chile, Mexico, Sri Lanka, Ecuador and Iran have all mandated the use of front-of-pack nutrition labelling [30]. Further, 16 out of 21 Pacific Island Countries and Territories have taxes on sugar-sweetened beverages [31]. Whilst these regulations will contribute to healthier food environments; they still focus on either consumer choice (e.g., front-of-pack labelling), or on specific nutrients (e.g., sugar). The focus on choice both at an individual level (e.g., individuals need to pick the healthier options) and at an industry level (e.g., with voluntary regulations, it is a decision for industry to comply or not) is reflective of findings from a review of national nutrition and obesity policies in HICs [32]. It was found that nutrition was often framed as an individual lifestyle problem or behavioural choice, with little acknowledgement of, or stated actions to, address the upstream determinants of poor diets such as low-socioeconomic status and poverty [32]. From an individual and community perspective in Fiji, it was identified that it is these upstream determinants of poor diets that desperately need to be addressed. People knew what to eat for their health, it just was not always possible to do so, due to: lack of money; easy accessibility of nutrient poor, yet energy dense processed packaged food compared to nutritious foods; and climate change impacting on the ability to grow their own fruits and vegetable. As such in the formulation of policies that focus on nutrition and NCDs, there needs to be ingrained actions and accountability systems for progress towards addressing the upstream determinants of health, encompassing social (inclusive of gender), physical, economic, and environmental determinants of health [33].

8.4.2 The need for broader equity considerations in food policy

Sex and gender are important determinants of health; however, there are other biological characteristics and socially constructed identities, like race, ethnicity, age, class, and socioeconomic status, that also interact with sex and gender, and with the relationship between diet and cardiometabolic disease. For example, there are marked differences in the burden of poor-quality diets between different socioeconomic groupings [34], and people who have a lower socioeconomic status have a higher risk of cardiometabolic disease [35]. Investigating the relationship between sex and gender with diet and cardiometabolic disease likely requires more nuance, with consideration of other equity factors, to understand how best to improve diets.

There are a range of frameworks that consider multiple equity factors and power dynamics when assessing health related issues. For example, the social determinants of health framework [33] and the sustainable development goals framework [36]. There is also the intersectionality framework, described and applied in chapter 7. Intersectionality was initially coined by Kimberlé Williams Crenshaw in 1990 [37], reflecting on the fact that people are often disadvantaged by multiple forms of oppression (based on factors like gender, ethnicity, age and race). All these frameworks acknowledge that multiple forms of disadvantage need to be assessed, and then addressed, to achieve health for all.

While this thesis was approached using a sex and gender lens, an intersectional framework was applied in chapter 7, to aid interpretation of the findings. This aided the identification of factors that will be important to address when aiming to improve diets for women and men in Fiji. For example, members of the focus group identified aspects of their identity (such as their religion and their income), aspects of discrimination (such as gendered norms and roles and perceptions of masculinity and femininity) and larger forces or structures (such as societal preferences, climate change and globalization) that interacted and influenced their ability to eat a healthy diet [38]. An intersectional framework was applied in this study as findings from the other studies in this thesis identified relatively minimal sex differences (chapters 3, 4 and 5), and because of the relatively low priority that gender considerations were given by policy makers in Fiji (chapter

6). Chapter 7 highlights the importance of applying an intersectional lens to perceptions on diets. It is likely that application of this framework in more contexts would aid further understanding of how the upstream determinants of poor diets interact, and therefore a greater understanding of how to address inequities in the ability to eat a healthy diet and in health outcomes.

8.5 Strengths and limitations of the thesis

A key strength of this work is that a mixed method approach was used to investigate the research questions from several perspectives and through a range of settings. The use of both quantitative and qualitative methods provides insight into the scope of the burden as well as potential policy and contextual factors related to the relationship between sex and gender, diet and cardiometabolic disease. As highlighted throughout the thesis, there is limited research in this space and so this thesis contributes towards addressing an important evidence gap.

A key strength of chapters 4 and 5 is the large sample sizes included within the studies. Chapter 4 used data from nationally representative surveys from seven LMICs and provided country specific analyses and analyses across countries. Chapter 5 used data from the UK Biobank, one of the largest modern cohort studies with comprehensive nutrition data and data linkage to medical events (hospital admissions) and death registry data [39].

Chapters 6 and 7 were conducted in Fiji, with clear policy implications for Fiji. Findings from these sections, and interpretation for policy could have been strengthened if the studies had been conducted in an order whereby the findings from the community group discussions were used to inform discussions with policy makers. However, given the Fiji studies are part of a broader government-funded program of work, there will be future opportunities to use findings from chapter 7 in discussions with policy makers and other relevant stakeholders. Additionally,, the approaches used in Fiji could be replicated in other countries, including in high income countries, to understand how gender considerations are included in nutrition and health-related policy, and to understand the importance that key stakeholders place on including gender considerations within these policies.

