

Examining inequalities in behavioural weight management interventions

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Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the preface and specified in the text. It is not substantially the same as any work that has already been submitted before for any degree or other qualification except as declared in 'Contributions' sections and specified in the text. It does not exceed the prescribed word limit for the Clinical Medicine and Clinical Veterinary Medicine Degree Committee.

Abstract

Examining inequalities in behavioural weight management interventions – Jack Michael Birch

Interventions designed to support individuals to change their health behaviours, such as behavioural weight management interventions, typically require a high amount of personal agency (such as time, money, and education) to be effective. As a result, these interventions may benefit advantaged groups with greater resources more than those who are less advantaged, and consequently may be inequitable and exacerbate health inequalities. However, there is currently limited empirical evidence about whether behavioural weight management interventions contribute to inequalities in overweight and obesity.

This thesis has examined whether there are inequalities in the attendance and effectiveness of behavioural weight management interventions using data from randomised controlled trials. Across four projects, I considered inequalities in these interventions in a range of individual-level characteristics captured by the PROGRESS-Plus framework (Place of residence, Race/ethnicity, Occupation, Gender/sex, Education, Socioeconomic status, Social capital, Plus other factors where discrimination may occur such as age and sexual orientation) and across a range of different outcomes (uptake, adherence, weight loss, weight loss maintenance, eating behaviour, physical activity, wellbeing, and mental health).

My first project was a systematic review of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions (thesis Chapter 2). I narratively synthesised data from 103 trials and summarised findings in harvest plots. Fifty-six trials considered inequalities in relation to at least one of intervention or trial uptake (n=15), intervention adherence (n=15), trial attrition (n=32), or weight outcome (n=34). Most trials found no inequalities gradient for trial uptake, intervention adherence and trial attrition. If a gradient was observed, it favoured those considered 'more advantaged'. A limitation of this systematic review is that the individual analyses in each trial are unlikely to be sufficiently powered to detect inequalities in intervention effectiveness should they exist, and that the data and analyses reported were not similar enough to be meta-analysed. A way to mitigate

these limitations is to access individual-level data from trials so that data can be harmonised and appropriate analyses conducted across all trials.

Consequently, my second project was a two-stage individual participant data meta-analysis (IPD-MA) of UK-based trials of behavioural weight management interventions (thesis Chapters 3-5). I obtained and harmonised data from 12 out of 14 eligible trials and reanalysed each trial to consider if there were inequalities in 1) the effectiveness of interventions at 12-month follow-up, and 2) attendance of these interventions. I then meta-analysed the relevant coefficients. The difference in weight loss between the intervention and control groups was 0.98kg larger for male compared to female participants, despite lower overall weight loss in men. The difference between intervention and control weight change was 2kg larger for participants of a White ethnicity compared to those from other ethnic groups, showing that these interventions may contribute to inequalities in obesity by ethnicity. I also found some evidence that behavioural weight management interventions had less effect in those who lived in areas of higher deprivation, although this was not consistent across the deprivation gradient. The intervention effect did not differ by occupation, education, socioeconomic status (annual household income), social capital (marital status), and age. There was no association between attendance and ethnicity, occupation, gender/sex, education, socioeconomic status (IMD and annual household income), social capital (marital status), and age.

The first two studies in this thesis focused on inequalities in effectiveness of behavioural weight management interventions at the 12-month follow up time point. Generally, there is a paucity of follow up data beyond this time point in UK-based randomised controlled trials. However, in the WRAP (Weight loss Referrals for Adults in Primary Care) trial there was an opportunity to consider if there are inequalities in the weight trajectories of participants up to five-year follow up. In the third study of this thesis, I conducted cohort analyses using data from the WRAP trial to consider if there are inequalities in weight change from one- to five-years post intervention baseline (thesis Chapter 6). This is important as weight regain often occurs post intervention. I did not find evidence of inequalities by ethnicity, occupation, gender, education, nor socioeconomic status, though older age was associated with lesser weight regain or greater weight loss between one- and five-years post-intervention.

The final project in this thesis used data from a trial of a web-based intervention to support weight management during Covid-19 (SWiM-C, thesis Chapter 7). I codesigned the baseline demographics questionnaire for this trial; as a result, data across a broad range of PROGRESS-Plus criteria were collected, such as access to green space, food insecurity, and perceived social support. I considered if there were differential effects of the SWiM-C intervention across a range of outcomes including weight, eating behaviour, physical activity, wellbeing, and mental health. I found that the intervention had a differential effect by marital status; it had a greater effect on weight, eating behaviour, and mental health in those who were living as single versus those who were married, in a civil partnership or cohabiting. I also found evidence that the SWiM-C intervention had a greater effect on weight in those who were unable to work due to sickness or disability versus those who were working full-time or were self-employed. I did not find evidence of a differential intervention effect by the other PROGRESS-Plus characteristics on weight, nor did I find consistent evidence of differential intervention effectiveness on the remaining outcomes.

Overall, this thesis makes several important contributions to the field. First, I identified characteristics in which there are inequalities in the effectiveness of behavioural weight management interventions. I found that these interventions have a greater effect in men (versus women) and that this effect was produced by men gaining weight overall in the control group; weight loss in the intervention group was similar between men and women. I also found that these interventions were more effective in participants from White, versus minority, ethnic groups, meaning they likely exacerbate existing health inequalities by ethnicity. Second, there were several of the PROGRESS-Plus characteristics I did not find evidence of inequalities in behavioural weight management interventions by, such as occupation, education, and socioeconomic status (particularly annual household income). Similarly, I did not find evidence of inequalities in attendance to behavioural weight management interventions. Third, I assessed the representativeness of trial participants and reporting of inequality related data in trials of behavioural weight management interventions. I found that, beyond gender or sex and age, the PROGRESS-Plus characteristics were inconsistently reported and that trials of behavioural weight management interventions were not representative of the population living with overweight and obesity. The fourth contribution of my thesis to the field is that it adds data to the field where there was a

previous paucity of data; this is particularly the case in Chapters 6 and 7 which were the first analyses of inequalities in weight regain following weight loss intervention (Chapter 6) and in outcomes other than weight (Chapter 7).

Future research should further explore the inequalities by ethnicity to ensure the effects of behavioural weight management interventions do not widen existing health inequalities, and how to better engage men into generic behavioural weight management interventions given their effectiveness.

Acknowledgements

There are broadly two schools of thought when it comes to completing the acknowledgements for a PhD. The first is to keep it brief and only acknowledge those who directly assisted you to complete a PhD. The other is to thank every person who has positively impacted you during the journey. It is such a rare opportunity to thank people who have helped me along the way, in black and white, that I must take the latter approach (with apologies to anyone I may have missed). I have been so lucky to have known so many amazing people along the way. I managed severe mental health issues throughout this PhD, and, at times, this has been my greatest challenge over the last four years. So those acknowledged have supported me as a person during that time, as well as in my PhD.

I will start with an analogy about what I saw as my role in completing this PhD. Those who know me (which I assume will be the *only* people who read this) know how into sports I am. I have refereed football and played (and latterly also refereed) korfbal, as well as making the occasional trip to King's Lynn to watch speedway. These have provided me with an invaluable outlet throughout my PhD – and in life more generally. So, the analogy is: being a PhD student is like being a Formula 1 driver. Lewis Hamilton, for example, is exceptionally talented and hardworking – he wouldn't be a multiple world champion if he wasn't. However, behind his titles is the Mercedes Formula 1 team. People in that team have every role imaginable – engineers, designers, sports scientists, human relations, accountants, chefs, directors. Each person in this team has an impact on the final design of the car, even if indirectly. Ultimately, Lewis Hamilton would never have become a multiple world champion if those people were not there. To me, completing a PhD is very similar. I have had to show my talent in different ways, overcoming many obstacles to reach submission. I would not have been able to navigate this journey had it not been for the countless people who have supported me in all sorts of ways. So, here (finally, I hear you say) comes the acknowledgements.

First, I start with those who have been significant in the years of my PhD in Cambridge. My primary supervisor, Dr Amy Ahern, provided crucial and thoughtful guidance to push me to produce work I am proud of. She regularly went above and beyond, and I absolutely would not have reached the end of my PhD without her guidance and support. My other supervisors, Professor Simon Griffin and Professor Mike Kelly, have provided multidisciplinary input and

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appreciated lunch buddy – from City. Sport has provided me with an invaluable outlet throughout my PhD, even if sometimes it felt like I was actually doing work to take a break from sport (whoops).

Of course, I didn't just rock up to Cambridge in 2019 to start my PhD having done it all by myself. Without the experiences prior to 2019, I would have never been able to undertake a PhD – never mind one at Cambridge. Before my PhD, I completed the MPhil in Public Health at Cambridge on a studentship that covered my tuition fees and provided a partial stipend. Without this, I would never have been able to fund my way through a master's. Thank you for Professor Jean Adams, and to the rest of the admissions team, for providing me with this opportunity. It was truly life changing. I made great friends this year, through the course and my college, who have kept in close contact with ever since. In particular, Bastian, Seb (who was lucky enough to proofread this whole thesis), and Emily-Jane from the MPhil, and Olivia from Homerton. Many people from my undergraduate degree at Southampton were fundamental in this journey too. My undergraduate tutor, Dr Jane Prichard, steered me away from making rash decisions around changing onto a different degree – if I had done, I wouldn't be where I am today. I remember the moment I emailed her with the news I'd been offered a place at Cambridge, and she immediately picked up the phone to tell me to make it happen. This pride and encouragement was felt from many lecturers at Southampton. It's also been a privilege to reconnect with my undergraduate course mate, Ewa, and share the trials and tribulations of completing PhDs in two very different institutions.

My love of public health was initiated as I hunted for a bachelor's degree to pursue, but was really ignited during my year working at Cancer Research UK in the Policy Research Centre for Cancer Prevention. This year taught me so much about public health that I was incredibly eager to pursue further. It was also the trigger for me to consider completing a PhD in the future. I was guided by incredibly managers, colleagues and collaborators; Jyotsna, Gillian, Rob, Lucie, and Linda – thank you.

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especially as I've taken a different path in my life to date than is common for 'people like us'. If my parents hadn't signed me and my twin, Nathan, up to the TEDS twin study all those years ago I don't think my interest in research would have been sparked. Also, thank you to Nathan for our frequent PlayStation catch ups, which have added some sanity to my life over the PhD. The hardest thing about being away from Leek and Staffordshire is missing seeing my wonderful niece Lacey grow up. I can't wait to see what you achieve as you get older and hopefully, one day, you'll find it a little cool that your uncle has a PhD from Cambridge!

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Abbreviations and Acronyms

10TT	Ten Top Tips
ACT	Acceptance and Commitment Therapy
BMI	Body Mass Index
CI	Confidence interval
EASO	European Association for the Study of Obesity
IMD	Indices of Multiple Deprivation
IPD-MA	Individual participant data meta-analysis
kg	Kilogram
N	Number of studies or participants
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
OECD	Organization for Economic Collaboration and Development
PI	Prediction interval
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RCT	Randomised controlled trial
RCTs	Randomised controlled trials
SIMD	Scottish Index of Multiple Deprivation
SES	Socioeconomic status
SWiM-C	Supporting Weight Management during Covid-19 trial
UK	United Kingdom
US	United States
USPSTF	United States Preventive Services Taskforce
WLs	Behavioural weight loss interventions
WLMs	Behavioural weight loss maintenance interventions
WRAP	Weight loss Referrals for Adults in Primary Care trial

Chapter 1 Introduction

1.1 Chapter overview

In this thesis, I examined whether there are inequalities in behavioural weight management interventions for adults living with overweight or obesity. There is theoretical suggestion that interventions that require individuals to apply a large amount of personal resource (such as time, money, and education) to take effect – such as behavioural weight management interventions – are susceptible to widening health inequalities. However, there is limited empirical evidence underpinning whether inequalities are actually generated, exacerbated, or attenuated by behavioural weight management interventions. My thesis uses a mix of novel evidence synthesis approaches and secondary data analysis of large randomised controlled trials to provide evidence to better understand if there is a differential impact of these interventions and in which characteristics these inequalities occur.

This introduction defines and discusses the key concepts of the thesis; particularly focusing on health inequalities, overweight and obesity, and interventions for overweight and obesity. It provides the overall rationale for my thesis and acts a reference point for the rationale of each of the studies I have conducted that are discussed in Chapters 2-7.

1.2 Health inequalities

1.2.1 Definition

The term 'health inequalities' is widely used across academia and policy. It usually refers to systematic patterns in mortality and morbidity between different social groups. However, the term is contested, and it is therefore necessary to begin by considering some of the different definitions and ideas involved.

The definition of health inequalities used in this thesis is from McCartney et al., and was developed in a literature review that synthesised existing definitions of health and health *inequalities (including equity-based terms)*. This defined health inequalities as “*systematic, avoidable and unfair differences in health outcomes that can be observed between populations, between social groups within the same population or as a gradient across a population ranked by social position*”.¹ There is overlap between the definitions of health inequalities, health inequities and health disparities. Some consider health inequities to be health differences that are unjust, unfair or avoidable, in the process restricting health inequalities to being the observed differences, without placing a value judgement on whether they are unfair or avoidable.^{2,3} Health inequalities may occur in disease prevalence and mortality,⁴⁻⁷ distribution of risk factors for disease,^{5,8-13} and in access to and uptake and effectiveness of interventions.^{4,14-18}

This thesis focuses on inequalities in high-income countries, in particular the United Kingdom [UK], where there are many examples of health inequalities by the characteristics outlined in section 1.2.2 below. It is important to note that health inequalities exist between and within countries, as well as across the income spectrum.¹⁹ For example, eighty-seven percent of premature mortality due to non-communicable disease occurs in low- and middle-income countries.¹⁹ Together with the continued higher incidence of infectious disease in low- and middle-income countries, this has contributed to the 'double burden of disease' in these countries.²⁰⁻²²

In the UK, there are large differences in life expectancy between those from the least- and most-deprived communities.^{23,24} For example, healthy life expectancy (i.e. years spent in good health) at birth was 19.3 years less for females and 18.6 years less for males born in the most deprived areas versus those born in the least deprived areas between 2018 and 2020.²⁵ There

are similarly stark inequalities in total life expectancy too; for example, in Glasgow the gap in life expectancy between the richest and poorest 10% of the population has grown from 12.4 to 15.4 years in men and 8.6 to 11.6 years in women between 2002 and 2019.²⁶ Whilst these are significant gaps between the most and least deprived segments of the population, the impact of deprivation is not just binary – it exists as a gradient. There is strong evidence that there is a health gradient within countries at all levels of income (within low-, middle-, and high-income countries), including in the UK.²⁷ Often, as the level of disadvantage increases, so does the adverse outcome. For example, a gradient in the prevalence of obesity in the England is observed as the level of socioeconomic deprivation increases.²⁸

1.2.2 Characteristics in which health inequalities may occur: the PROGRESS-Plus framework.

In addition to socioeconomic deprivation, health inequalities occur across many other personal characteristics. These characteristics include ethnicity, gender or sex, sexual orientation, and education. Inequalities can also arise due to interactions between these characteristics, for example the health of black women with less formal education might be significantly worse than would be linearly predicted by the individual effects of any of these characteristics in isolation. There are different ways of categorising the many characteristics in which inequalities in health may be observed. Several of these are encompassed in what have been legally defined as “protected characteristics” in the United Kingdom (UK) in the Equality Act 2010.²⁹ This act states that the public sector has a duty to make strategic decisions in a way that seeks to reduce inequalities in outcomes – not just in health – that occur from the disadvantage experienced by individuals with one or more of the protected characteristics. These protected characteristics are defined as: age, disability, gender reassignment, marriage and civil partnership, pregnancy and maternity, race, religion or belief, sex, and sexual orientation. Other measures that could indicate socioeconomic disadvantage, such as occupation type or social class are not included. Specifically for health inequalities, organisations such as NHS England have a legal requirement to reduce inequalities in access to healthcare services as well as healthcare outcomes (stated in the Health and Social care Act 2012).³⁰ To achieve this, evaluation of policy impact – including

healthcare interventions – on health inequalities must take place to ensure that strategic decisions by healthcare organisations do not exacerbate health inequalities.

Inequalities are known to exist in characteristics beyond those protected in law, for example by income and education attained. There are differences in inequality definitions used between the protected characteristics and in wider research. The Equality Act (2010) suggests socioeconomic disadvantage occurs across the stated protected characteristics. However, frequently in research, socioeconomic disadvantage is considered as an additional characteristic (often categorised by income level or area-level deprivation calculated using the indices of multiple deprivation). A fuller range of characteristics for which inequalities may be observed, are outlined in the 'PROGRESS-Plus' acronym, which ensures that inequalities are considered beyond socioeconomic status.³¹ This includes: Place of residence, Race/ethnicity, Occupation, Gender/sex, Religion, Education, SES, Social capital, and other factors that could discriminate including sexual orientation and disability. Table 1-1, adapted from Attwood et al., defines and gives example measures of each of these criteria.³²

A key feature of the PROGRESS-Plus characteristics is that occupation and education are considered separately from socioeconomic status; they are often considered to measures of socioeconomic status themselves as both occupation and education may indicate the amount of resource, privilege, power, and someone's position within a hierarchy.³³ By distinguishing them from socioeconomic status, greater consideration can be given to how features distinct to each of these characteristics may impact upon health. For example, the number of years of education someone attains is likely to impact on someone's ability to engage with an intervention, especially one with complex content, differently to someone's current employment status (such as if someone is working full-time, part-time, or is unable to work). Similarly, area-level deprivation is likely to affect someone's health, and public health more generally, differently to income. Area-level deprivation could affect what healthcare services are available in an area, the quality of public sector services, and availability of leisure activities. Income may impact on what food someone can afford to buy and prepare, whether they can afford public or private transport, or whether they can afford to take time away from work to attend appointments that could benefit their health.