Findings from chapter 5 (based on data from the UK Biobank) adds further evidence to other studies published using UK Biobank data [40-44]. With each study conceptualizing diet in different ways, and focusing on different disease outcomes, there is now substantial evidence to inform food policy and dietary guideline strengthening or development for disease prevention in the UK. However, a key weakness of the UK Biobank data is the lack of robust salt intake data. Salt intake is estimated from spot-urine samples in the UK Biobank. There are well established methodological issues and limitations with using salt intake estimations from spot-urine to look at the relationship between intake and disease [45, 46]. Chapter 5 is also an outlier to the main focus of this thesis on LMICs; however, it was considered important to look at sex differences in the relationship between diet and cardiometabolic health outcomes in a prospective cohort, and there is no comparable study based on a LMIC.

There are also limitations to the way in which sex and gender have been defined within this thesis. As set-out in chapter 1 and 2, sex and gender were defined based on the data available. For chapter 3, it was intended that gender bias in the self-report of energy intake would be investigated, as defined in the published study protocol (appendix 1) [47]. However, on conducting the systematic review, most studies included used sex and gender interchangeably, albeit most presented results for females and males. Given this, the manuscript (chapter 3) focused on sex differences [3]. Sex differences were also a focus for chapters 4 and 5, although as discussed above, reasons for identified differences could be due to gender. Further, sex differences were conceptualised as female/woman verses male/men differences, as data were not available on intersex variations. Gender was the focus of the research undertaken in Fiji, given data were collected during the development of this thesis. However, gender was referred to in binary (women or men) terms, by both policy documents and by community members and key informants (chapters 6 and 7). Additionally, for the key informants' interviews, most informants conflated gender with the needs of women and specifically women of reproductive age. Further, in chapter 7 participants self-reported their gender identity, and therefore the focus group that they participated in. Respondents self-identified as either a woman or a man, and therefore findings were limited to binary groupings. Future studies of larger sample sizes may capture perspectives from people with a broader range of gender identities. In future it will be important to collect these perspectives as they may differ from those reported within chapter 7. A clear limitation of this thesis is, therefore, the limited investigation of sex and gender in non-binary terms, and the thesis does highlight limitations with how information on sex and gender is collected and reported in studies. There has been progress in this space; the Australian government has released standards for the collection and dissemination of sex, gender, variations of sex characteristics and sexual orientation variables [48]. For LMICs, there is scope for the development of contextually appropriate guidelines for the collection and reporting of sex and gender data. Development of these guidelines should be based on development with community members within specific countries and regions, given gender identities and terms used can differ by culture, time, and place. There are also guidelines for academic articles on the inclusion of sex and gender factors, with some journals making compliance to these guidelines' compulsory [49]. Such measures will aid the collection and reporting of more inclusive, and therefore representative, data.

8.6 Proposed future directions

Poor diets have been one of the leading causes of preventable premature mortality for the past two decades and continue to be. Given this consistency, there is a need to reassess current efforts to improve diets and reduce the related burden of disease. This thesis explored whether a stronger focus needs to be placed on sex and gender considerations to improve diets. It showed that sex and gender considerations should continue to be focused on going forward. However, this thesis also found that diets need to be improved across populations studied (inclusive of sex and gender). It is important to monitor and assess impacts of changing diet by sex and gender, and to assess and address gendered roles and responsibilities around food. However, these factors are not the only factors impacting on people's ability to eat a healthy diet, nor the relationship between diet and cardiometabolic disease. Findings from this thesis indicate the need to take a broader equity approach rather than just focussing on sex and gender alone. For example, by applying an intersectionality lens that considers the upstream determinants of health, and how these determinants interact, it is possible to understand the factors having the largest impacts on the diet-related burden of cardiometabolic disease. More research, and the development of equity orientated policy and interventions is therefore needed to reduce the burden of diet-related diseases, particularly in LMICs.

A range of diet assessment methods have been discussed, and have been used, in this thesis. Both the usefulness of routine diet assessment, and the limitations of these methods have been highlighted. In particular there is a need for more comprehensive dietary intake data from LMICs. The dietary factors focused on from LMICs were limited to diet behaviours (chapter 4, [4]) and perceptions on the ability to eat a healthy diet (chapter 7). While there are other routinely collected diet related measures from LMICs, these mainly focus on children and mothers (for example Demographic and Health Surveys collects indicators of nutritional status [50]), or focus at the household level (for example Household Income and Expenditure surveys that collect information on food purchased for a household [51]). There is a need to develop quantitative, easy and quick to administer diet assessment tools in LMICs. An area that shows promise is the development of a diet quality scores for LMICs [52], that assess nutrient adequacy, food variety, and moderation of foods or food groups. These scores or indices are quicker and require less resource than more traditional diet recall measures (for example, the 24-hour diet recalls used in the UK Biobank study). There is scope to use these scores or indices, and to link with other health data, for example the WHO STEPs data [4], to get a more comprehensive intake of nutritional risk. There are also growing global databases, that focus on food systems across LMICs, which could aid the monitoring and evaluation of the food environments more broadly [53]. Further, it will be important for collection of data in LMICs to also collect information on participant gender, in addition to participant sex, to further understand the role of gender in dietary intake and disease.

While the focus of this work was in LMICs, there is scope to carry out further similar research in Australia. The Australian dietary guidelines are currently in the process of being updated, and investigation into sex and gender, in addition to other equity factors like ethnicity, location of residence, socioeconomic factors and age, would aid translation and support for compliance to the updated guidelines. There is also a planned National Nutrition Survey for 2023, which intends to follow the Australian Bureau of Statistics standards for sex, gender, variations of sex characteristics and sexual orientation variables [48], aiding the ability to conduct analysis with a more inclusive range of variables and therefore more representative of the Australian population.

8.7 Conclusions of thesis

Collectively, some modest sex differences were identified in dietary intake, behaviour, and the relationship with cardiometabolic risk factors and outcomes. However, the sizes of these differences were small. Poor diets were prevalent across study populations, for both women and men. Poor diets contribute to overweight and obesity, with increasing prevalence of overweight and obesity evidenced as a reason for the slowing declines in CVD mortality in HICs, the increasing burden of CVD in LMICs and the increasing burden of diabetes in HICs and LMICs. There is a need to reassess current efforts to improve diets and reduce the related burden of disease. Findings highlight the need to monitor sex differences in the diet-disease relationship to assess if differential impacts by sex are evidenced when diets change or improve within populations.

Through the focus on Fiji, evident gendered roles and responsibilities around food and perceptions of health were identified. While there was an acknowledgement of gender differences in the diet-related burden of cardiometabolic disease by stakeholders and community members, most did not express the need to focus on gender or gendered roles and responsibilities when aiming to improve diets. However, gender unequal food systems are known to be intrinsically linked to gender inequality more broadly. As such, gender needs to be a factor in nutrition research and nutrition related policy development, to ensure that inclusive data is collected within studies, and that policies are gender responsive and contribute towards gender equity in health outcomes.

This thesis has contributed to the understanding of the relationship between sex, gender, diet and cardiometabolic disease. However, this is a very broad area, and this thesis has been limited to looking at both sex and gender in binary forms. Sex and gender, inclusive of a broader variable range for sex and gender terms, should continue to be considered in nutrition research. Further, there is a need to consider sex and gender factors and the relationship with cardiometabolic diseases through broader equity frameworks. For example, by applying an intersectionality lens that considers the upstream determinants of health, and how these determinants interact, it will be possible to understand the equity factors having the largest impacts on the diet-related burden of cardiometabolic disease. Findings from this thesis contribute to a narrative on including equity considerations, inclusive of sex and gender considerations, when assessing, developing, and implementing policies to address the burden of diet-related cardiometabolic disease globally. Development and implementation of equity focused nutrition and health policies will be essential to achieving the Sustainable Development Goals by 2030.

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Appendix 1. Gender differences in the accuracy of dietary assessment methods to measure energy intake in adults: protocol for a systematic review and meta-analysis.

Publication details

McKenzie BL, Coyle DH, Burrow T, Rosewarne E, Peters SAE, Carcel C, Collins CE, Norton R, Woodward M, Jaacks LM, Webster J. Gender differences in the accuracy of dietary assessment methods to measure energy intake in adults: protocol for a systematic review and meta-analysis. *BMJ Open*. 2020 Jun 1;10(6):e035611.

Author contributions

As the first author of this publication, I contributed significantly to this piece of work. I was responsible for conceptualising the study and designed the initial protocol with co-authors (DHC and JW). I drafted the search terms and engagement with Librarians at the University of New South Wales for their review of the search terms. I was responsible for writing the first draft of the manuscript, and for co-ordinating and incorporating feedback from co-authors and from journal reviewers. All authors have approved for this manuscript to be included in my thesis.

The roles and responsibilities of all authors on this manuscript are as follows (and as published): BLM, DHC and JW conceptualised and designed the protocol. BLM drafted the initial manuscript. Search terms were drafted in consultation with a Librarian at the University of New South Wales. Data extraction processes and statistical analysis were drafted by BLM, then reviewed and discussed with all authors. All authors provided critical insights: TB, CEC and ER provided expert content knowledge on energy intake and energy expenditure methods; CC, SAEP and MW provided insight into the proposed approach to quantitative synthesis of the data; and RN, LMJ and JW provided general oversight. All authors contributed to the manuscript and approved the final written manuscript.