Table 1-1 Definition of PROGRESS-Plus factors

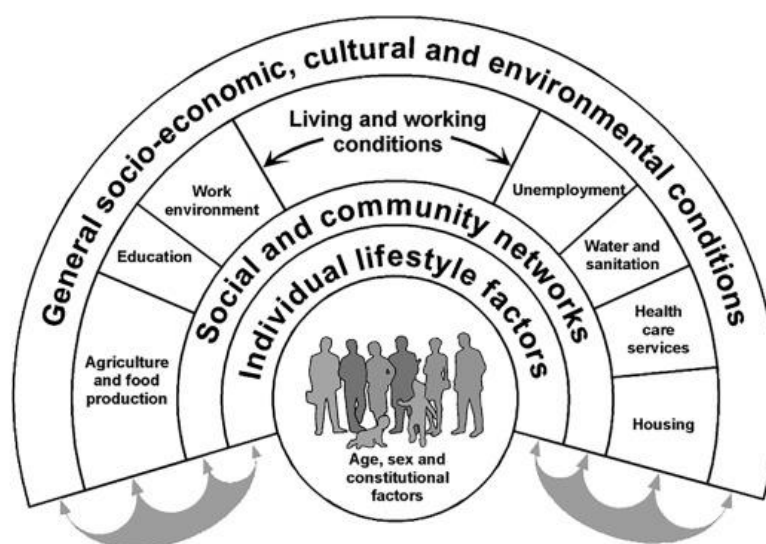
PROGRESS-Plus Factor	Description	Example measures
Place of residence	Places, and perceptions of, where individuals live	<ul style="list-style-type: none"> • Post code • Country, state, region, town or community • Urban/rural • Housing characteristics • Distance to attend weight loss session • Local food environment • 'Walkability'
Race/ethnicity	Racial or ethnic group, or other classification of culture, language or nationality status	<ul style="list-style-type: none"> • Ethnicity classifications • Country of origin • Language • Other classifications of culture
Occupation	Occupational situation, patterns of work or features of working environment	<ul style="list-style-type: none"> • Professional/skilled/unskilled/unemployed • Unemployed/employed/retired • Full time/part time • Manual/non-manual
Gender/sex	<p>Gender is self-identified by individuals, incorporating ideas around socially constructed roles and behaviours</p> <p>Sex refers to biological and physiological characteristics that define an individual as a man or woman</p>	<ul style="list-style-type: none"> • Gender • Sex (e.g., male/female classifications)
Religion	Religious affiliation or system of religious/spiritual beliefs or values	<ul style="list-style-type: none"> • Religious denomination
Education	Extent and type of education or other formal training	<ul style="list-style-type: none"> • Years in education • Level of education attained (e.g. for UK: GCSE's, A-Levels, Undergraduate) • Institutions attended (e.g. for USA: high school/some college/college graduate/university)

Socioeconomic status	An individual's position within a hierarchical social structure. Measures of socioeconomic status aim to capture access to resources, privilege, power or control	<ul style="list-style-type: none"> • Indices of Multiple Deprivation (IMD, UK only, Scottish Index of Multiple Deprivation); IMD is a combined measure of relative deprivation for small areas based on 37 separate indicators across seven domains (income, employment, education, health, crime, barriers to housing and services, and living environment) • Social class • Individual income • Household income • Receiving state welfare (e.g. benefits/free prescriptions in the UK, Medicaid in the USA) • Asset-based measures (e.g. home or car ownership) • Occupation class
Social capital	Social capital aims to capture the obligations and benefits conferred upon an individual by their society and social relationships. Can be viewed as a measure of interconnectedness between an individual and their social surroundings or group	<ul style="list-style-type: none"> • Marital/relationship status (e.g. single, cohabiting) • Household size • Social support • Social networks • Civic participation/group membership • Ability to use technology
Plus	Any other factors over an individual's life course that could lead to discrimination. Examples include age, disability and sexual orientation	<ul style="list-style-type: none"> • Self-reported age in years • Physical or emotional/mental health disability • Self-reported sexual orientation (e.g. heterosexual, homosexual, bisexual)

Adapted from Attwood et al.,³²

1.2.3 Causes of health inequalities

Health inequalities do not occur by chance. They are caused by an unequal distribution of income, wealth and power.³⁴ They reflect broader structural social and economic inequalities in society. These broad factors that have an impact on health are referred to as the ‘determinants of health’,^{35,36} subsets of which include social and commercial determinants of health. These are described in the Dahlgren and Whitehead ‘rainbow model’ (Figure 1-1). They describe their model as conceptualising “the main determinants of health for the whole population” and not a “model of the determinants of inequalities in health”. It is differences in these factors that contribute to the health inequalities that we observe, for example in occupational type as shown in the Whitehall studies by Marmot and colleagues and in the data presented in the Black Report .^{6,7,37,38} There are limitations with these studies, however. In particular, the Black Report focused on the gap between the most and least advantaged rather than considered the gradient to health that has been established, whilst the Dahlgren and Whitehead’s ‘rainbow model’, and the Whitehall studies, report associational rather than causal data. Whilst causation can be established from observational data when considered against the Bradford Hill criteria,³⁹ it makes precisely identifying relationships between causal conditions and diseases more difficult.



Source: adapted from Dahlgren and Whitehead, 1991

Figure 1-1 Dahlgren and Whitehead ‘rainbow model’, taken from Dahlgren and Whitehead 2021³⁶

Marmot suggests that some of the main contributors to health inequalities are differences in the prevalence of behavioural health risk factors (such as unhealthy diet, physical inactivity, excessive alcohol consumption, and smoking) between different groups. For example, smoking and obesity prevalence are much higher amongst lower socioeconomic groups.^{2,40} However, these inequalities, Marmot suggests, are not just caused by the differences in behavioural risk factors, but that the prevalence of these risk factors are caused by factors associated with the characteristics that inequalities occur by. These characteristics are outlined in 1.2.2, and include factors such as someone's income, education, or occupation. This is referred to as the "causes of the causes".² Hence, action on health inequalities, especially when considering behavioural health risk factors, is required at multiple levels (as further outlined in 1.4). First, by tackling the social determinants of health that make people more or less likely to engage in certain health determining behaviours – for example by reducing the level of socioeconomic deprivation in communities so they can afford to eat a healthier diet. Second, to enable all to have a realistic possibility of carrying out healthier behaviours by changing the environment and reducing the likelihood of unhealthy behaviours from being initiated. Finally, by ensuring interventions for those who already have a behavioural health risk factor work at least equally across all social groups so that any effective interventions do not exacerbate health inequalities.

Even where Marmot considers the "causes of causes", the reasons why someone may have a particular occupation, a low income, or live in a deprived area are not fully considered. A contributor of someone's socioeconomic position, occupation, and attained education is where they are from, largely informed by the position of their parent(s) in each of these categories. If someone is from an affluent area, they are more likely to have had access to better education and work opportunities, that in turn informs their current socioeconomic status – these inequalities are intergenerational, and can either be entrenched or challenged by public policy.^{41,42} For ethnicity, it is likely that issues around systemic racism drive inequalities in health and the determinants of health. Systemic racism affects someone's income,⁴³ education,⁴⁴ job prospects,⁴⁵ where they live,⁴⁶ access to health and other services,^{47,48} experience of healthcare,⁴⁹ trust in authority, and social opportunities.⁵⁰

There is also a lack of consilience between disciplines, on what health inequalities are, how to measure them, and how to tackle them,^{51,52} especially linking the social causes of

inequality and how these inequalities are actually enacted at the individual-level. For example, psychosocial pathways offer one explanation of how the social determinants of health impact on physical and mental health,^{53,54} where social factors impact an individual's state of mind which can affect their health-related behaviours and how the body reacts to psychobiological processes.^{53,55,56} Similarly, there is evidence to suggest that inflammation biomarkers are increased when individuals face disadvantage.⁵⁷ This includes growing up in an economically poor family,⁵⁸ lack of supportive close relationships,⁵⁹ being stigmatised due to being sexually- or gender-diverse,⁶⁰ during unemployment,⁶¹ and current low socioeconomic status.⁶² A more specific example is how systemic racism is enacted at the individual level. Perceived racism is associated with physiological pathways such as abnormal activation of the sympathetic nervous system leading to release of cortisol from internalised stress,⁶³ increased inflammatory markers,^{64,65} and being directly associated with increased risk of mental illness and cardiovascular disease and poorer health generally.⁶⁶⁻⁶⁸ Whilst in this thesis I examine inequalities in relation to behavioural weight management interventions, it is important to reflect upon what may be causing people to have had disadvantage prior to the intervention being offered or taking effect.

1.3 Overweight and obesity

1.3.1 Epidemiology and prevalence

Overweight and obesity are used to describe when an individual has excess body fat that presents an increased risk to their health.⁶⁹⁻⁷¹ Overweight and obesity are associated with an increased risk of several non-communicable diseases including type 2 diabetes, cardiovascular disease, dementia, and some cancers (e.g., endometrial, bowel and post-menopausal breast).^{72,73} Further, there is the issue of the 'double burden of malnutrition' – where a high prevalence of adult overweight and obesity coexists alongside childhood undernutrition (stunting and wasting).⁷⁴⁻⁷⁶ Consequently, those living with overweight and obesity are at increased risk of premature mortality versus those within a healthy weight range.⁷⁷ Overweight and obesity also has a wider impact beyond physical health; there are also psychological,^{78,79} social (including weight bias and stigma),⁸⁰ and economic implications. The latter was estimated to be around \$2 trillion in 2014 worldwide (a more contemporary

figure does not appear to have been produced to date),⁸¹ and £58 billion annually in the UK using data from 2020.⁸²

Body Mass Index [BMI] is a frequently used screening tool for overweight and obesity; a BMI of 25 kg/m² may indicate someone has overweight and a BMI of 30 kg/m² indicates an individual may have obesity. The prevalence of some obesity-related diseases, such as type 2 diabetes, occurs at lower levels of BMI for people from minority ethnic groups. This is particularly the case for those of South Asian, Chinese, Middle Eastern, Black African or African-Caribbean ethnicities.^{70,83,84} Hence, the National Institute for Health and Care Excellence in England recommend using BMI cut offs of 23 kg/m² for overweight and 27.5 kg/m² for obesity in people of these ethnicities.⁷⁰ There is suggestion that further refinement is needed to ensure appropriate BMI category cut offs are used for people of non-White ethnicities.⁸³

The prevalence of people living with overweight and obesity is increasing globally.⁸⁵ It has tripled worldwide since 1975 and in 2016 the World Health Organization reported that 1.9 billion adults (39% of the population) had overweight, of which 650 million (13%) were living with obesity. In 2014, the McKinsey Global Institute estimated that by 2030 the overall worldwide prevalence of overweight and obesity could increase to 50%.⁸¹ It is already the case in the United Kingdom that the prevalence of overweight and obesity has exceeded 50%. Specifically in England, the Health Survey for England in 2019 estimated that 28.0% of adults live with obesity and a further 36.2% have overweight.⁸⁶ This prevalence has increased over time, moving from 55% of the population living with overweight or obesity in 1995 to 64% in 2019.⁸⁷ The prevalence and increasing prevalence of overweight and obesity is comparable across the other devolved nations of the UK (66%, 61% and 65% in Scotland, Wales and Northern Ireland respectively).⁸⁸⁻⁹¹

1.3.2 Inequalities in overweight and obesity prevalence

Observational data suggest there are inequalities in overweight and obesity across some of the PROGRESS-Plus criteria. I focus on data from the UK, but many of the inequalities discussed here are mirrored in other high-income countries. Table 1-2 outlines where there

is, and is not, evidence of inequalities in prevalence of overweight and obesity in the UK. There is evidence of inequalities in prevalence by ethnicity, education and SES.^{8,92-96}

Table 1-2 Prevalence of overweight and obesity in adults in England by PROGRESS-Plus characteristics (data from Office for Health Improvement and Disparities Public Health Profiles England in 2021/22)⁹⁷

PROGRESS-Plus characteristic	Overweight and obesity prevalence data (% of population with obesity)
Place of residence	Regions with highest prevalence (<i>based on Sport England Survey data</i>) ⁹⁸ : North East, North West, East Midlands and West Midlands Regions with lowest prevalence: London and South
Ethnicity	Asian (57.6) Black (70.8) Chinese (33.1) Mixed (60.1) Other (59.4) White British (65.2) White Other (59.1)
Occupation	Unemployed (65.8) Employed (65.3)
Gender/sex	Female (58.4) Male (69.1)
Religion	<i>No data available</i>
Education	No formal qualifications (71.0) Level 1 and below (<i>lower GCSE</i> , 68.1) Level 2 (<i>GCSEs or equivalent</i> , 68.3) Level 3 (<i>A-Levels</i> , 67.3) Level 4 (<i>Higher education</i> , 60.1)
Socioeconomic status	Indices of multiple deprivation: Most deprived quintile (70.8) Least deprived quintile (59.1)
Social capital	<i>Data for marital status not available</i>
Plus (age)	18-24 (36.9) 25-34 (56.2) 35-44 (64.3) 45-54 (69.6) 55-64 (72.8) 65-74 (70.8) 75-84 (71.4)
Plus (disability)	Lives with a disability/disabled (72.2) No disability (61.7)

For ethnicity, data from England (Table 1-2) shows that the prevalence of overweight and obesity in adults is highest in Black and White British ethnic groups. Prevalence is lowest in Chinese and “Asian” (all Asian ethnicities excluding Chinese) ethnic groups. Evidence of inequalities by socioeconomic status (using area-level indices of multiple deprivation as an indicator of SES) suggests that prevalence of obesity is higher in those living in the most deprived versus the least deprived areas and this is consistent across the four devolved nations (England, Scotland, Wales and Northern Ireland) of the UK.⁹⁸⁻¹⁰¹ However, in England and Scotland there only appears to be a gradient of deprivation and obesity prevalence in women and not men,^{95,98,100,102} this is consistent across other high- and upper-middle-income countries.⁸

In England, there is also evidence of inequalities in obesity prevalence by place of residence, with prevalence in adults highest in the North East, North West, East Midlands and West Midlands and lowest in London and the South.⁹⁸ A significant contributor of this is the inequality seen in obesity by area-level deprivation, with a higher concentration of deprivation seen in these regions. There is also evidence that lesser educational attainment is associated with a greater prevalence of obesity in adults.⁹⁶

Regarding other PROGRESS-Plus characteristics, there is evidence that the prevalence of overweight and obesity is either less consistent or higher in more advantaged groups. For gender/sex, when overweight and obesity are combined the prevalence is higher in men, but the prevalence of obesity alone is higher in women.^{98,100} Prevalence generally increases with age and peaks at age 55 to 64 (men) and 65 to 74 (women) before declining.⁹⁸ For sexual orientation, a lower proportion of lesbian, gay, or bisexual adults have overweight or obesity than heterosexual adults.⁹⁸

When inequalities in prevalence of overweight and obesity are observed, their causes are likely to be multi-factorial, including: the higher financial and time cost of healthier diets, greater exposure to unhealthy takeaway food outlets, and higher food insecurity.¹⁰³⁻¹⁰⁶ People who have food insecurity are more likely to have unhealthy diets, consume fewer fruits and vegetables, and have overweight and obesity.¹⁰⁷ Given these inequalities, it is important to consider if interventions for those living with overweight and obesity are effective in groups in which the prevalence of obesity is known to be higher.