Manuscript

Abstract

Introduction: Diet is an important modifiable risk factor for many chronic diseases. Measurement of dietary intake usually relies on self-report, subject to multiple biases. There is a need to understand gender differences in the self-report of dietary intake and the implications of any differences for targeting nutrition interventions. Literature in this area is limited and it is currently unknown whether self-report dietary assessment methods are equally accurate for women and men. The aim of this systematic review is to determine whether there are differences by gender in reporting energy intake compared with a reference measure of total energy expenditure.

Methods and analysis: A comprehensive search of published original research studies will be performed in MEDLINE, Scopus, Web of Science, EMBASE, CINAHL and Cochrane library. Original research studies will be included if they were conducted in free-living/un-hospitalized adults and included a measure for both women and men of (a) self-reported energy intake and (b) total energy expenditure by doubly labelled water. One author will conduct the electronic database searches, two authors will independently screen studies, conduct a quality appraisal of the included studies using standardised tools and extract data. If further information is needed, study authors will be contacted. If appropriate, a random-effects meta-analysis will be conducted, with inverse probability weighting, to quantify differences in the mean difference in agreement between reported energy intake and measured energy expenditure between women and men, by self-report assessment method. Subgroup analyses will be conducted by participant factors, geographical factors, and study quality.

Ethics and dissemination: All data used will be from published primary research studies, or de-identified results provided at the discretion of any study authors that we contact. We will submit our findings to a peer-reviewed scientific journal and will disseminate results through presentations at international scientific conferences.

Protocol registration: PROSPERO CRD42019131715

Article Summary

Strengths and limitations of this study

- To the best of our knowledge this systematic review will be the first to investigate gender differences in the accuracy of self-reported energy intake in comparison to a reference measure of energy expenditure, doubly labelled water.
- If appropriate we will meta-analyse the difference in mean differences in the accuracy of self-reported energy intake, in comparison to energy expenditure as measured by doubly labelled water, by gender in order to quantify differences between women and men.
- Comparable studies, with data disaggregated into woman/man categories may be limited.
- We are only including studies published in the English language which may lead to language bias.

Introduction

The burden of nutrition-related disease and disease risk factors is increasing for women and men globally [1]. Approximately a quarter of deaths were estimated to be attributable to poor diets in 2017 [1], therefore monitoring of dietary intakes at a population level is crucial for the targeting of interventions. Nutrition epidemiology has been criticised in relation to the use of self-reported diet measures, subject to multiple biases, including misreporting [2]. Commonly used self-reported diet measures include 24-hour diet recall, diet histories, food records and food frequency questionnaires. These measures enable the assessment of dietary intakes at the individual and/or group level and provide information about eating habits, nutrient intakes (e.g. energy, fibre) and micronutrient intakes (e.g. sodium). Doubly labelled water is an objective reference measure of total energy expenditure, based on providing participants with water in which the hydrogen and oxygen have been replaced with uncommon isotopes that can be measured in urine [2]. In weight-stable conditions energy expenditure correlates to energy intake. However, measurement of doubly labelled water is expensive and holds a high respondent burden, and is therefore not routinely conducted as part of surveys.

Over the past decade a growing body of high-quality research has identified differing impacts of non-communicable disease risk factors, such as high systolic blood pressure, diabetes and smoking, on cardiovascular disease outcomes, for women and men [3, 4]. However, dietary intake as a risk factor for disease outcomes has not been investigated to this extent via a gender lens. While there is evidence that self-reported dietary behaviours and intake differ for women and men [5-8], It is unclear whether these are real differences or due to systematic mis-reporting of intake by women and men. Given the Sustainable Development Goals (SDG) of achieving good health and well-being (SDG 3) and gender equality (SDG 5) [9], it is important to investigate gender differences in dietary intake and any relationship with health outcomes, to inform nutrition interventions.

In order to investigate gender differences in dietary intake we first need to know if there is differential reporting bias of dietary intake between women and men. This current review, to the best of our knowledge, will be the first to systematically review studies that have investigated dietary intake via self-reported measures compared with doubly labelled water, disaggregated for women and men. If a meta-analysis is possible, it will also be the first to quantify gender differences between energy intake from self-reported dietary assessment methods and energy expenditure.

Objective

To conduct a systematic review and meta-analysis comparing energy intake assessed using self-reported dietary assessment methods with measured energy expenditure for women and men.

Methods

Terminology, gender-sex

According to the World Health Organization gender refers to “the socially constructed characteristics of women and men such as norms, roles and relationships of, and between, groups of women and men. While most people are born either male or female, they are taught appropriate norms and behaviours – including how they should interact with others of the same or opposite sex within households, communities and work places” [10]. In comparison sex is “the classification of living things, as male or female according to their reproductive organs and functions assigned by chromosomal complement.”[11] In relation to our study, we are likely to include studies with data disaggregated by sex (a binary male/female measure). However, given the reference measure of doubly labelled water gives a value of energy expenditure at a constant for males and females we hypothesise that any differences observed in the accuracy of self-reported measures are due to gender based reasons; as such, the term gender (woman/man) has been used throughout this protocol.