1.4 Public health intervention approaches

1.4.1 Population vs high-risk approaches and levels of prevention

Interventions to reduce the prevalence of disease and preventable risk factors in a population are often framed as targeting either a 'population' as whole or being focused on 'high-risk' individuals. The conceptual issues around these approaches were outlined in Rose's 'Sick Individuals and Sick Populations'.¹⁰⁸ Population-level interventions seek to shift the distribution of risk by affecting a small change in across the whole population risk spectrum, generally having the greatest overall positive contribution to health. Conversely, interventions targeted at high-risk groups have a greater impact upon individual risk, but overall have a lesser contribution to population health. This is known as the 'prevention paradox'. A study of the relative contributions of population and high-risk approaches to population health in the Netherlands between 1970 and 2010 demonstrates this, as it estimated that interventions using the high-risk approach accounted for approximately a quarter of the total health gain achieved by preventive interventions.¹⁰⁹

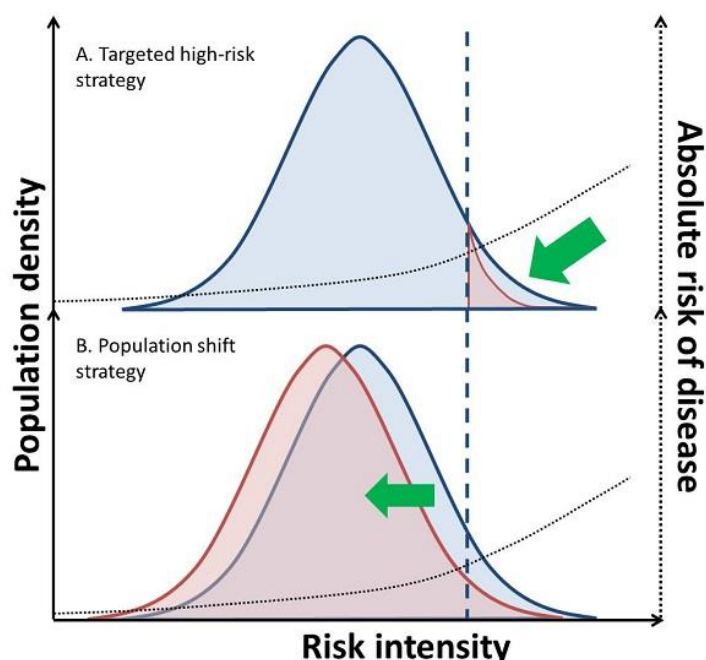


Figure 1-2 Effect of high-risk versus population-level approaches to reducing disease risk in a population, taken from Feldman 2017¹¹⁰

In addition to being targeted towards populations or high-risk groups, public health interventions also focus on different levels of prevention. Primary prevention is taking actions

to reduce the incidence of a disease or the prevalence of risk factors for disease.^{111,112} Interventions targeting primary prevention may seek to change the social and environmental conditions by affecting change at a policy level to promote good health (such as increasing active travel infrastructure or the soft drink industry levy). Alternatively, they may be more targeted at subgroups in the population which are more susceptible to developing a disease or risk factor.¹¹³ For example, offering dietary or physical activity interventions to prevent someone of a healthy weight from developing obesity, in particular to children and their families.^{114,115} There is some suggestion in the literature that interventions that are at a policy-level or change the social or environmental conditions and have an impact on an entire population should be described as primordial prevention,^{113,116} and that interventions delivered to individuals are primary prevention,¹¹⁷ but this is not universal across the literature. Secondary prevention is the early identification and treatment of a disease, offering intervention before the symptoms of a disease fully develop.^{111,112,114} For overweight and obesity, this consists of interventions that can help people to lose weight to a level where they no longer have overweight or obesity. Behavioural weight management interventions meet the definition of secondary prevention.¹¹⁴ Finally, tertiary prevention is reducing the implications of an ongoing condition that has a long-lasting impact.^{111,112} For obesity, tertiary prevention focuses on preventing an individual's obesity increasing in severity or taking actions to treat the associated diseases that develop as a result of obesity (such as Type 2 Diabetes Mellitus).¹¹⁸

1.4.2 Differing impact on inequalities and role of 'agency'

In considering only the population-wide impact, Rose's paper overlooks the differential impact interventions may have on health across different groups in the population, meaning that the shifts in risk that Rose hypothesises may not occur equitably across the population.¹¹⁹ Even though population-level interventions, such as taxation (such as for tobacco and alcohol),^{120,121} are suggested as the most likely intervention type to have a positive impact on health inequalities, these interventions only have a small impact on individuals. Therefore, those at high-risk – such as those who are already using tobacco or have overweight or obesity – will be in need of more intensive, individual-level interventions to reduce their risk.¹²²

However, It is suggested that individual-level interventions targeted towards high-risk groups are more likely to exacerbate health inequalities than population-level interventions.¹⁸

A possible mechanism causing the differential impact on inequalities of interventions targeting populations versus high-risk groups is the level of agency – or personal resource – required for the intervention to take effect. People who are disadvantaged may have less personal agency or have less freedom in how to enact their agency. Adams et al., propose that public health interventions sit across two continuums;¹²³ the first being Rose’s population vs high-risk continuum, and the second being the amount of personal agency required from an individual for them to receive a benefit from the intervention. Further to this, it has been suggested by Adams et al., that the level of individual agency required for an intervention to take effect is a mechanism by which interventions may generate inequalities; the greater the amount of agency required for the intervention to be enacted, the more likely “intervention-generated inequalities” are to occur.¹⁸ For example, interventions requiring active-decision making, whether they are population-level (e.g. changing purchasing habits according to front-of-pack nutritional information), or targeted at high-risk individuals (e.g. attending a commercial weight loss programme), may be more likely to exacerbate inequalities than interventions requiring very little agency such as fluoridation of tap water or decreasing convenience food portion sizes.¹²³

A similar framework for conceptualising intervention impact on inequalities was suggested by Backholer et al.,¹²⁴ The main difference between the two frameworks is the non-agency continuums used; Adams et al., use high-risk vs population levels, whereas Backholer et al., use micro- (such as homes or workplaces) vs macro-level (such as national or community level) as the other continuum. An important factor to note around the two intervention agency frameworks highlighted here is that they may imply that those who are disadvantaged (socioeconomically or otherwise) do not have agency, but this is not the case. Rather, all people have agency and a level of decision making in how they apply their agency. For those who are disadvantaged, they may have to focus their more limited agency on providing for themselves or their families which means they have less agency to be enacted on health interventions. Both frameworks were developed to consider obesity prevention interventions in particular. The Backholer et al., framework was used to explore socioeconomic inequities in obesity and obesity-related behaviours in a systematic review.¹²⁵ Focusing on universal

policies, the review found no differences in the equity of agentic, agento-structural or structural interventions, therefore failing to provide evidence supporting the Backholer et al., framework. As the authors of the review suggest, this was likely due to the few agentic policies that were included in the review, therefore making it difficult to fully consider any differential impact between the intervention types.

Another feature of interventions that are targeted towards high-risk groups, that may make them more likely to exacerbate health inequalities, is that they often require several steps for the intervention to take effect, which all present opportunities for inequalities to be generated. Tugwell and colleagues have suggested that the equity of interventions should be considered iteratively;^{126,127} as explained by White, Adams, and Haywood, this essentially suggests that the effectiveness of an intervention depends on equity in access to the intervention itself, healthcare practitioner compliance or patient adherence, and diagnostic accuracy.¹⁸ As suggested by Welch et al., it is important to consider this 'equity-effectiveness loop' systematically to fully understand the impact public health interventions have on inequalities.¹²⁷

1.4.3 Other contributors of differential intervention effects

In addition to agency, there are other contributors to the differential effectiveness of interventions. Two likely contributors are 1) interventions being designed and tested with a limited diversity of participants and 2) differences in healthcare experiences.

First, there are historic inequalities in who are involved as participants in the development of public health and healthcare interventions. Historically, participants in trials of interventions prior to their implementation into practice are more likely to have been male, of a White ethnicity, and of higher SES.¹²⁸⁻¹³⁴ Therefore, these interventions may not be as effective in groups not included in their development and trialling. Second, delays in offering prompt treatment or intervention to certain groups may reduce the effectiveness of an intervention. There are many examples in the literature of women and people from minority ethnic groups, for example, being less likely to be provided with prompt treatment,¹³⁵⁻¹⁴¹ or being less likely to access healthcare services.¹⁴² These may arise from stereotypes, health literacy, and lack of trust in authority.¹⁴³

1.4.4 Management and intervention of obesity

It is not possible to just take primary (or primordial) prevention approaches to reduce the prevalence of obesity, especially given how highly prevalent obesity is in countries such as the UK (as outlined in 1.3.1). Approaches seeking to shift the population risk curve (as highlighted in Figure 1-2 in section 1.4.1) will not sufficiently reduce the risks associated with obesity in those who already live with obesity. Therefore, it is necessary to have provision for secondary prevention interventions, such as behavioural weight management interventions, to help those who have overweight or obesity to manage their weight.

According to the National Institute for Health and Care Excellence [NICE], these interventions are generally multi-component programmes that aim to reduce an individual's energy intake and increase physical activity by changing their behaviour.¹⁴⁴ They often take the form of weekly sessions, where participants partake in sessions on different topics over the course of an intervention. In the UK, for example, these interventions may be delivered by, or referred to from, primary care providers – primary care patients may be given access to 12-weeks of a commercial programme, paid for by the NHS. Behavioural weight management interventions have been shown to be effective in promoting weight loss in those with overweight or obesity.^{145,146} Further, they are also likely to be cost-effective to provide.¹⁴⁷

In England, [NICE] provides guidance for healthcare practitioners around which circumstances healthcare interventions should be offered. In their guidance on obesity identification, assessment, and management [CG189], they recommend that in the first instance adults with obesity are offered behavioural intervention to change their dietary and physical activity behaviours.⁷⁰ Should intervention at this point not be successful, or a person's obesity be more severe, then they may be referred onto more specialist behavioural programmes or to further pharmacological interventions in a 'Tier 3' setting (Figure 1-3). These may include prescription of orlistat if a person's BMI is $>30 \text{ kg/m}^2$ or $>28 \text{ kg/m}^2$ with an additional weight-related risk factor, or liraglutide or semaglutide for those with a BMI $>35 \text{ kg/m}^2$ or at a lower threshold if someone has additional risk factors or has an ethnicity where type 2 diabetes and other weight-related diseases are known to occur at lower thresholds. Further referral to Tier

4 bariatric surgery services may be offered if someone's BMI is $>40 \text{ kg/m}^2$ (or $>35 \text{ kg/m}^2$ with additional risk factors).

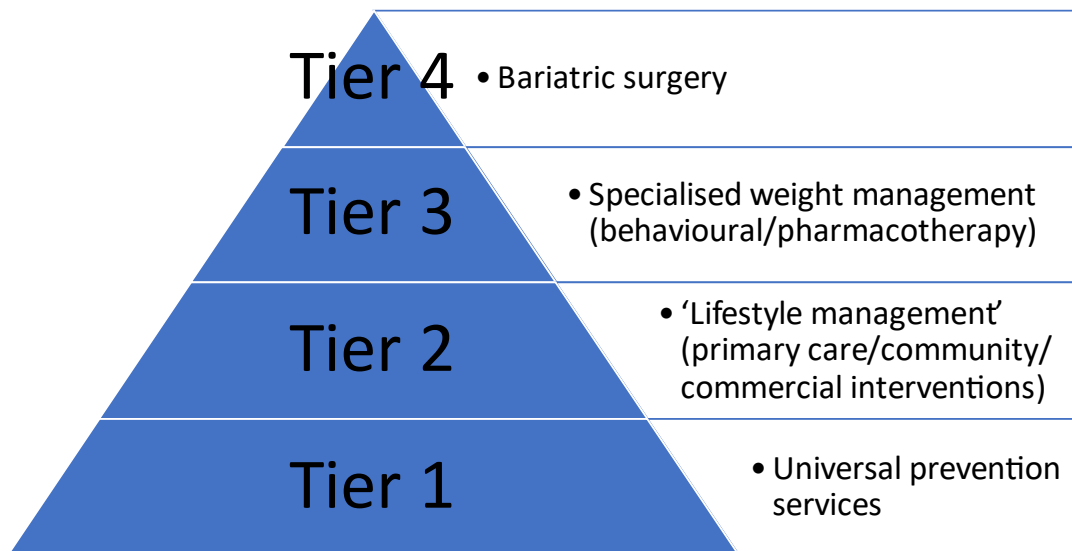


Figure 1-3 'Tiers' of weight management provision in the United Kingdom. Adapted from Wilding 2018 and Local Government Association 2021^{148,149}

In this PhD, I focus on behavioural weight management interventions, particularly those that are offered through primary care or can be self-referred and accessed via commercial providers. I focus on these interventions in particular as it is suggested that behavioural weight management interventions require a high degree of individual agency in order for someone to benefit from the intervention.¹²³ This makes them potentially susceptible to increasing or generating inequalities in obesity. As they are widely available, it is important to consider if they work well for all groups, or if inequalities in uptake, effectiveness, or weight change outcomes are present. For example, should behavioural weight management interventions be shown to have lower uptake or effectiveness in people from socioeconomically deprived areas then they could be contributing to inequalities in the prevalence of overweight and obesity.

1.5 Inequalities in the management of overweight and obesity

As highlighted in section 1.3.2, it is important to consider the different intervention stages in which inequalities may occur; otherwise, the true impact of an intervention on inequalities

may be missed. Where inequalities have been considered in other public health interventions, such as in school-based health promotion,¹⁵⁰ to improve diet quality,^{151,152} for smoking cessation,^{152–155} or for cardiovascular disease prevention,¹⁵⁶ the focus has predominantly been on the differential effectiveness of an intervention (i.e., if there are differences in intervention outcome by socioeconomic position, gender or sex, or ethnicity). A useful model, building on key foundational work in the field, is presented in a recent paper by Veinot, Mitchell and Ancker.^{18,157,158} For health informatics interventions, they suggested that interventions generate or enact inequalities when they are “(a) more accessible to, (b) adopted more frequently by, (c) adhered to more closely by, or (d) more effective in socioeconomically advantaged groups such as those with more resources or education”. I present an adapted version of these intervention stages related specifically to weight management in Figure 1-4.

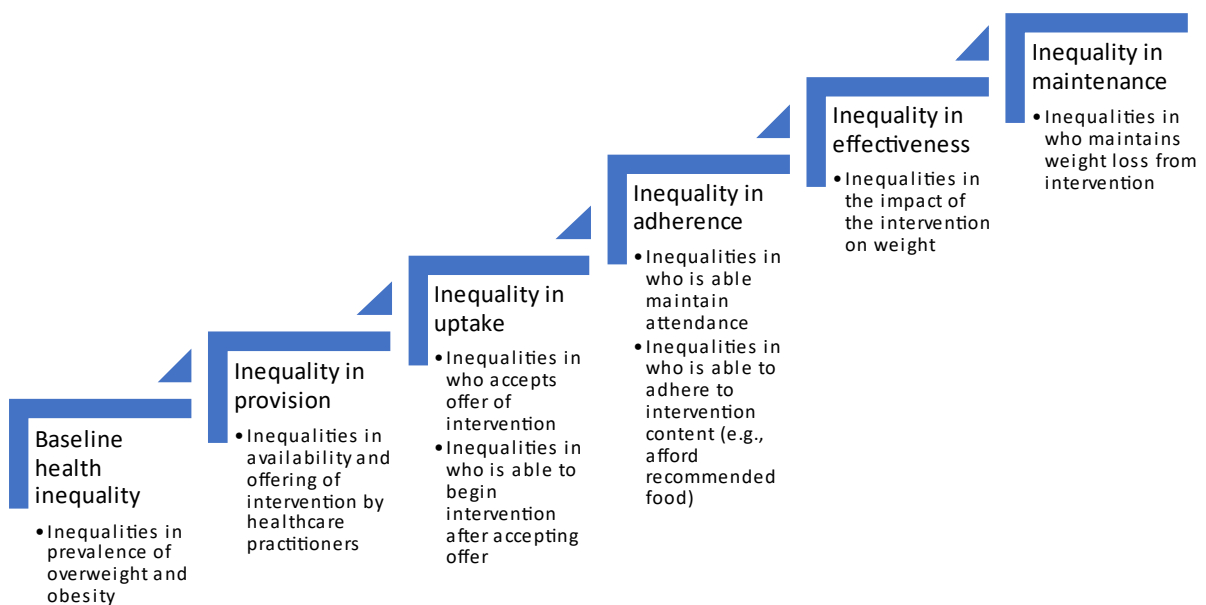


Figure 1-4 Behavioural weight management intervention stages in which inequalities may occur. Informed by Veinot, Mitchell and Ancker 2018¹⁵⁸

1.5.1 Empirically assessing inequalities in the management of overweight and obesity using data from randomised controlled trials

In Chapters 2-7, I analyse data from randomised controlled trials [RCTs] to examine inequalities across different stages of behavioural weight management intervention. RCTs are commonly used to guide decisions on healthcare provision.¹⁵⁹ They are considered as the ‘gold-standard’ of evidence on effectiveness when rigorously conducted,^{160,161} where randomisation allows for causality to be established between the intervention and outcome. However, from a health inequalities perspective, the differential effectiveness of interventions are often not reported,¹⁵⁹ and the data relevant to the characteristics in the PROGRESS-Plus framework are often not collected at baseline.^{159,162} Demographic data at baseline are typically used to assess successful randomisation and to enable adjustment for baseline imbalances rather than to investigate potential effect modification.¹⁵⁹ Reviews of how many trials consider equity or differential effectiveness of the studied intervention have frequently found that fewer than half of RCTs report any sub group analyses by the characteristics included in the PROGRESS-Plus framework.^{160,163,164}

There is some debate about the methodological validity of conducting subgroup analyses in RCTs to establish the differential effectiveness of interventions.¹⁶⁵ They do not have the same level of controlling for confounders that the primary analyses, underpinned by randomisation across intervention and control groups, possess. Further concerns include such analyses not being conducted in response to prespecified hypotheses and that subgroup analyses against each of the PROGRESS-Plus criteria “should not be used as a ‘shopping list’ to dredge for subgroup differences – a compelling pre-hoc argument is needed” (and therefore constituting multiple testing).^{165,166} For overweight and obesity, as presented in section 1.3.2, there is evidence of inequalities in prevalence by characteristics including ethnicity, gender or sex, socioeconomic position, and age. Consequently, it is important to consider if behavioural weight management interventions add to – or could potentially mitigate – these inequalities. In addition, given the primary care relevance of behavioural weight management interventions, and the widespread inequalities in healthcare access and utilisation across most PROGRESS-Plus characteristics (such as place of residence (urban vs rural), ethnicity, and socioeconomic position), there is justification for examining if these inequalities are also present in behavioural weight management interventions. This provides one of the

foundations for the systematic review presented in Chapter 2 and the individual participant data meta-analysis presented in Chapters 3-5.

There have been several prior systematic reviews that have explored the equity of behavioural weight management interventions by some of the PROGRESS-Plus characteristics.^{102,125,145,167-178} The characteristics considered were ethnicity,¹⁶⁸⁻¹⁷⁴ gender or sex,¹⁷⁵⁻¹⁷⁷ and socioeconomic position.^{102,125,178} The findings of these systematic reviews are discussed in more detail in Chapter 2 (section 2.2), but this previous systematic review literature is disparate in nature and is inconsistent in how it has considered inequalities in weight management across the PROGRESS-Plus characteristics. To date there has been no meta-analyses of published analyses of inequalities in trials of behavioural weight management interventions.