Protocol registration and review reporting

This systematic review has been registered with the International Prospective Register of Systematic Reviews (PROSPERO), registration number CRD42019131715 [12]. We used the Preferred Reporting Items for Systematic reviews and Meta-Analysis Protocols (PRISMA-P) checklist when writing this protocol [13] and we will conduct this systematic review in line with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [14].

Data sources and searches

An electronic literature search will be conducted using the following databases: MEDLINE, Scopus, Web of Science, EMBASE, CINAHL and Cochrane Central Register of Controlled Trials. All peer-reviewed original research articles published before March 2020 will be included. The reference list of included studies will be searched for further relevant studies. Combinations of key words (diet*, nutrition, self, survey, diet*survey, diet*questionnaire, diet*recall, diet*record, food recall and doubly labelled water) and subject headings (diet, eating, energy intake, nutrition assessment, dietary intake, diet assessment, energy expenditure, surveys and questionnaires, self-report and diet surveys) will be used in the respective databases. The search strategy was designed in consultation with the University of New South Wales librarian services and trialled by two authors. The electronic database searches will be conducted by one author (BLM). See **supplementary table one** for an example of the MEDLINE search strategy.

Study screening

Screening of studies will be conducted based on the following inclusion and exclusion criteria, and will be conducted in Covidence [15], an online systematic review data management software.

Inclusion criteria

- Published original research studies, in peer-reviewed journals
- Studies conducted in free-living/un-hospitalised adults aged 18 years or older
- Studies that include a measure of self-reported energy intake and a measure of total energy expenditure via doubly labelled water
- Studies that include at least two participants of each sex, and that present results disaggregated into male and female (men/women) categories.
- The full-text is available in English

Exclusion criteria

- Studies conducted in populations where significant weight change is likely. For example, conducted in elite athletes, weight loss trials or in people with medical conditions where weight change is a common side effect of the disease and/or treatment
- Studies conducted in hospitalised populations, as these populations are unlikely to be eating in their usual manner and/or are unlikely to have control over their food choices
- Controlled feeding studies
- Published conference abstracts

- Published study protocols
- Published reviews
- Studies conducted on animals

Notes on inclusion/exclusion criteria

Reviews will be excluded, however their reference lists will be searched for studies. Studies will be excluded if results are not disaggregated by male and female (man/woman) categories. If some results are presented in a disaggregated manner but we require more information, then we will contact the authors of the studies. For publications that have utilised information from the same study population, findings from the first (earliest) publication that meets our inclusion and exclusion criteria will be included.

Study selection

Title and abstracts of the identified studies from the electronic searches will be screened by two authors (BLM and DHC) to assess potential eligibility. Full texts of the potentially eligible studies will then be retrieved and reviewed against the inclusion and exclusion criteria in order to obtain our final sample of studies, again in duplicate. Any disagreement in eligibility of studies will be discussed at both the title and abstract and the full text review stage, and a third author (ER) will be included in discussions if necessary. We will present the studies included and excluded at each stage of the screening process in a PRISMA flow-chart [14]. For the full-text review stage we will also provide reasons for the exclusion of studies.

Data extraction and management

Relevant variables will be extracted using a data extraction template (Microsoft Excel). This template will be piloted by two authors (BLM and DHC) on a sub-sample of the full texts before the commencement of data extraction and will be discussed with the author team. Data will be extracted independently by two authors (BLM and DHC) and cross-checked, with any disagreements resolved by discussion with a third author (ER) when consensus cannot be achieved. Data to be extracted will include: author, title, journal, year of publication, study setting, study design, study population, sample size, aim, participant characteristics (including any weight change during the study and prevalence of chronic disease states), method(s) used to measure dietary intake, methods used for energy expenditure (period of doubly labelled water collection, number of samples, dosage of labelled water given), intervention details (where applicable), study outcomes (reported mean energy intake and energy expenditure, any reported correlations between energy intake and expenditure, limits of agreement and percentage under, accurate and over reporters) and funding source. Sex-disaggregated data will be extracted for all variables if possible.

Quality assessment of included studies

Our final pool of studies will be assessed for quality using *The Academy of Nutrition and Dietetics evidence analysis manual: steps in the academy evidence analysis process* [16], which includes a *Quality Criteria Checklist*. This checklist includes categories with questions regarding the relevance of the study to clinical (dietetic) practice and the validity of the research. The questions regarding study validity cover study sampling, blinding of interventions, reliability of outcome measurement, statistical analysis, and the likely influence of study funding or sponsorship [16]. Each category is marked positive, negative or neutral, and an overall assessment is made depending on the number of categories, and which specific categories are answered in a particular way. A level of evidence will also be defined, following the *National Health and Medical Research Council levels of evidence and grades for developers' guidelines* [17]. The quality of each included study will be assessed by two researchers (BLM and DHC) independently, and any disagreements will be resolved by discussion with a third author (ER).