Instead, reviews have relied on narratively reporting the analyses conducted in individual trials. In Chapter 2, I conducted the most comprehensive narrative review to date, and used Harvest Plots to synthesise published analyses of inequalities in trials of behavioural weight management interventions across all PROGRESS-Plus criteria. Given that most trials are only sufficiently powered to detect a difference in main outcome by trial arm, it is unlikely that these individual-trial subgroup analyses will be sufficiently powered. Moreover, because trials are not powered to identify inequalities, many studies do not report these analyses. In Chapters 3-5, I address these limitations by conducting a meta-analysis of individual participant data, which requires the central collation, aggregation, and reanalysis of individual participant data from all relevant trials, regardless of whether they have previously reported these analyses.^{179,180} This allows for data in each study to be analysed and defined in a uniform way, overcoming heterogeneity issues associated with using aggregate data. Individual participant data meta-analyses may provide sufficient statistical power to consider whether there are inequalities in uptake, attendance and effectiveness of interventions.^{179,181}

Where subgroup analyses of the effectiveness of behavioural weight management interventions have taken place, this is commonly completed using data from the 12-month follow-up time point – reflecting that many trials only collect data until this time point. Where data from trials are available until five years of follow-up, they show that weight regain is common.¹⁸² It is, therefore, important to consider if there are particular demographic groups

where this weight regain is more likely to occur. In Chapter 6, I analysed data from the Weight loss Referrals for Adults in Primary care [WRAP] trial to consider this.

There is also the issue, more generally, of a lack of data across some of the PROGRESS-Plus characteristics where there is a lack of evidence in either the prevalence of overweight and obesity or differential intervention effects by measures of these characteristics. For example, links between measures of place of residence (such as proximity to parks or green spaces) and social capital (such as perceived social support), and differential effects of behavioural weight management interventions are not well established. This is important to examine as both opportunities for physical activity and social support are likely to influence an individual's ability to manage their weight. Hence, provided these analyses are considered exploratory, there is justification for conducting them. This explains the approach taken to my development of the demographics questionnaire and analyses conducted in Chapter 7, where I considered inequalities in the 12-month outcomes of the Supporting Weight Management during Covid-19 [SWiM-C] trial of a weight gain prevention intervention.

The SWiM-C trial also offered an opportunity to consider if there are inequalities in the impact of a weight management intervention on outcomes in addition to weight change. This is important to consider as there is evidence that behavioural weight management interventions may also impact on other health outcomes. These outcomes may be determinants of weight, such as physical activity and eating behaviour traits,^{183–185} but it is also important to consider if the intervention impacts on other outcomes - as the intervention could have an adverse unintended impact on outcomes that are not the primary focus of the intervention. This includes mental health outcomes such as anxiety, depression, and wellbeing.¹⁸⁶ Examination of inequalities in the impact of the SWiM-C intervention on these outcomes is presented in Chapter 7.

1.6 Thesis aims and structure

The overall primary aim of my thesis is *to examine the nature and extent of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions in adults*. What each chapter covers in terms of the uptake of, adherence to, or effectiveness of behavioural weight management interventions is presented in Figure 1-5.

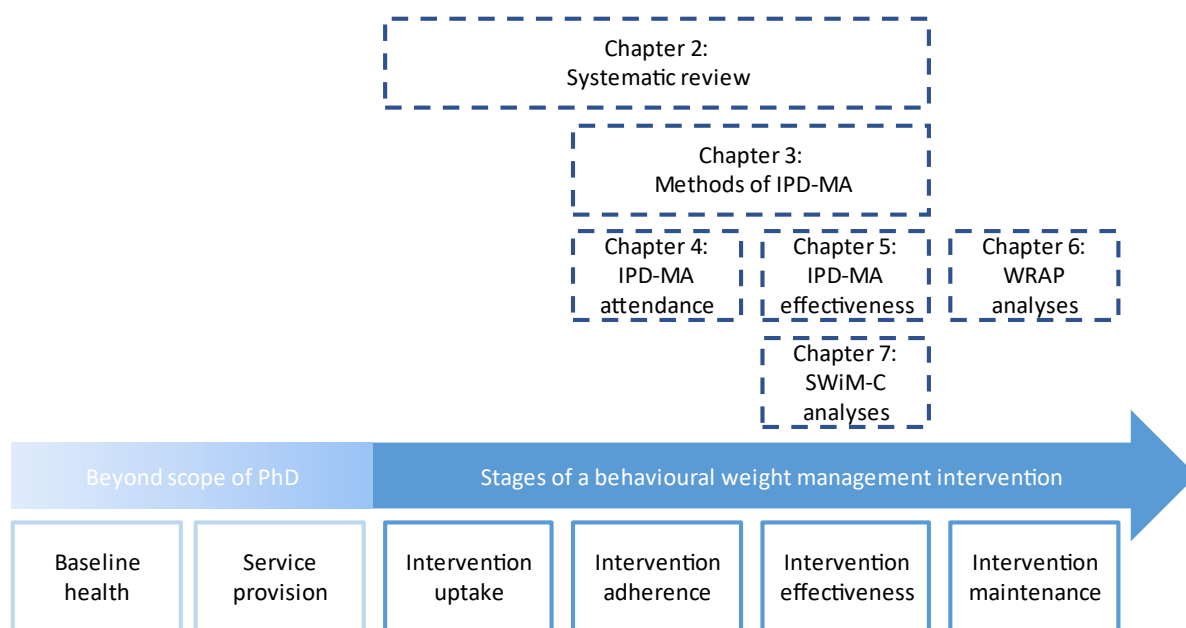


Figure 1-5 Stages of a behavioural weight management interventions and corresponding thesis chapters

In Chapter 2, I conducted a narrative synthesis using Harvest plots to assess if inequalities were present in trials of behavioural weight management interventions conducted in 'economically developed' countries. The aims of Chapter 2 were to:

- i. Summarise the number and characteristics of trials of behavioural weight management interventions that report measures of inequalities as defined by the PROGRESS-Plus criteria.
- ii. Identify, describe and synthesise published trial data on inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions.

- iii. Synthesise data on differential attrition in trials of behavioural weight management interventions.

Chapters 3-5 covers an individual participant data meta-analysis using individual level data from 12 UK-based trials to assess if there are inequalities in the attendance to and effectiveness of behavioural weight loss interventions. Chapter 3 describes the methods I used and summarises the included trials, the PROGRESS Plus characteristics I obtained individual-level data for, and how these data were harmonised.

Chapter 4 focused on the attendance data acquired in the IPD-MA project and aimed to:

- iv. Quantify the extent that attendance at behavioural weight management interventions differed by individual characteristics that stratify health opportunities and outcomes.

Chapter 5 contains the results of two sets of analyses focusing on the weight outcomes and aimed to:

- v. Quantify to what extent the effectiveness of behavioural weight management interventions (defined as the difference in weight change between intervention and control) differed by individual characteristics that stratify health opportunities and outcomes (defined using the PROGRESS-Plus Framework).
- vi. Quantify to what extent the weight outcomes of those who have participated in a behavioural weight management trial (defined as weight change in the overall cohort) differed by individual characteristics that stratify health opportunities and outcomes.

Chapters 6 and 7 focus on analyses within single trials. In Chapter 6, I used data from the Weight loss Referrals for Adults in Primary care [WRAP] trial as it is one of the few UK-based trials that offers to the opportunity to consider if there are inequalities in the weight loss maintenance phase post one-year follow up. Therefore, the aim of Chapter 6 was to:

- vii. Investigate if there are inequalities in weight change following participation in a weight loss intervention by analysing data from the WRAP trial as a cohort.

In Chapter 7, I used data from the Supporting Weight Management during Covid-19 [SWiM-C] trial, which evaluated a remotely delivered acceptance and commitment therapy-based intervention to help people with overweight or obesity to manage their weight during the

Covid-19 pandemic. This trial contains data on a range of characteristics for which health inequalities are known to occur across a range of health outcomes including weight, physical activity, mental health, and eating behaviour traits. Therefore, in Chapter 7 I aimed to:

- viii. Identify if there are inequalities in the effectiveness of the SWiM-C intervention on weight change.
- ix. Identify if there are inequalities in the effectiveness of the SWiM-C intervention in outcomes that are determinants of an individuals' weight.
- x. Identify if there are inequalities in the effectiveness of the SWiM-C intervention in outcomes where there was a significant intervention effect at four or 12 months.

At the end of the thesis, Chapter 8 presents the overall discussion of my thesis. It brings together the findings of the four studies presented in Chapters 2-7, and highlights a) the key contributions this thesis makes to the literature; b) strengths and limitations of the overall thesis; and c) implications for public health policy, practice, and research.

Finally, Chapter 9 contains the cited references and Chapter 10 contains all appendices that are referred to in Chapters 2-7.

Chapter 2 Systematic review of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions

The results presented in this chapter have been published with the following citation: Birch JM, Jones RA, Mueller J, McDonald MD, Richards R, Kelly MP, Griffin SJ, Ahern AL (2022). A systematic review of inequalities in the uptake of, adherence to, and effectiveness of behavioral weight management interventions in adults. Obesity Reviews. 23(6), e13438. doi:10.1111/obr.13438.¹⁸⁷

The protocol for this systematic review was published with the following citation: Birch JM, Griffin SJ, Kelly MP, Ahern AL (2020). Inequalities in the uptake of, adherence to and effectiveness of behavioural weight management interventions. BMJ Open (2020) 10(11), e039518. doi:10.1136/bmjopen-2020-039518.¹⁸⁸

This systematic review has also been presented at the following conferences: UK Society for Behavioural Medicine Annual Scientific Meeting 2021 (oral presentation); UK Association for the Study of Obesity Hot Topics 2021 (oral presentation); Society of Social Medicine and Population Health 2021 (poster presentation); and the European Congress on Obesity 2022 (poster presentation).

2.1 Contributions

I designed this study with Dr Amy Ahern, Prof Simon Griffin, and Prof Mike Kelly. I extracted the relevant trials from the USPSTF review and performed the updated search. I conducted the title/abstract and full text screening in duplicate with Dr Rebecca Jones. I performed data extraction along with Dr Rebecca Jones, Dr Julia Mueller, Matthew McDonald, and Dr Rebecca Richards. I produced the Harvest plots and narratively synthesised the findings, which were revised following input from all co-authors.

2.2 Background

As introduced in Chapter 1 (section 1.5.1), several previous systematic reviews have considered the relationship between characteristics in which inequalities may occur and the effectiveness of interventions for overweight or obesity. The United States Preventive Services Taskforce [USPSTF] considered the overall effectiveness of behavioural and pharmacological interventions for overweight and obesity,¹⁴⁵³ and provided narrative comment about some aspects of inequality. The authors found that unless the intervention was targeted towards a specific ethnicity, ethnicity and socioeconomic status [SES] were frequently not reported. In studies in which these were reported, most participants were White and of mid-to-high SES. Another systematic review, from Szinay et al., considered if inequalities were present in the uptake, engagement, and effectiveness of mobile-delivered interventions for weight-related behaviours by characteristics such as age, gender, ethnicity, education, and occupation.¹⁶⁷ They found that analyses in uptake, engagement, and effectiveness by these characteristics were inconsistent in reporting and observed results.

The other previous systematic reviews that I identified focused on a single characteristic for which inequality may occur (one of race or ethnicity, gender, and SES). Seven reviews focussed on race or ethnicity.¹⁶⁸⁻¹⁷⁴ Two only included interventions that were targeted towards Latinos in America^{168,173} and one only included interventions that were tailored towards African American women.¹⁶⁹ Four systematic reviews included studies if they reported more than one race or ethnicity represented in their sample. Haughton et al.,¹⁷² found that only 2/60 studies of weight loss interventions conducted analysis of differential attendance by ethnicity and 8/60 conducted analysis of differential outcome by ethnicity. Across 71 trials of interventions that focused on using technology for weight loss, Rosenbaum et al., found that there was low enrolment (trial uptake) of racial minorities.¹⁷¹ Fitzgibbon et al., included all trials (n=25) that reported including Black women (not only trials of interventions that were targeted towards Black women).¹⁷⁰ They found that Black women had lower weight loss and higher study attrition than other groups but no differences in intervention adherence. Tussing-Humphreys et al., reviewed 17 studies of behavioural weight loss maintenance interventions that included African American women,¹⁷⁴ and found that African American women generally lost less weight during the weight loss phase and regained more weight during the maintenance phase when compared to Caucasian women.

Also identified were systematic reviews that considered gender in behavioural weight management trials.¹⁷⁵⁻¹⁷⁷ These reviews found that males are generally under-represented in trials of behavioural weight management interventions,¹⁷⁵ that male-only interventions may effectively engage and assist men in achieving weight loss but,¹⁷⁶ in interventions that are delivered to males and females, attained weight loss was similar.¹⁷⁷

Three systematic reviews synthesised data on inequalities by SES.^{102,125,178} Olstad et al., in a review of universal policies for obesity in adults and children, found no evidence to support the theory that interventions targeted towards individuals/households, such as behavioural weight management interventions, were more likely to be inequitable (i.e., less effective in groups with higher disadvantage) than population-level interventions.¹²⁵ However, Olstad et al., noted that this may have been due to the few 'agentic' (i.e. interventions requiring a high amount of personal agency in order to take effect, as outlined in Chapter 1, section 1.4.2) policies included in the review. In an earlier review, Hillier-Brown et al., considered effectiveness of individual-, community-, and population-level interventions at reducing socioeconomic inequalities in obesity.¹⁰² The authors identified evidence from interventions targeting deprived groups, rather than those aimed at the population more generally. The authors only included studies reporting differential effects by SES, and only looked at outcome measures rather than process measures (such as uptake and trial attrition). Finally, McDonald et al., found that trials of male-only behavioural weight management interventions rarely considered socioeconomic status in their design or recruitment, and few trials considered if there was differential effectiveness by socioeconomic status.¹⁷⁸

The highlighted systematic reviews generally focused on a single PROGRESS-Plus characteristic. It is useful to examine all of the PROGRESS-Plus characteristics in a single review to gain a broader understanding of inequalities and identify any under-researched characteristics. Furthermore, some of the previous systematic reviews restricted their inclusion criteria to specific races or ethnicities^{168,173} or a specific sub-category of behavioural intervention.¹⁷¹ Few reviews assessed if there were inequalities at trial stages other than weight outcome, especially in reviews that focused on SES.^{102,125} It is important to understand at what stage inequalities in behavioural weight management interventions occur in order to effectively address them. In addition, previous reviews – such as in the USPSTF systematic review – have focused their consideration of inequalities to the main published trial paper.

Research questions around inequalities are often explored in subsequent publications; it is important to review all publications from trials for this data. In this chapter, I systematically reviewed the evidence concerning inequalities in the uptake, attendance and effectiveness of adult behavioural weight management interventions across the full range of PROGRESS Plus characteristics.

2.3 Aims

The aims of this chapter were to:

- Summarise the number and characteristics of trials of behavioural weight management interventions that report measures of inequalities as defined by the PROGRESS-Plus criteria.
- Identify, describe and synthesise trial data on inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions.
- Synthesise data on differential attrition in trials of behavioural weight management interventions.

2.4 Methods

I conducted this systematic review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis [PRISMA] guidelines and the PRISMA-Equity extension.^{189,190} The protocol was published in BMJ Open and registered on PROSPERO (CRD42020173242).¹⁸⁸ The search strategy and eligibility criteria replicated those from the USPSTF systematic review.¹⁴⁵ I used the USPSTF review due to the comprehensive search strategy used in the review which increased the likelihood of identifying relevant trials of behavioural weight management interventions for inclusion.

2.4.1 Eligibility Criteria

- 1 Participants: adults aged 18 years and over with overweight or obesity (body mass index [BMI] > 25 kg/m² with no upper limit) who were deemed suitable (either by the applicable

study team or healthcare practitioner) for behavioural weight loss or behavioural weight loss maintenance interventions. Participants may have additional risk factors such as hypertension, dyslipidaemia, impaired glucose tolerance or impaired fasting glucose. Studies were excluded if the population was not selected based on a weight-related measure, included participants with BMI < 25 kg/m², were selected based on having a chronic disease where weight loss is part of disease management, was selected based on being pregnant, or if the intervention was targeted at parents to change behaviour of children. Only studies conducted in member countries of the Organisation for Economic Collaboration and Development [OECD] were eligible, as per the search strategy used in the USPSTF report.

- 2 Interventions: behavioural weight management interventions with the primary aim of supporting weight loss or weight loss maintenance. Studies were included if they were conducted in, or were applicable to, primary care settings. Interventions may have been delivered alone or as part of a wider multicomponent intervention targeting diet and nutrition, physical activity, sedentary behaviour, or a combination of these. Interventions may include, but were not limited to, assessment with feedback, advice, provider training, goal-setting, or exercise referral. Studies of pharmacological and surgical interventions were excluded unless the trial included behavioural only and control arms. Interventions were considered feasible for application to primary care if they were conducted in a healthcare setting or are widely available in the community at a national or regional level (such as commercial weight loss programmes, text-message based interventions); examples of settings that are not relevant to primary care include interventions delivered in inpatient settings, or in residential care homes.
- 3 Comparators: wait-list control, usual care, or minimal intervention (such as generic print or electronic materials).
- 4 Outcomes: studies must report a weight outcome (weight change in kg, $\geq 5\%$ weight loss, or change in waist circumference) at either the 12- or 18-month follow up.

- 5 Study designs: randomised or cluster-randomised controlled trials [RCTs]. Studies that were not available in English were excluded.

2.4.3 Search strategy and information sources

I adopted a two-stage search strategy to identify relevant publications. The first stage involved identifying 'parent' RCTs (trials included in the USPSTF review).¹⁹¹ I then replicated the search used in the USPSTF review to identify relevant trials published since the USPSTF database search date (June 2017). The updated search was performed on 5th March 2020 in Medline, Cochrane CENTRAL and PsycInfo. The search strategy used in Medline is shown in Table 2-1.

Table 2-1 Literature search strategy applied in Medline

1 Obesity/
2 Obesity, Morbid/
3 Overweight/
4 Obesity, Metabolically Benign/
5 Weight loss/
6 obes\$.ti.
7 overweight.ti.
8 weight.ti.
9 (adipos\$ or body fat).ti.
10 (obes\$ or overweight or weight loss).ti,ab.
11 limit 10 to ("in data review" or in process or "pubmed not medline")
12 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11
13 Weight Reduction Programs/
14 Behavior Therapy/
15 Cognitive Therapy/
16 Counseling/
17 Directive Counseling/
18 Self-Help Groups/
19 counsel\$.ti,ab.
20 (behav\$ adj3 (therap\$ or program\$ or intervention\$)).ti,ab.
21 Health Education/
22 Diet, Reducing/
23 Diet, Fat-Restricted/
24 Caloric Restriction/
25 Diet Therapy/
26 (diet\$ adj counsel\$).ti,ab.
27 (diet\$ adj education\$).ti,ab.
28 (nutrition\$ adj counsel\$).ti,ab.
29 (nutrition\$ adj education\$).ti,ab.
30 (nutrition\$ adj intervention\$).ti,ab.
31 (diet\$ adj (modif\$ or therapy or intervention\$ or strateg\$)).ti,ab.
32 ((diet or dieting or slim\$) adj (club\$ or organi?ation\$)).ti,ab.
33 (weight reduc\$ adj diet\$).ti,ab.
34 (weightwatcher\$ or weight watcher\$).ti,ab.
35 Exercise/
36 Exercise Therapy/
37 Motor Activity/
38 Physical Conditioning, Human/
39 Physical Fitness/
40 physical activity.ti,ab.
41 (exercise adj3 (therap\$ or program\$ or intervention\$)).ti,ab.
42 ((lifestyle or life style) adj (modification\$ or intervention\$)).ti,ab.
43 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or
29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42
44 12 and 43
45 Obesity/dh, th, dt, rh [Diet Therapy, Therapy, Drug Therapy, Rehabilitation]
46 Obesity, Morbid/dh, th, dt, rh
47 Overweight/dh, th, dt, rh
48 (weight loss adj (intervention\$ or program\$ or trial\$)).ti,ab.
49 (weight reduc\$ adj (intervention\$ or program\$ or trial\$)).ti,ab.
50 (weight management adj (intervention\$ or program\$ or trial\$)).ti,ab.

The second stage involved conducting a further Medline search to curate ‘publication families’ for each eligible included trial. Publication families are all publications, of any type, that have been produced as a result of the ‘parent’ RCT.¹⁹¹ To search for these additional papers that make up the publication family for each RCT, I extracted author and study identifier (such as trial name or registration identification) information and searched these in Medline. Each publication family was considered as one study.

2.4.4 Study selection

I included all behavioural weight management interventions identified in the USPSTF report in the review. The titles and abstracts from the updated search were independently screened by myself and one other investigator (RAJ) using Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Any discrepancies were resolved by consensus. Full texts of studies identified from the title and abstract screening as being potentially relevant were screened independently by myself and RAJ, and conflicts resolved through discussion. Trials already identified from the USPSTF report and included in the search results were de-duplicated at this stage. Where necessary, conflicts were discussed with my primary supervisor (ALA) to reach consensus.

2.4.5 Data extraction

Data extraction was completed by myself using a standardised form and checked by a second investigator (RAJ, JM, MDMcD, RR). The data extraction form was developed using the Cochrane Public Health Group data extraction form, the Consolidated Standards of Reporting Trials 2010 statement, the Template for Intervention Description and Replication checklist, and the PROGRESS-Plus criteria.^{31,192–194}

2.4.6 Outcomes

2.4.6.1 Trial and intervention uptake

Trial uptake was defined as participants accepting an invitation to participate in a trial of a behavioural weight management intervention. Therefore, I defined differential trial uptake as whether those who accepted invitation to participate differed from those who declined to take part by a measure of a PROGRESS-Plus criterion.

Intervention uptake was defined as a participant attending or completing at least one session of the intervention. Therefore, differential intervention uptake was defined as a statistically

significant difference between participants attending at least one session of an intervention versus those who did not, by a measure of a PROGRESS-Plus characteristic.

2.4.6.2 Intervention adherence

Adherence was defined as number of intervention sessions attended out of those offered or as engagement with any intervention component (such as completion of food diaries or number of times logged into a mobile application). Differential adherence was defined as a statistically significant difference in the number of sessions of an intervention attended or engagement with an intervention component by a measure of a PROGRESS-Plus characteristic.

2.4.6.3 Trial attrition

Trial attrition was defined as those lost to follow up at the 12-month follow up. If attrition for the 12-month time point was not reported, data reported up until 18 months of follow up were extracted instead. Differential trial attrition was considered as a statistically significant difference in a measure of a PROGRESS-Plus characteristic, between those who were and were not followed up in the intervention arm at this time point.

2.4.6.4 Weight outcome

Weight-related outcomes (weight change in kilograms, >5% weight loss, or change in waist circumference in centimetres) at 12-month follow up were extracted. If 12-month follow up data were not reported, data for the closest time point after 12 months, up to 18 months of follow up were extracted instead. Differential weight outcome was defined as a statistically significant difference by a measure of a PROGRESS-Plus characteristic.

2.4.6.5 Categorisation of more and less advantaged groups

I used the PROGRESS-Plus framework and previous inequality-focused systematic reviews to inform the categorisation of which groups under each PROGRESS-Plus criterion would be defined as 'more advantaged' or 'less advantaged'.^{31,32,195,196} 'More advantaged' groups were: urban (Place of residence, people living in urban areas often have more proximal access to healthcare and other amenities), White (Race/ethnicity), employed full-time (Occupation), male (Gender or sex), majority religion (Religion), more education (Education), less deprived – for area based measures – or higher income level (SES), being married (Social capital), and being older (PLUS). I categorised being older as 'more advantaged' as evidence suggests older

adults have fewer barriers to accessing primary care and are more likely to be offered weight management intervention in routine practice.^{197–199} For other measures of the Plus criterion, I considered those who spoke the predominant language, were born in the country where the trial was conducted, or were free from disability to be ‘more advantaged’.

Less advantaged groups were defined as: rural (Place of residence), ethnicity other than white (Race/ethnicity), not employed full-time (Occupation), female (Gender or sex), minority religion (Religion), less education (Education), more deprived – for area-based measures – or lower income level (SES), not married (Social capital), and being younger (PLUS). For other measures of the Plus criterion, those who did not speak the predominant language or were not born in the country where the trial was conducted, or who had a disability, were considered to be ‘less advantaged’.

2.4.7 Quality assessment

First, I extracted the categorisation of quality assessment (good, fair, or poor) given to the studies included in the USPSTF report. Next, I replicated the quality assessment process from the USPSTF report for the additional studies identified as meeting eligibility criteria.²⁰⁰ Studies were graded as ‘good’ if follow up was $\geq 80\%$, valid measurement instruments used, interventions clearly outlined, and confounders were appropriately controlled for, during analysis. A study was rated as ‘fair’ if some minor limitations occurred. For example, there may be minor differences in follow up, follow up $< 80\%$, or not all potential confounders accounted for. A ‘poor’ rating was given to a study if major limitations existed, such as unreliable weight measurement methods (such as self-reported weight), inadequately conducted randomisation (e.g., not truly randomised), or important confounders were given little or no consideration.

2.4.7.1 Deviations from original protocol

In the protocol, I originally intended to use Cochrane’s Risk of Bias (RoB) 2 tool to conduct risk of bias assessment.¹⁸⁸ However, upon further reading of the USPSTF report that the search strategy I used was derived from, I instead aligned the quality assessment methods with those used in the USPSTF report,¹⁴⁵ as the USPSTF method incorporates risk of bias assessment into its quality assessment of included trials.

2.4.8 Data synthesis

Due to heterogeneity of intervention types and measures of the PROGRESS-Plus criteria, such as country-specific measures of socioeconomic status or ethnicity, it was deemed not possible to conduct a meta-analysis. Therefore, I conducted a narrative review with the addition of Harvest plots. Harvest plots were originally proposed by Ogilvie et al., as a method of synthesising evidence of differential effectiveness of public health interventions when a meta-analysis may not be appropriate.²⁰¹ They allow for all available and relevant data to be used and presented, even when there is heterogeneity in measures used. Several study features can be graphically demonstrated on a single plot, such as study quality, statistical significance and sample size. In the Harvest plots in this study, bar height represents the sample size of the study, with the smallest bars representing studies with 0-200 participants, and the tallest bars studies with 801+ participants. A study was categorised as favouring a particular group if a statistically significant difference was observed. The Harvest plots were produced using Microsoft PowerPoint (version 2016, Microsoft Corporation).

2.5 Results

The PRISMA Flow Diagram (Figure 2-1) shows the number of papers identified in each stage of the review.¹⁸⁹ A total of 103 studies met the inclusion criteria, 89 of which were extracted from the USPSTF report and a further 14 identified through the replicated search strategy. As publication families of each included trial were identified, information was extracted from 266 publications across the 103 studies.

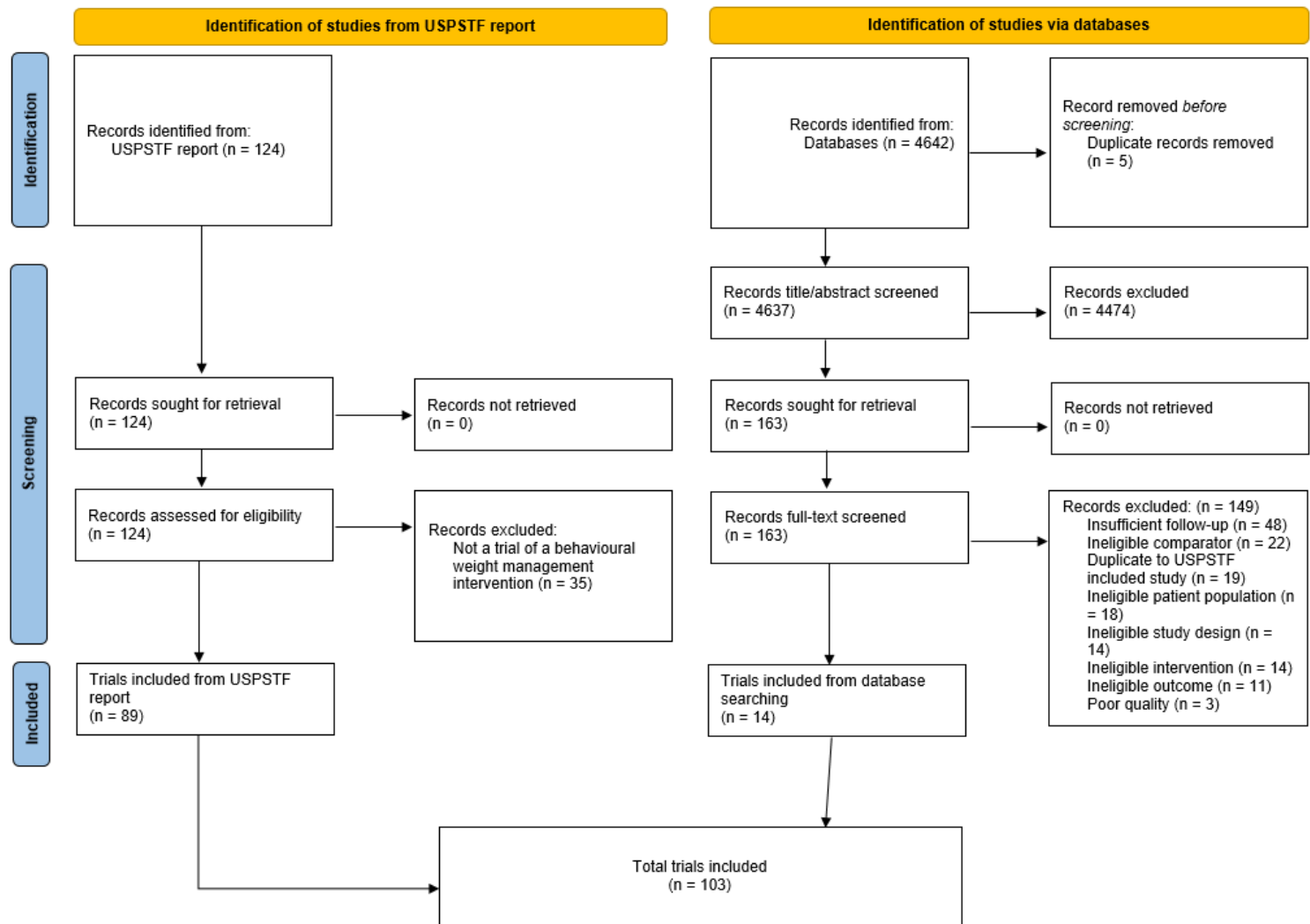


Figure 2-1 Preferred Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram for the inclusion of studies

2.5.1 Study characteristics

Of the 103 included studies (Table 2-1 and Supplementary Table 1), 90 were trials of behavioural weight loss interventions [WLs]^{202–291} and 13 were of behavioural weight loss maintenance interventions [WLMs].^{292–304} Across the studies there were a total of 36,805 participants, with the sample size of each study ranging from 30²¹⁰ to 2,161 participants.²⁵⁹ Sixty-six percent of participants were female. Most studies were from the USA (n=57).

Thirty-six of the included studies explicitly stated that the intervention targeted a specific group that covered at least one of the PROGRESS-Plus criteria.^{203,205,208,209,211,213,215,216,223,225,228,229,231,232,234,235,238,241,242,244,246–248,251,260,268–}

^{271,275,276,279,283,285,290,295} Ten studies targeted a specific race or ethnic group (such as Black African-American or Hispanic),^{209,213,223,229,231,235,242,268,279,290} three targeted specific occupations,^{269,275,285} 22 studies targeted based on gender or sex (six interventions were targeted at men^{215,225,232,269,275,294} and 16 at women^{211,213,216,223,234,238,246,248,260,267,268,270,271,276,283,295}), eight targeted low-income groups,^{203,208,223,231,234,235,247,268} and five targeted particular age groups.^{205,241,244,251,295} Participants belonging to certain health groups were also targeted in eight of the studies identified,^{205,211,216,228,234,246,271,276} such as postpartum women or those at elevated risk of breast cancer.

2.5.2 Quality assessment

As shown in Figure 2-1, three studies were scored as ‘poor’ quality; these were excluded from the synthesis.^{305–307} Of the 14 studies identified in the updated search, 11 were scored ‘fair’ quality and three were scored ‘good’ quality. In total, 74 studies were of ‘fair’ quality and 29 of ‘good’ quality (Appendix 3, Chapter 2 Supplementary Table 1).