Data synthesis, assessing heterogeneity and publication bias

If two or more studies of similar methodology are identified in our review, we will quantify gender differences in the agreement between reported energy intake and measured energy expenditure by a random effects meta-analysis model with inverse variance weighting. We will extract the mean values of energy intake and energy expenditure, with corresponding measures of variability, by gender. Values of energy intake and energy expenditure will be extracted in kilojoules per day (kJ/day). If data was reported in kilocalories it will be converted to kilojoules by multiplying by 4.184 (2). The mean difference, and 95% confidence interval between intake and expenditure will then be calculated by gender. In order to quantify gender differences, the difference in the mean differences will be calculated within each study and pooled across studies in the meta-analysis with corresponding 95% confidence interval [4]. Separate meta-analyses will be conducted for each self-reported dietary assessment method (24-hour dietary recall, diet histories, food records and food frequency questionnaires). Heterogeneity will be assessed using Cochran's Q-test and the I^2 statistic. Subgroup analyses will be conducted by participant factors (age, weight, education, chronic disease states), geographical factors (setting (urban/rural), country income level, world region), and by study quality assessment. The GRADE guidelines will be followed when developing our tables to display our results [18]. Analysis will be conducted using STATA version 15 statistical software (Stata Corporation, College Station, TX).

Narrative synthesis of the included studies will be conducted, where all studies will be summarised, including findings from studies that are not able to be included in the meta-analysis.

Patient and public involvement

Patients and public were not involved in the design of the systematic review protocol. Their involvement is not applicable given that no participant recruitment will take place for this review.

Ethics and dissemination

We are not collecting primary data and will only be using published or author provided (de-identified) data, therefore ethical clearance is not needed. We will publish this review and meta-analysis in a recognized peer-reviewed public health nutrition journal under open access. We will also present our findings at an international scientific conference.

Supplementary material

Supplementary table one. Example search strategy for MEDLINE

Search	Search terms
1	Exp Diet/ OR Energy Intake/ OR Energy Metabolism/
2	(energy intake OR energy expenditure OR calories OR kilojoules).mp.
3	Exp Nutrition surveys/ OR Self-report/ OR diet records/ OR self-disclosure/ OR selfassessment/ OR Nutrition assessment/
4	(Diet* survey or diet* recall or diet* record or diet* questionnaire or food recall or food record or food diary or food frequency questionnaire or FFQ).mp.
5	Doubly label?ed water.mp.
6	(1 or 2) and (3 or 4) and 5
7	6 not (exp animals/ not humans.sh.)
8	limit 7 to English language

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Appendix 2. Ethics approval forms

Chapter 4. Ethics approval letter

30-Apr-2019

Dear Associate Professor Jacqui Webster,

Project Title	The Harvard Project on Access to Care for Cardiometabolic Diseases (HPACC): Sex-specific analysis of dietary behaviours and prevalence of disease in low- and middle- income countries
HC No	HC190279
Re	HC190279 Notification of Ethics Approval
Approval Period	30-Apr-2019 - 29-Apr-2024

Thank you for submitting the above research project to the **HREAP Executive** for ethical review. This project was considered by the **HREAP Executive** at its meeting on **16-Apr-2019**.

I am pleased to advise you that the **HREAP Executive** has granted ethical approval of this research project. The following condition(s) must be met before data collection commences:

Conditions of Approval:
N/A

Conditions of Approval - All Projects:

- The Chief Investigator will immediately report anything that might warrant review of ethical approval of the project.
- The Chief Investigator will seek approval from the **HREAP Executive** for any modifications to the protocol or other project documents.
- The Chief Investigator will notify the **HREAP Executive** immediately of any protocol deviation or adverse events or safety events related to the project.
- The Chief Investigator will report to the **HREAP Executive** annually in the specified format and notify the
  HREAP Executive when the project is completed at all sites.
- The Chief Investigator will notify the **HREAP Executive** if the project is discontinued before the expected completion date, with reasons provided.
- The Chief Investigator will notify the **HREAP Executive** of his or her inability to continue as Coordinating
  Chief Investigator including the name of and contact information for a replacement.

The **HREAP Executive** Terms of Reference, Standard Operating Procedures, membership and standard forms are available from https://research.unsw.edu.au/research-ethics-and-compliance-support-recs.

If you would like any assistance, or further information, please contact the ethics office on: P: +61 2 9385 6222, + 61 2 9385 7257 or + 61 2 9385 7007

Chapter 5. Ethics approval letter

21-Jul-2020

Dear Professor Jacqui Webster,

Project Title	The association of energy and macronutrient intake with all-cause mortality, cardiovascular disease and dementia:
HC	HC200560
Re	HC200560 Notification of Ethics Approval
Approval	20-Jul-2020 - 19-Jul-2025

Thank you for submitting the above research project to the **HREAP Executive** for ethical review. This project was considered by the **HREAP Executive** at its meeting on **21-Jul-2020**.

I am pleased to advise you that the **HREAP Executive** has granted ethical approval of this research project. The following condition(s) must be met before data collection commences:

Conditions of Approval:
N/A

Conditions of Approval - All Projects:

- The Chief Investigator will immediately report anything that might warrant review of ethical approval of the project.
- The Chief Investigator will seek approval from the **HREAP Executive** for any modifications to the protocol or other project documents.
- The Chief Investigator will notify the **HREAP Executive** immediately of any protocol deviation or adverse events or safety events related to the project.
- The Chief Investigator will report to the **HREAP Executive** annually in the specified format and notify the **HREAP Executive** when the project is completed at all sites.

- The Chief Investigator will notify the **HREAP Executive** if the project is discontinued before the expected completion date, with reasons provided.
- The Chief Investigator will notify the **HREAP Executive** of his or her inability to continue as Coordinating Chief Investigator including the name of and contact information for a replacement.

The **HREAP Executive** Terms of Reference, Standard Operating Procedures, membership and standard forms are available from https://research.unsw.edu.au/research-ethics-and-compliance- support-recs.

If you would like any assistance, or further information, please contact the ethics office on: P: +61 2 9385 6222, + 61 2 9385 7257 or + 61 2 9385 7007
E: humanethics@unsw.edu.au

Kind Regards,

Director, Research Ethics Compliance Support (RECS)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research (2007).* The processes used by this HREC to review multi-centre research proposals have been certified by the National Health and Medical Research Council.

Chapter 6. Ethics approval letters

03-Mar-2020

Dear Professor Jacqui Webster,

Project Title	Scaling up food policy interventions to reduce non-communicable diseases in the Pacific Islands (SUP Pacific) - Policy Landscape Analysis
HC No	HC200055
Re	HC200055 Notification of Ethics Approval
Approval Period	03-Mar-2020 - 02-Mar-2025

Thank you for submitting the above research project to the **HREAP D: Biomedical** for ethical review. This project was considered by the **HREAP D: Biomedical** at its meeting on **03-Mar-2020**.

I am pleased to advise you that the **HREAP D: Biomedical** has granted ethical approval of this research project. The following condition(s) must be met before data collection commences:

Conditions of Approval:

The Panel could not locate any information to be specifically sent to Samoan participants; and n reference to Samoan organizations in the PISCF. Would this be the same than for Fijian organizations? Please provide copies prior to dissemination to this participant group.

Conditions of Approval – All Projects:

- The Chief Investigator will immediately report anything that might warrant review of ethical approval of the project.
- The Chief Investigator will seek approval from the **HREAP D: Biomedical** for any modifications to the protocol or other project documents.
- The Chief Investigator will notify the **HREAP D: Biomedical** immediately of any protocol deviation or adverse events or safety events related to the project.
- The Chief Investigator will report to the **HREAP D: Biomedical** annually in the specified format and notify the **HREAP D: Biomedical** when the project is completed at all sites.
- The Chief Investigator will notify the **HREAP D: Biomedical** if the project is discontinued before the expected completion date, with reasons provided.
- The Chief Investigator will notify the **HREAP D: Biomedical** of his or her inability to continue as Coordinating Chief Investigator including the name of and contact information for a replacement.

The **HREAP D: Biomedical** Terms of Reference, Standard Operating Procedures, membership and standard forms are available from https://research.unsw.edu.au/research-ethics- and-compliance-support-recs.

If you would like any assistance, or further information, please contact the ethics office on: P: +61 2 9385 6222, + 61 2 9385 7257 or + 61 2 9385 7007
E: humanethics@unsw.edu.au

Kind Regards,

Convenor HREA Panel D: Biomedical

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research (2007).* The processes used by this HREC to review multi-centre research proposals have been certified by the National Health and Medical Research Council.

College Human Health Research Ethics Committee (CHREC)
Fiji Institute of Pacific Health Research (FIPHR)
College of Medicine Nursing and Health Sciences
Fiji National University (FNU)
Hoodless House, Brown Street, Suva
PH: (679) 323 3403

5th February, 2020.

Subject: Full Approval of your research project proposal.

Title of Research	Scaling up food policy interventions to reduce non-communicable diseases in the Pacific Islands (SUP Pacific) – A Policy Landscape Analysis
CHREC ID	184.20
Primary Investigator (s)	Professor Jacqui Webster, Associate Professor Anne Marie Thow, Dr. Gade Waqa
Supervisor(s)	Not Applicable.
Co - investigators	Ms. Sarah Mounsey, Ms. Briar McKenzie

Dear **Professor Jacqui Webster, Associate Professor Anne Marie Thow and Dr. Gade Waqa.**

Thank you for your application for ethics review of your research project proposal.

I am pleased to advise you that CHREC has granted **FULL APPROVAL** for your above-mentioned study.