Table 2-2 Characteristics of included trials

	Number of trials (%)	Citations
Intervention type		
Weight loss	90 (87.4)	202–291
Weight loss maintenance	13 (12.6)	292–304
Database searching vs identification from USPSTF report		
Studies identified from database searching	14 (13.6)	250,280–288,301–304
Studies identified from USPSTF report	89 (86.4)	202–249,251–279,289–300
Trial Location		
United States	57 (55.3)	202,203,208–213,218,221–223,229–232,234,235,237,239–247,249–251,253,256,258–260,262,264,267,268,270,271,273,276–279,281,283,285,289,293,295–297,299,300
United Kingdom	16 (15.5)	204–207,214,215,219,227,233,261,266,280,290,298,301,304
Australia	5 (4.9)	225,282,284,291,294
Finland	5 (4.9)	252,269,274,288,292
Japan	4 (3.9)	226,257,265,303
Germany	3 (2.9)	220,263,302
The Netherlands	3 (2.9)	224,248,275
Spain	3 (2.9)	272,286,287
Canada	2 (1.9)	236,255
Sweden	2 (1.9)	216,254
Norway	1 (1.0)	228
Portugal	1 (1.0)	238
Multiple countries	1 (1.0)	217
Sample size at baseline		
0-200	41 (39.8)	202,210–212,214,216,220,223–225,230,233,237,242,246,247,252,254,256,257,263,265,267–270,273,276,278,279,285–287,290,294–296,298,302,303
201-400	32 (31.1)	205,208,209,213,218,221,222,226–229,234,235,238,241,243,249,250,253,258,264,277,280–284,291,292,299,300,304
401-600	15 (14.6)	203,207,232,236,239,244,245,248,251,260,274,288,289,297,301
601-800	5 (4.9)	215,217,219,262,269
>800	10 (9.7)	204,206,240,255,259,261,266,272,275,293
Proportion female at baseline		
0% (all male)	6 (5.8)	215,225,232,269,275,294
1-49%	11 (10.7)	205,214,220,224,239,240,257,263,285,299
50-99%	70 (68.0)	202,203,206–210,212,217–219,221,226–231,233,235–237,241–245,247,249–256,258,259,261,262,264–266,272–274,277–282,284,286–293,296–298,300–304
100% (all female)	16 (15.5)	211,213,216,223,234,238,246,248,260,267,268,270,271,276,283,295
Mean age (years) at baseline*		
18-40	11 (10.7)	216,218,225,234,238,241,242,251,252,267,283
41-54	63 (61.2)	203,204,208,209,211–213,215,217,219,221–223,226–232,235–237,239,240,245,247,249,250,253–255,259,261–264,266,268–270,273,275,277,278,280–282,284,285,287–290,292,294–298,300–302,304
≥55	28 (27.2)	202,205–207,210,214,220,224,233,243,244,246,248,256–258,260,265,271,272,274,276,279,286,291,293,299,303
Number of PROGRESS-Plus measures reported at baseline		
0	0 (0.0)	
1	0 (0.0)	
2	20 (19.4)	210,212,224,226,236,254,263,265,269,272,274,278,287,295–297,300,302,303
3	16 (15.5)	202,209,217,220,251,253,256,257,261,262,266,271,273,279,288,298

4+	67 (65.0)	203–208,211,213–216,218,219,221–223,225,227–235,237–250,252,255,258–260,264,267,268,270,275–277,280–286,289,290,292–294,299,301,304
Number of PROGRESS-Plus measures differential trial uptake considered by		
0	89 (86.4)	202,203,205,207,209,210,212,213,215–223,225–231,233,235,238,239,241–244,246–292,295–298,301–304
1	6 (5.8)	214,224,234,236,237,293
2	4 (3.9)	208,211,232,280
3	3 (2.9)	204,206,240
4+	1 (1.0)	245
Number of PROGRESS-Plus measures differential intervention uptake considered by		
0	98 (95.1)	202,204,205,207–217,219–233,235–249,251–304
1	3 (2.9)	206,218,234
2	0 (0.0)	
3	0 (0.0)	
4+	1 (1.0)	203
Number of PROGRESS-Plus measures differential adherence considered by		
0	88 (85.4)	202,205,207,209–217,219,220,222,224,226–233,235,238,240,241,243–249,251–279,281–284,286–292,295–300
1	7 (6.8)	206,218,221,234,236,239,242
2	1 (1.0)	225
3	2 (1.9)	237,280
4+	5 (4.9)	203,204,208,285,293
Number of PROGRESS-Plus measures differential trial attrition considered by		
0	71 (68.9)	203,205,206,209,212,214,215,221,222,224,226,230,239–242,244,246–249,251–279,289–292,295–300,302–304
1	6 (5.8)	217,218,225,229,233,235
2	7 (6.8)	210,216,228,231,232,236,283
3	7 (6.8)	202,207,220,223,237,238,280
4+	12 (11.7)	204,209,211,213,219,227,234,243,245,282,293,301
Number of PROGRESS-Plus measures differential weight outcome considered by		
0	72 (69.9)	202,203,207,211,213,214,216,217,220,221,223,224,226,228–233,236–238,242,243,246–249,251–258,260–279,285–291,295–300,302–304
1	10 (9.7)	206,212,218,219,222,225,227,235,282,284
2	8 (7.8)	210,239,244,245,259,281,283,301
3	7 (6.8)	204,205,209,240,280,292,294
4+	6 (5.8)	208,215,234,241,250,293

*mean age not available for Perri et al., 1998²⁹⁶

2.5.3 Findings

At baseline, all 103 trials reported age and almost all (n=101) reported participant gender or sex (Figure 2-2). The next most commonly reported baseline measures were race/ethnicity (n=67), education (n=57), socioeconomic status (n=40), social capital (predominantly marital status, n=33), and occupation (n=31). Nine trials reported measures (other than age) that meet the definition of ‘Plus’ according to the PROGRESS-Plus characteristics – the most common measures meeting this criterion were health literacy and language at home. The least commonly reported measures at baseline were place of residence (n=1) and religion

(n=1). Sexual orientation was not reported in any of the included studies. Fifty-six of the 103 trials considered inequalities in intervention or trial uptake (n=15), intervention adherence (n=15), trial attrition (n=32), or weight outcome (n=34) in relation to at least one PROGRESS-PLUS criterion.

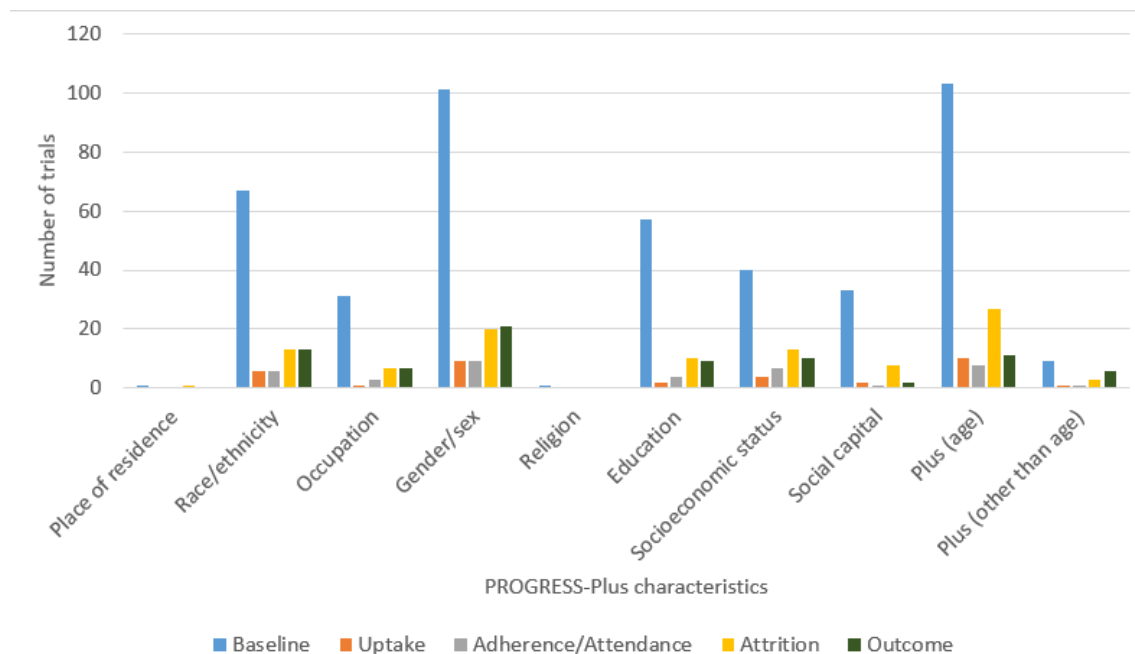


Figure 2-2 Number of trials reporting PROGRESS-Plus criteria at each trial stage

2.5.3.1 Inequalities and uptake

2.5.3.1.1 Trial uptake

Twenty-nine analyses (WLs=28, WLMs=1) across 15 trials (Figure 2-3) examined inequalities in trial uptake.^{204,206,208,211,214,224,232,234,236,237,240,245,280,285,293}

In the 28 analyses across 14 trials of WLs, 16 analyses found no evidence that trial uptake favoured more or less advantaged. Three analyses found that trial uptake was highest in 'less advantaged' groups and nine analyses found trial uptake was highest in 'more advantaged' groups.

One study (one analysis) considered if differential trial uptake occurred in WLMs trials. This analysis found no evidence that trial uptake favoured more or less advantaged.

Trial uptake higher in:			
	Less advantaged	No significant difference	More advantaged
Place of residence	Rural		Urban
Race/ethnicity	Other than white		White
Occupation	Not full-time		Full-time
Gender/sex	Women		Men
Religion	Minority		Majority
Education	Less educated		More educated
SES	More deprived		Less deprived
Social capital	Unmarried		Married
Plus (age)	Younger		Older
Plus (other than age)	Less advantaged		More advantaged

Key: Number under bar denotes study reference, bar height denotes sample size and bar colour denotes intervention type. SES = Socioeconomic status

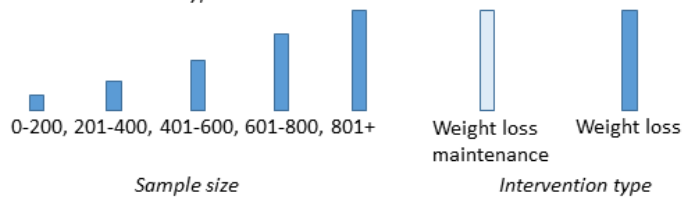


Figure 2-3 Harvest plot of inequalities in trial uptake

2.5.3.1.2 Intervention uptake

Seven analyses across 4 trials (all WLs) considered whether there were inequalities in intervention uptake (Figure 2-4).^{203,206,232,239} One study considered inequalities by race or ethnicity, two studies considered inequalities by gender, one by SES, one by social capital (marital status), one by age and one by protocol language (English versus Spanish). One analysis found that intervention uptake favoured 'less advantaged',²⁰⁶ three analyses found no gradient,³⁷ two found intervention uptake favoured 'more advantaged',²³² whilst one analysis was unclear in whether it favoured a particular group or not.²³⁹

Intervention uptake higher in:			
	Less advantaged	None	More advantaged
Place of residence	Rural		Urban
Race/ethnicity	Other than white		White
Occupation	Not full-time		Full-time
Gender/sex	Women		Men
Religion	Minority		Majority
Education	Less educated		More educated
SES	More deprived		Less deprived
Social capital	Unmarried		Married
Plus (age)	Younger		Older
Plus (other than age)	Less advantaged		More advantaged

Key: Number under bar denotes study reference, bar height denotes sample size and bar colour denotes intervention type. SES = Socioeconomic status

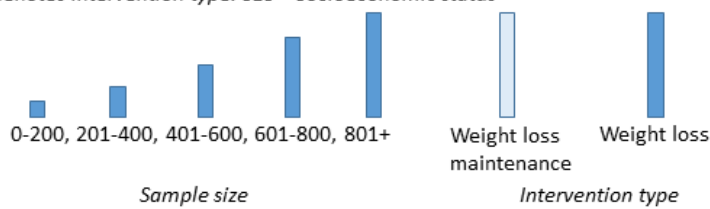


Figure 2-4 Harvest plot of inequalities in intervention uptake

2.5.3.2 *Inequalities and intervention adherence*

Thirty-nine analyses (WLs=34, WLMs=5) from 15 trials (Figure 2-5) examined inequalities in intervention adherence.

Thirty-four analyses across 14 trials of WLs examined inequalities in intervention adherence.^{203,204,206,208,218,221,225,234,236,237,239,242,280,285} Twenty of the 34 analyses found no gradient. Eleven analyses found that intervention adherence favoured more advantaged groups (i.e., that intervention adherence was highest in these groups) and three found that intervention adherence was highest in the less advantaged groups. Intervention adherence was higher in those who had a full-time occupation versus not full-time (3/3 analyses), and also appeared to be higher in older participants (3/7 analyses).

Five analyses, from one trial, explored inequalities in adherence to WLMs.²⁹³ Three out of the five analyses favoured the more advantaged groups (1/1 analysis of ethnicity, 1/1 analysis of education and 1/1 analysis of age). The remaining two analyses found that intervention adherence did not favour either less or more advantaged groups.

Intervention adherence higher in:			
	Less advantaged	No significant difference	More advantaged
Place of residence	Rural		Urban
Race/ethnicity	Other than white 		White
Occupation	Not full-time		Full-time
Gender/sex	Women 		Men
Religion	Minority		Majority
Education	Less educated 		More educated
SES	More deprived 		Less deprived
Social capital	Unmarried		Married
Plus (age)	Younger 		Older
Plus (other than age)	Less advantaged 		More advantaged

Key: Number under bar denotes study reference, bar height denotes sample size and bar colour denotes intervention type. SES = Socioeconomic status

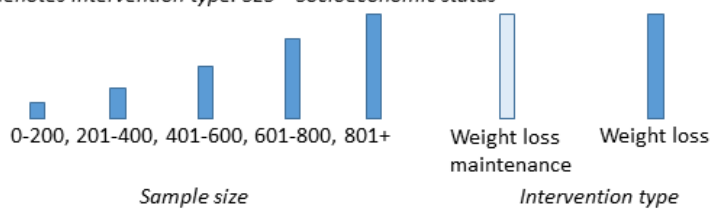


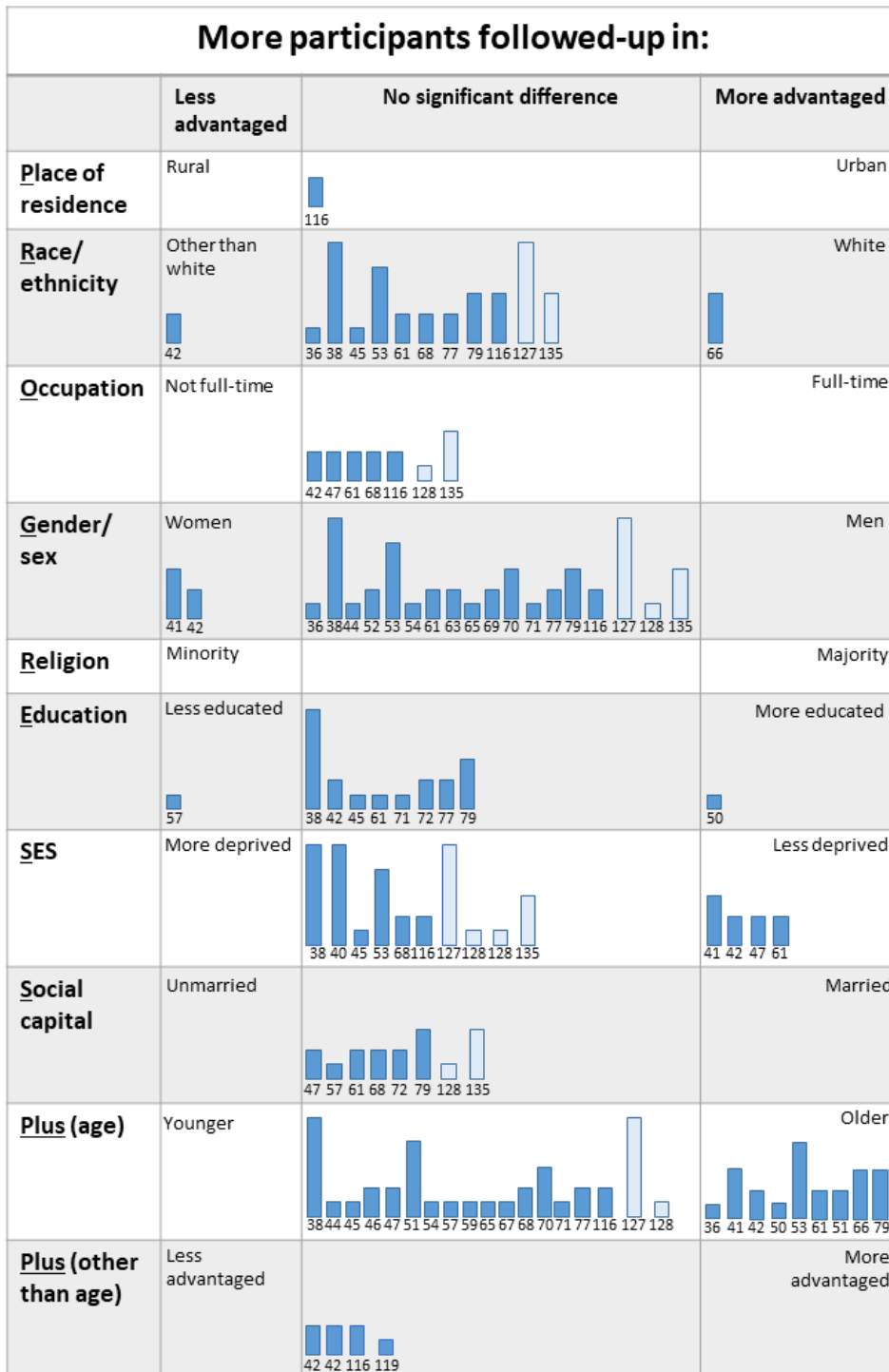
Figure 2-5 Harvest plot of inequalities in adherence to behavioural weight management interventions

2.5.3.3 Inequalities and trial attrition

In total, ninety-three (WLs=78, WLMs=15) analyses across 32 trials considered inequalities in trial attrition (Figure 2-6).

Seventy-eight analyses from 29 trials assessed inequalities in trial attrition in WLs.^{202,204,207,208,210,211,213,216–220,223,225,227–229,231–238,243,245,280,282} The majority of these analyses (n=59) found that trial attrition favoured no particular group; four analyses found that trial attrition was lower in less advantaged groups and in 15 analyses trial attrition was lower in more advantaged groups. Most of the analyses favouring ‘more advantaged’ were of age, followed by socioeconomic status (i.e., those who were older or of a less deprived socioeconomic status were less likely to be lost to follow up). There was little evidence to suggest inequalities in trial attrition by other PROGRESS-Plus criteria.

All analyses (15 across three trials) considering if there were inequalities in trial attrition in WLMs found that trial attrition did not favour any particular group.^{293,294,301}



Key: Number under bar denotes study reference, bar height denotes sample size and bar colour denotes intervention type. SES = Socioeconomic status

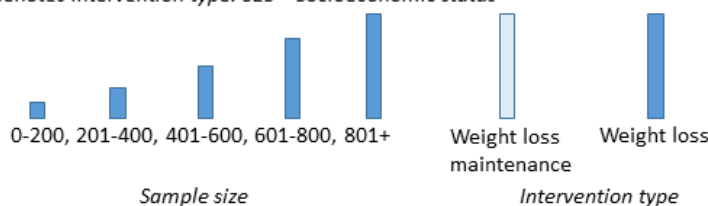


Figure 2-6 Harvest plot of inequalities in trial attrition

2.5.3.4 Inequalities and weight outcome

A total of 79 analyses (WLs=64, WLMs=15) across 34 trials that considered inequalities in weight outcome were identified (Figure 2-7). The results of four of these analyses (three for gender or sex^{226,230,236} and one for occupation²⁹²) were unclear and are consequently omitted from the Harvest plot.

Sixty-five analyses in 30 trials of WLs considered inequalities in weight loss.^{202–206,208–210,212,215,218,219,222,225,226,230,234–236,239–241,244,245,250,259,280,281,283,284} Four analyses found that less advantaged groups lost more weight, 11 that more advantaged groups lost more weight, and the majority (n=50) found that weight loss favoured neither less nor more advantaged groups. For gender or sex, men lost more weight than women in three out of 17 analyses conducted, whilst women lost more weight in one of the 17 analyses. For SES, two of nine analyses favoured those in less advantaged groups.

There were 15 analyses of inequalities in weight loss maintenance identified across five WLMs.^{292–294,301,302} None of the analyses found evidence of inequalities in the weight outcome of WLMs (i.e., there was no significant difference observed in weight loss maintenance by any measure of inequality).

Weight outcome favours:			
	Less advantaged	No significant difference	More advantaged
Place of residence	Rural		Urban
Race/ethnicity	Other than white 115	43 49 68 73 75 79 84 117 127	White 34 74 78
Occupation	Not full-time	39 42 49 59 68 75 126	Full-time
Gender/sex	Women 115	38 39 42 43 44 53 56 73 78 79 84 114 118 126 127 135 136	Men 34 52 69 74
Religion	Minority		Majority
Education	Less educated	38 42 49 61 75 116 127 128 135	More educated
SES	More deprived	38 42 49 68 75 114 117 128	Less deprived 39 40
Social capital	Unmarried 49 68		Married
Plus (age)	Younger 75	43 44 49 68 74 126 127 128 136	Older 84 114
Plus (other than age)	Less advantaged 46	42 42 84	More advantaged

Key: Number under bar denotes study reference, bar height denotes sample size and bar colour denotes intervention type. SES = Socioeconomic status

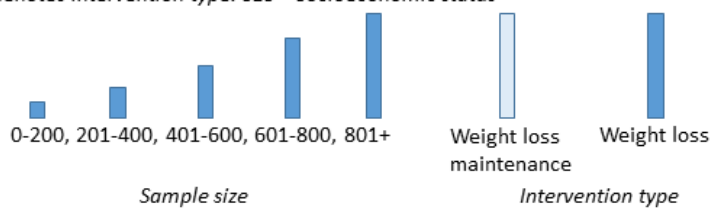


Figure 2-7 Harvest plot of inequalities in weight outcome

2.6 Discussion

This comprehensive systematic review found that most trials of behavioural weight management interventions do not examine whether differential trial/intervention uptake, intervention adherence, trial attrition or outcome occurs in different social groups. In those that did examine differences, most found no gradient (e.g., intervention uptake or trial attrition was not higher in either more or less advantaged groups). If a gradient was observed, it mostly favoured those who were 'more advantaged'. This was not the case for weight outcomes, for which a similar number of trials favoured 'less advantaged' groups as those favouring 'more advantaged'. The findings suggest that inequalities may occur in intervention/trial uptake, intervention adherence, and trial attrition, although behavioural weight management interventions may be equitable for those who reach the 12-month follow up.

2.6.1 Comparison with existing literature

In this review, I examined two types of behavioural weight management interventions: interventions targeting weight loss [WLs] and interventions targeting weight loss maintenance [WLMs]. There were differences in inequalities observed between the two intervention types; evidence of inequalities in WLMs was only present in intervention adherence and not in trial or intervention uptake, whereas there was some evidence of inequalities at all stages in WLs. There may be several underpinning reasons for this. Firstly, there were fewer trials of WLMs than of WLs (13 versus 90), meaning that there were fewer data available for WLMs. Secondly, it is possible that inequalities in behavioural weight management interventions are being generated in the interventions targeting weight loss, and those who are less successful in a weight loss intervention may be less likely to be invited to take part in a further weight loss maintenance trial.

There is also some evidence to suggest that, when taking into account the age of people invited to take part in a weight management trial, a significantly higher proportion of older people took up the offer. This was the case in four of the ten studies I identified that examined this. This is supported by survey data showing that older people report better access to primary care,³⁰⁸ and by evidence from a UK-based population-based cohort study which

observed that weight management interventions were more often accessed by older participants.¹⁹⁹ The study authors also noted that weight management interventions were more often accessed by women and those in deprivation.¹⁹⁹ Overall, this review found that two-thirds of the total number of participants taking part across the trials included in this review were female. This is similar to the findings of previous systematic review which focused on the issue of male inclusion in RCTs in WLs, which found that only 27% of participants were male.¹⁷⁵ When accounting for the total number of men and women invited to take part in the trial, I did not find evidence to suggest that there were inequalities in those who were likely to accept invitation to the trial or to the intervention arm. It has previously been observed that the proportion of male participants in studies of commercial weight management programmes is higher when all those in the population who are eligible are invited than when patients are invited opportunistically, suggesting the inequality in male participation can be reduced by inviting more men to take part.³⁰⁹

When compared to the wider RCT literature, trials of behavioural weight management interventions are atypical in that recruitment favours women and older participants. Outside of trials of behavioural weight management interventions, for example in RCTs used for cardiovascular guidelines or drug and vaccine research, recruitment tends to favour men and younger participants.^{310–312} Therefore, this may suggest that a nuanced perspective on inequalities should be taken when addressing behavioural weight management interventions, as some groups that are typically under-researched; women and older people are the most researched. Hence, there is less research in groups that would typically be considered as advantaged in other health and wider societal domains.

Whilst there is some evidence in this systematic review to suggest that trial uptake is higher in less socioeconomically advantaged groups, I found that intervention adherence, trial attrition and weight outcome favoured those who were less deprived. This supports findings from trials of other behavioural interventions (such as those targeting smoking cessation), in which attrition is higher or intervention adherence is lower in those who are more deprived.^{313–316}

The findings in this review relating to inequalities in behavioural weight management interventions by race or ethnicity are broadly similar to previously conducted systematic reviews that were identified. I found that few studies reported if there was differential

adherence or outcome by race or ethnicity, supporting the findings of Tussing-Humphreys et al., and Haughton et al.,^{172,174} I did not have sufficient evidence to support Tussing-Humphreys et al., and Kong et al's., findings that behavioural weight management interventions led to less weight loss and more weight regain in African American women.^{169,174} This may have been due to the different inclusion criteria used across the reviews, leading to variation in the studies included (17 studies in the Tussing-Humphreys review, 103 in this review).

There are several factors by which discrimination or differential health outcomes may occur that were either not captured at all, or were only partially captured, in this review. Some factors, such as sexual orientation, were not measured in any of the 103 trials included in my review. This is despite there being known inequalities in weight by sexual orientation. For example, women who identify as lesbian are more likely to have overweight or obesity than women who identify as heterosexual.^{317,318} The NHS in England has highlighted the need for further research to gain a better contextual understanding of weight issues in this group.³¹⁹ Other factors that discrimination or differential health outcomes can occur by, such as gender and social capital, were only captured in a limited way. For example, gender was predominantly recorded in trials as either male or female, which does not reflect the full gender spectrum. Similarly, despite its broad definition, social capital was only captured in trials as marital status, meaning that the full nature of people's personal support networks was not captured. Additionally, depending on the categorisation of marital status, this measure may not reflect contemporary attitudes towards relationships and marriage. Similarly, my consideration of several PROGRESS-Plus characteristics, such as Place of Residence (Urban vs Rural), was binary, which loses detail in the complexity of people's circumstances and living arrangements. Future trials should consider broader categorisations of factors, such as of gender, to ensure demographic information fully represents how participants wish to identify.

Due to heterogeneity in intervention types and measures of the PROGRESS-Plus criteria, such as country-specific measures of socioeconomic status or ethnicity, in discussion with my supervisors I decided that it was not appropriate to conduct a meta-analysis. Some of this heterogeneity can be overcome by accessing individual-level participant data and conducting data harmonisation, as demonstrated in Chapters 3-5 of this thesis. Otherwise, I suggest that

future research should identify if a common range of measures covering the PROGRESS-Plus criteria could be reported across trials of behavioural interventions, as well as identifying key stages of a trial (such as trial uptake, intervention adherence and outcome) for which differences in these measures should be reported. Whilst reporting common measures across key stages of a trial will not overcome the issue that most trials may not have sufficient statistical power to identify if inequalities are present, more consistent reporting would facilitate future meta-analyses that could address inequalities-focused research questions.

2.6.2 Strengths and limitations

This systematic review is the most comprehensive review investigating the association between indicators of inequality and behavioural weight management interventions published to date. In particular, it is the first to investigate the impact of inequalities at several stages of an intervention (such as trial or intervention uptake and follow up). Utilising the PROGRESS-Plus criteria ensured a comprehensive examination of inequality beyond the individual measures (such as SES¹⁰² or gender¹⁷⁵) that previous reviews have focused on. In using ‘publication families’,¹⁹¹ I endeavoured to capture all papers published from each included trial. Furthermore, I also contacted authors of trials included in this review to request any missing relevant data, aiding the completeness of my data collection.

Despite the usefulness of Harvest plots in graphically synthesising information across studies that cannot be meta-analysed, they are unable to overcome the limitation of low statistical power of the individual studies in detecting differential effects of interventions. This is pertinent when considering the impact inequalities have on trial/intervention uptake, adherence, attrition and effectiveness, as studies are generally only sufficiently powered to detect a significant difference in weight outcomes between the intervention and control groups. This is likely attributable, in part, to analyses of inequalities rarely being part of the main analysis plan and such analyses often being performed post-hoc. A large number of the included studies had a relatively small sample size (e.g., 41 studies had 0-200 participants). This may explain why a large number of studies included in the Harvest plots found no inequality gradient for any of the outcomes I studied. It may be that an inequalities gradient is present in some of these studies, but there was insufficient statistical power to detect it. In

the next chapter, I address this limitation by using individual participant data meta-analysis. In individual participant data meta-analyses, data from studies using different measures of an inequality criterion (such as SES) can be harmonised and pooled, providing greater statistical power to detect significant differences in uptake, adherence, attrition and intervention effectiveness.

A further limitation of this review is that, although I took a comprehensive approach to considering various indicators of inequality and their interaction with behavioural weight management interventions, I did not consider weight status (e.g. higher BMI category vs lower BMI category) as a factor where differential uptake, adherence, attrition or effectiveness may occur. Higher weight status is associated with increased weight stigma, which is linked to worse mental and physical health, and healthcare avoidance.^{80,320–324} Therefore, inequalities in behavioural weight management interventions may also exist in this group. Furthermore, this review only included studies from high-income (OECD) countries, meaning that the results cannot be extrapolated to low- and middle-income countries. Similarly, by using a minimum BMI cut-off of 25 kg/m², I may have excluded a number of studies conducted across Asia-Pacific countries which typically use lower BMI cut-offs for overweight (23-24.9 kg/m²) and obesity (≥ 25 kg/m²).³²⁵

2.6.3 Conclusion

In this review, I found that most trials of behavioural weight management interventions did not consider whether inequalities in trial or intervention uptake, adherence, trial attrition or weight outcomes occurred by a measure of the PROGRESS-Plus criteria. This is likely to have been because analyses of inequalities in trials are often post-hoc and are not commonly included in the main analysis plan of a trial, as randomised controlled trials are generally only sufficiently powered to detect an interaction between trial arm and the primary outcome. In studies that did conduct such analyses, most did not find evidence that an inequalities gradient was present. In the studies that did find a gradient, they mostly found that the intervention favoured those who were 'more advantaged' for uptake, adherence, and trial attrition. However, this was not the case for weight outcomes at 12-month follow up, where there was a more equal balance between trials favouring more and less advantaged groups.

These findings may suggest that behavioural weight management interventions are equitable for those who reach the 12-month follow up.

In Chapters 3-5, I use meta-analysis of individual participant data to overcome some of the limitations of this systematic review, such as insufficient statistical power, in order to better understand if inequalities in behavioural weight management occur. Chapter 3 describes the methods for this IPD meta-analysis.

Chapter 3 An individual participant data meta-analysis of inequalities in the attendance at and effectiveness of behavioural weight management interventions - Methods

The protocol for the individual participant data meta-analysis presented in Chapters 3-5 was published with the following citation: Birch JM, Mueller J, Sharp SJ, Logue J, Kelly MP, Griffin SJ, Ahern AL (2022). Are there inequalities in the attendance and effectiveness of behavioural weight management interventions for adults in the UK? Protocol for an individual participant data (IPD) meta-analysis. BMJ Open. 13(3). doi:10.1136/bmjopen-2022-067607

In Chapters 3-5 I present the methods and results of an individual participant data meta-analysis of inequalities in the attendance at and effectiveness of behavioural weight management interventions in adults using data from UK-based RCTs. Chapter 3 outlines the methods used to identify relevant trials and to acquire the individual participant data. In section 3.4, I describe the trials meeting the eligibility criteria for inclusion in the IPD-MA and the trials I successfully acquired individual participant data for. The results are presented and discussed in Chapters 4 and 5. Chapter 4 includes the analyses of inequalities in intervention attendance and Chapter 5 inequalities in weight change.

3.1 Contributions

I designed this study with Dr Amy Ahern, Prof Simon Griffin, and Prof Mike Kelly. I extracted the relevant UK-based trials from the systematic review in Chapter 2 and performed the updated literature search. I conducted the title/abstract and full-text screening in duplicate with Dr Rebecca Jones. Prof Jennifer Logue provided a template for requesting individual participant data and contributed to protocol development. I led the development of the statistical analysis plan with input from Dr Julia Mueller and Mr Stephen Sharp.

3.2 Background

In my systematic review presented in Chapter 2, I was unable to perform a quantitative synthesis of the reported results. Therefore, I determined that it was not possible to fully explore inequalities using aggregated data from published literature alone.

This lack of reporting may have occurred because individual trials may not be large enough to detect an interaction between moderators such as socioeconomic status [SES] and the outcome; they are likely just to have been designed to detect an overall effect. This limitation can be addressed by conducting a meta-analysis of individual participant data, which requires the central collation, aggregation and re-analysis of individual participant data from relevant trials.^{179,180} This allows for data in each study to be analysed and defined in a uniform way, overcoming heterogeneity issues associated with using aggregate data. Meta-analysis of individual participant data may provide sufficient statistical power to consider whether there are inequalities in uptake, attendance and effectiveness of interventions.^{179,181}

Furthermore, it is also likely that a meta-analysis has yet to be conducted due to heterogeneity in the way the PROGRESS-Plus characteristics are reported across trials; ethnicity, for example, is reported differently across different countries (e.g., the USA versus the UK) and within countries (e.g., binary versus census categories in the UK). An individual participant data meta-analysis [IPD-MA] can partially overcome this limitation by facilitating uniform recoding and analysis of data across trials. However, it is not possible to completely remove this heterogeneity in an IPD-MA, as not all data can be harmonised in a way that logically would allow them to be pooled. Therefore, to better facilitate data harmonisation I focused the IPD-MA on a single country – the UK.

3.3 Aims

The aims of this IPD-MA were to:

- Quantify to what extent attendance at behavioural weight management interventions differs by individual characteristics that stratify health opportunities and outcomes?

- Quantify to what extent the effectiveness of behavioural weight management interventions differs by individual characteristics that stratify health opportunities and outcomes?
- Quantify to what extent the weight outcomes of those who have participated in a behavioural weight management trial differs by individual characteristics that stratify health opportunities and outcomes?

This Chapter describes the methods I used for the IPD MA and summarises the characteristics of the included trials, the PROGRESS Plus criteria I obtained data for, and how these data were harmonised.

3.4 Methods

3.4.1 Trial identification

3.4.1.1 Search strategy

This study includes UK-based trials of behavioural weight management interventions that I identified through a previous systematic review (Chapter 2),¹⁸⁷ and through an updated search. I focused on UK-based trials to reduce heterogeneity in measures of the PROGRESS-Plus characteristics and in the context in which the interventions were delivered. Characteristics such as ethnicity and socioeconomic status are conceptualised differently in different countries, which makes synthesising data across these characteristics inappropriate or not possible. For example, socioeconomic status in the UK is often captured using Indices of Multiple Deprivation (IMD), an area-based measure, which is not replicated in other countries. There are also pragmatic reasons for focusing on UK-based trials; the complexity of arranging cross-country data sharing may have made the timelines for this project unviable within the timeframe of my PhD.

Studies published since the search strategy in the systematic review was conducted were identified through an updated Medline search and through discussions with the corresponding authors of the included trials. The inclusion and exclusion criteria that were used to identify relevant trials for this IPD meta-analysis are:

1. Participants: adults aged 18 years and over with overweight or obesity (body mass index [BMI] > 25 kg/m² with no upper limit) who were deemed suitable (either by the applicable study team or healthcare practitioner) for weight loss or weight loss maintenance intervention. Participants may have additional risk factors such as hypertension, dyslipidaemia, impaired glucose tolerance or impaired fasting glucose. Studies were excluded if the population was not selected based on a weight-related measure, included participants with BMI < 25 kg/m², were selected based on having a chronic disease where weight loss is part of disease management or being pregnant, or if the intervention was targeted at parents to change behaviour of children. Only studies conducted in the UK were eligible.
2. Interventions: behavioural weight management interventions with the primary aim of supporting weight loss or weight loss maintenance. Studies were included if they were conducted in, or were applicable to, primary care settings. Interventions may have been delivered alone or as part of a wider multi-component intervention targeting diet and nutrition, physical activity, sedentary behaviour, or any combination of these. Interventions may include, but were not limited to, assessment with feedback, advice, provider training, goal-setting, or exercise referral. Studies of pharmacological and surgical interventions were excluded unless the trial included behavioural only and control arms. Interventions were considered feasible for application to primary care if they were conducted in a healthcare setting or were widely available in the community at a national or regional level (such as commercial weight loss programmes, text-message and other digital-based interventions); examples of settings that are not relevant to primary care include interventions delivered in inpatient settings, or in residential care homes.
3. Comparators: wait-list control, usual care, or minimal intervention (such as generic print or electronic materials).
4. Outcomes: studies must have reported weight change in kilograms at a time point between a 12- or 18-month follow up.
5. Study designs: randomised or cluster-randomised controlled trials [RCTs].