Please note that the following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval and/or disciplinary action.

i. A copy of approval letters from each Government Ministry, NGOs and other agencies are to be sent to CHREC for records of facility approvals. (Refer to section 3.5 of your proposal (page 6) , "Recruitment of interviewees will be through formal (written) approaches to the heads of relevant agencies, via our in-country collaborators. Once approval is obtained, we will contact the delegate to request interviews."

ii. **Changes to approved research proposal**: The researcher cannot make any changes to the approved research project proposal without making a formal application to CHREC for further consideration.

iii. **Duration of Approval** – approval is granted for the duration of project as outlined in the approved research proposal. If the study cannot be completed on time as planned, the researcher must apply to CHREC for an extension by sending an email to CMNHS-RCO@fnu.ac.fj explaining the reasons and attach a progress report.

iv. **Adverse events reporting**: Any adverse events that occur shall be reported immediately by the researcher to CHREC.

v. **Monitoring:** CHREC monitors all research activities after approval is granted.

vi. **Final Report:** You must submit a final report at the end of the project by completing the Final Report Form.

If you have any further queries on these matters or require information, please do not hesitate to contact the secretariat on email: CMNHS-RCO@fnu.ac.fj or telephone: (679) 323 3403.

Yours sincerely

Chapter 7. Ethics approval letters

16-Feb-2019

Dear Associate Professor Jacqui Webster,

Project Title	Understanding gender disparities in relation to diet and cardio-metabolic diseases in
HC No	HC180959
Re	HC180959 Notification of Ethics Approval
Approval Period	16-Feb-2019 - 15-Feb-2024

Thank you for submitting the above research project to the **HREAP G: Health, Medical, Community and Social** for ethical review. This project was considered by the **HREAP G: Health, Medical, Community and Social** at its meeting on **11-Feb-2019**.

I am pleased to advise you that the **HREAP G: Health, Medical, Community and Social** has granted ethical approval of this research project. The following condition(s) must be met before data collection commences:

Conditions of Approval:
N/A

Conditions of Approval - All Projects:

- The Chief Investigator will immediately report anything that might warrant review of ethical approval of the project.
- The Chief Investigator will seek approval from the **HREAP G: Health, Medical, Community and Social** for any modifications to the protocol or other project documents.
- The Chief Investigator will notify the **HREAP G: Health, Medical, Community and Social** immediately of any protocol deviation or adverse events or safety events related to the project.
- The Chief Investigator will report to the **HREAP G: Health, Medical, Community and Social** annually in the specified format and notify the **HREAP G: Health, Medical, Community and Social** when the project is completed at all sites.
- The Chief Investigator will notify the **HREAP G: Health, Medical, Community and Social** if the project is discontinued before the expected completion date, with reasons provided.
- The Chief Investigator will notify the **HREAP G: Health, Medical, Community and Social** of his or her inability to continue as Coordinating Chief Investigator including the name of and contact information for a replacement.

FNU	College Human Health Research Ethics Committee (CHREC) Fiji Institute of Pacific Health Research (FIPHR) College of Medicine Nursing and Health Sciences Fiji National University (FNU) Hoodless House, Brown Street, Suva PH: (679) 323 3403

17th September 2019

Briar Louise McKenzie
The George Institute for Global Health, UNSW
Sydney, Australia

Subject: Full Approval of your research project proposal.

Title of Research	Gender differences in dietary intake and the influence on cardio-metabolic disease in Fiji "GENFOOD-FIJI
CHREC ID	111.19
Primary Investigator (s)	Briar Louise McKenzie
Supervisor(s)	Dr Jacqui Webster
Co - Supervisor(s)	Dr Amerita Ravuvu, Dr Gade Waqa, Prof Mark Woodward, Dr Sanne Peters

Dear **Briar McKenzie,**

Thank you for your application for ethics review of your research project proposal.

I am pleased to advise you that CHREC has granted **FULL APPROVAL** for your above-mentioned study.

Please note that the following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval and/or disciplinary action.

i. **Changes to approved research proposal**: The researcher cannot make any changes to the approved research project proposal without making a formal application to CHREC for further consideration.
ii. **Duration of Approval** – approval is granted for the duration of project as outlined in the approved research proposal. If the study cannot be completed on time as planned, the researcher must apply to CHREC for an extension by sending an email to CMNHS-RCO@fnu.ac.fj explaining the reasons and attach a progress report.
iii. **Adverse events reporting**: Any adverse events that occur shall be reported immediately by the researcher to CHREC.
iv. **Monitoring:** CHREC monitors all research activities after approval is granted.
v. **Final Report**: You must submit a final report at the end of the project by completing the **Final Report Form.**

If you have any further queries on these matters or require information, please do not hesitate to contact the secretariat on email: CMNHS-RCO@fnu.ac.fj or telephone: (679) 323 3403

Yours sincerely