3.4.2 Study outcomes, exposures and covariates

3.4.2.1 Outcomes

Outcomes were weight (kg) at 12-month follow up (Chapter 5) and intervention attendance (Chapter 4). Attendance was considered as the percentage of offered sessions which were attended. Further information on the outcomes is outlined in the relevant chapters.

3.4.2.2 Exposures

Exposure variables were measures of the PROGRESS-Plus criteria where data were available in the eligible UK-based trials of behavioural weight management interventions. Coding of each exposure variable depended on the variables and coding used in each study providing individual participant data; the data provided and coding used in the analyses are shown in section 3.5.

3.4.3 Risk of bias assessment

I used Cochrane's risk of bias tool for randomised controlled trials (RoB 2) to assess the risk of bias in all studies meeting the inclusion criteria.³²⁶ The tool facilitates researchers to consider bias across six domains: the randomisation process; allocation concealment; participant and trial personnel blinding; blinding of outcome assessment; incomplete outcome data; and selective reporting. A rating of 'low risk', 'high risk', or 'unclear' was assigned to each domain by myself and a colleague (Dr Rebecca Jones). Where disagreements occurred, these were resolved by discussion to reach consensus. The results of the risk of bias assessment are presented in a summary figure outlining a study's overall risk of bias in addition to the risk of bias in each domain in section 3.5.

3.4.4 Data collection and management

The approach taken to collecting and aggregating the individual participant data was informed by the PRISMA-IPD extension and previously published IPD meta-analysis protocols.^{179,327–330}

3.4.4.1 Invitation of authors

Trial investigators of all eligible trials were invited by email, using contact details acquired through trial publications, to contribute data and collaborate on this study. The email outlined my research aims and the specific data I was requesting.

3.4.4.2 Data collection

Standardised data specification forms were sent to trial authors. These forms highlighted the preferred variable names and coding for data transfer, though I accepted the data in any format to increase convenience for the trial collaborator. Once received, a master copy of each trial dataset was saved in its original format and preserved. Any non-Microsoft Excel format datasets were converted and then imported into Stata version 17 (StataCorp. 2021. Stata Statistical Software: Release 17.). I asked for detailed definitions of the variables in each individual trial so that appropriate harmonisation could be completed.

3.4.4.3 Data checking

Once data were received from trial authors, a colleague (Dr Julia Mueller) and I checked for quality and to ensure they pertain to the correct trial. Descriptive statistics (sample size, demographic variables, weight loss or BMI change) were generated for each individual trial; where discrepancies occurred between my analysis and the original trial publication, the study authors were contacted for clarification. If the discrepancy was small and unlikely to bias the results, then the data were included in the IPD meta-analysis. Large data inaccuracy and excessive missing data (versus what is reported in the trial publication) may have led to a trial being excluded.

3.4.4.4 Contingency for when individual participant data could not be acquired

If I was unable to obtain the individual participant data for an eligible trial, I asked the trial investigator if they were able to conduct the analyses using the same coding of variables as defined in section 3.5.2 and provide me with the outcome statistics. I offered this as an option to ensure that I could include as much relevant data as possible. Where I synthesised results from datasets for which I did not receive individual participant data for, I conducted sensitivity analyses excluding these data to consider the impact including these data had on the results.

Further sensitivity analyses excluding studies scoring a 'high' risk of bias were also planned but as no trials scored 'high' risk these analyses were not conducted.

3.4.5 Statistical analysis

The statistical analyses used for research question 1 are outlined in Chapter 4 (section 4.4) and for research questions 2 and 3 in chapter 5 (section 5.4).

3.4.5.1 Two-stage IPD-MA approach

As my research questions explored differential attendance (Chapter 4), treatment effect and covariate interactions (Chapter 5) and differential weight change in the trial cohort (Chapter 5), I decided that a two-stage IPD meta-analysis would be most appropriate. In the first stage, regression analyses are performed individually in each trial. Then in the second stage, the outcome estimates from each model are combined (i.e. synthesising data across trials) using a standard meta-analysis approach (e.g. random-effects meta-analysis).³³¹ I used a two-stage approach because it inherently avoids aggregation bias and controls for trial-level confounding, to which one-stage IPD meta-analyses are more susceptible.³³¹ An additional benefit of performing a two-stage IPD meta-analysis is that trials for which I was unable to acquire individual-level data may still be included in the synthesis provided the relevant outcome statistics can be obtained. Data analysis was conducted using Stata v17 (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC.).

3.4.5.2 Analysis of study outcomes

I initially planned six sets of analyses (two for each of my research questions), where data on weight loss interventions would be analysed separately to data for weight loss maintenance interventions. However, as I was not able to acquire data from any behavioural weight loss maintenance trials (as highlighted in section 3.5), I only analysed data from weight loss trials.

The subgroups used for each exposure variable are listed below (reference subgroup in bold). If free-text responses were available for any 'other' subgroup for each exposure, I recoded to the most appropriate subgroup in that exposure. If this was not possible, I recoded 'other' to missing. 'Prefer not to say' responses were also recoded to missing. I anticipated that certain

subgroups of some variables would likely have few, if any, data. These were recoded to missing and excluded from the analyses.

- Ethnicity (**White**/Ethnic minorities (excluding White minorities))
- Occupation (Unemployed/**Employed**/Unable to work/Retired/Student)
- Gender (**Female**/Male/Other or Non-binary)
- Religion
- Education (No formal qualifications/**GCSEs, O-Levels, or equivalent**/A-Levels or equivalent/Some additional training/University degree)
- Index of Multiple Deprivation (**1 – Most deprived**/2/3/4/5 – Least deprived)
- Household income (<**£40,000**/≥£40,000)
- Relationship status (Single/**Married or co-habiting**/Widowed, separated, or divorced)
- Age (continuous)
- Randomised group (**Control**/Intervention)

3.4.5.3 Missing data

A complete-case analysis was performed, i.e. participants who have missing data for either the outcome, exposure or covariates will be excluded. I analysed whether having outcome data at 12-month follow up was associated with the PROGRESS-Plus characteristics using chi-square tests.

3.4.5.4 Sensitivity analyses

As highlighted in 2.4.4, I conducted sensitivity analyses excluding the results of studies I did not receive individual-level data. Sensitivity analyses excluding studies with ‘high’ risk of bias were also conducted to consider whether these studies have an impact on the results.

3.4.6 Ethics

Ethical approval was not required for this study as no primary data were collected, and the individual participant data were analysed in accordance with the purpose for which they were originally collected. Ethical approval for each eligible trial for this IPD-MA was obtained by the original investigators of each trial.

3.5 Results

3.5.1 Eligible and included trials

Seventeen trials from my previous systematic review met the inclusion criteria for the IPD-MA.^{204–207,214,215,217,219,227,233,261,266,290,298,301,304,332} The results at each stage of the updated database search are shown in Figure 3-1. I identified 212 unique records at the first stage, which was reduced to four potentially eligible articles following title/abstract screening. Once the full-texts of these four articles were accessed, I determined two of the articles to be trials meeting the inclusion criteria of the IPD-MA.^{333,334} This meant there were 19 eligible trials in total; 16 were trials of behavioural weight loss interventions^{204–207,214,215,217,219,227,233,261,266,290,332–334} and three were trials of behavioural weight loss maintenance interventions^{298,301,304} (overview of each trial shown in Table 3-1). I acquired individual level data for twelve out of sixteen eligible weight loss trials.^{204–207,214,215,217,227,233,261,332,334} A collaborator conducted the analyses and reported the results for inclusion in meta-analysis in one further trial.²¹⁹ I was unable to access the data or obtain results of the analysis for two weight loss trials meeting the inclusion criteria.^{266,290} I was unable to obtain individual level data, or receive aggregate-level results, for the three weight loss maintenance trials. Therefore, the IPD-MA includes the weight loss trials only.

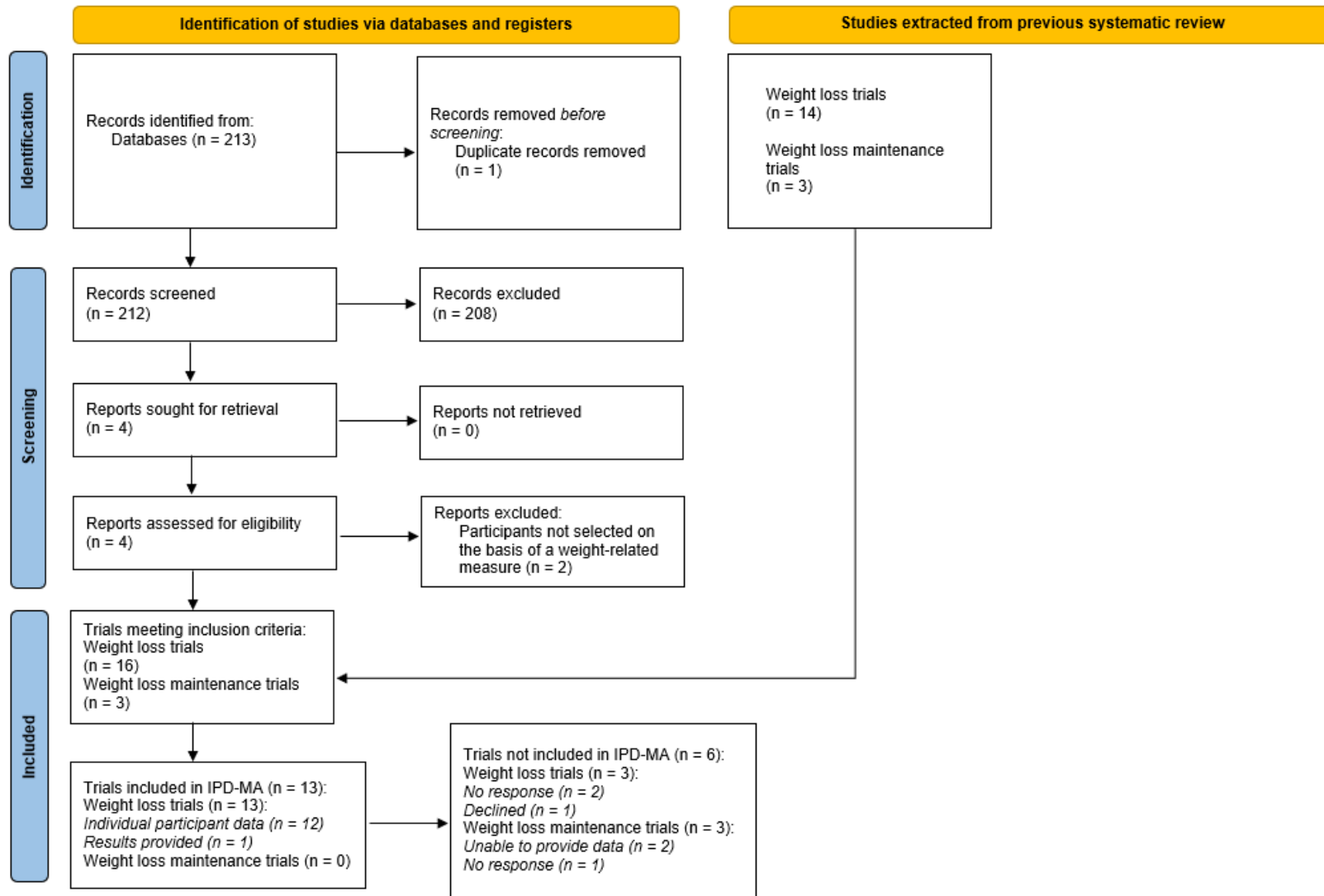


Figure 3-1 PRISMA study selection flow diagram

Table 3-1 Summary of eligible studies for inclusion in IPD meta-analysis

Study name (first author)	Year published	Intervention group description	Control group description	Participant eligibility criteria
WRAP (Ahern)	2017	Participants were given vouchers to attend WW (previously Weight Watchers) meetings once a week and access WW digital tools for the duration of their intervention (12- or 52-weeks) for free.	A printed booklet of self-help weight-management strategies (British Heart Foundation).	Inclusion: Aged ≥ 18 years and BMI ≥ 28 kg/m ² . Exclusion: Planned or current pregnancy, previous or planned bariatric surgery, current participation in a weight-loss programme, having an eating disorder, non-English speaking.
BeWEL (Anderson)	2014	12-month intervention delivered by trained lifestyle counsellors in 3 x 1-hour one-to-one visits during the first 3 months, followed by 9 monthly 15-minute telephone conversations, leading to a total contact time of 5.25 hours.	A printed booklet of self-help weight-management strategies (British Heart Foundation).	Inclusion: Aged 50 to 74 years, had undergone polypectomy for adenoma, and BMI >25 kg/m ² . Exclusion: Pregnancy, insulin dependent diabetes mellitus, and any cancer diagnosis.
BWeL (Aveyard)	2016	General Practitioners offered participants referral to a commercial weight management programme of 12 1-hour sessions (Slimming World, Rosemary Conley) and gave vouchers to allow them to attend for free.	General Practitioners advised participants to lose weight	Inclusion: Aged ≥ 18 years, BMI ≥ 25 kg/m ² (if Asian ethnicity) or BMI ≥ 30 kg/m ² (if other ethnicities), have a raised body fat percentage. Exclusion: Planned or current pregnancy, previous bariatric surgery, completed or participating in a weight management programme within previous 3 months, non-English speaking.
Ten Top Tips [10TT] (Beeken)	2017	10TT was a self-guided leaflet-based intervention that used habit-formation theory to aid weight loss.	Usual care, dependent on the participant's General	Inclusion: Aged ≥ 18 years, BMI ≥ 30 kg/m ² .

		A logbook was provided for participants to self-monitor target behaviours.	Practitioner. May include dietary advice or referral to a commercial programme.	Exclusion: Unable to provide informed consent due to mental incapacity or active psychotic illness, pregnant, or terminally ill.
PODOSA (Bhopal)	2014	15 visits from a dietitian over 3 years, where the dietitian would advise participants on achieving weight loss through culturally adapted and translated resources.	4 visits from a dietitian over 3 years where standard advice on healthy eating, diabetes prevention and physical activity was given.	<p>Inclusion: Aged ≥ 35 years, self-identified men and women of Indian or Pakistani origin with waists measuring ≥ 90cm (men) or ≥ 80cm (women), impaired glucose tolerance or impaired fasting glucose tolerance, the family cook was cooperative.</p> <p>Exclusion: Receiving long-term oral corticosteroids or weight loss medication, having long-term health disorders making adherence improbable, pregnant, and unlikely to remain in the UK for 3 years.</p>
Waste the Waist (Greaves)	2015	4 x 2-hour group-based sessions in the first month to support behaviour change for weight loss, then 5 x 90-minute group sessions over the next 8 months to support maintenance of behaviour change, totalling 13.5 hours of contact time.	Participants were provided written information on the effects of diet and physical activity on cardiovascular risk.	<p>Inclusion: Aged 40-74 years, BMI ≥ 28 kg/m², and having a high cardiovascular risk defined using either the Framingham or QRISK2 algorithm.</p> <p>Exclusion: Existing heart disease, type 2 diabetes mellitus, BMI > 40 kg/m²,</p>
Football Fans in Training (Hunt)	2014	12 weekly sessions of 90-minutes in length, delivered at 13 Scottish professional football club stadiums. Each 90 min session combined	12 month waiting list to receive the FFIT intervention.	Inclusion: Men, aged 35-65 years, BMI ≥ 28 kg/m ² , completed physical activity readiness questionnaire, not taken part in FFIT previously.

		advice on healthy diet with physical activity. The balance of classroom and physical activity sessions changed during the 12 weeks; later weeks focused on physical activity as men became fitter, and the shorter classroom sessions focused on revision. The 12-week active phase was followed by a weight maintenance phase with six post-programme email prompts during 9 months and a group reunion at the club 6 months after the end of the sessions.		Exclusion: Blood pressure that contraindicated vigorous exercise (systolic ≥ 160 mm Hg or diastolic ≥ 100 mm Hg) were excluded from the more intense physical activity programme sessions.
(Jebb)	2011	Participants were given vouchers to attend WW (previously Weight Watchers) meetings once a week for 12 months and access digital tools for free.	Advice from their GP and other standard care in line with national treatment guidelines.	<p>Inclusion: Aged ≥ 18 years, BMI 27-35 kg/m², and at least one risk factor for obesity related disease (such central adiposity, type 2 diabetes mellitus without insulin treatment, family history of diabetes).</p> <p>Exclusion: Achieved weight loss of ≥ 5kg in previous 3 months, history of clinically diagnosed eating disorder, orthopaedic limitations preventing regular physical activity, untreated thyroid disease or more than one change in thyroid treatment in the previous 6 months; receiving treatment with effects on weight or appetite; gastrointestinal disorders; previous surgical procedure for weight loss; major surgery in the previous 3 months;</p>

				<p>pregnancy or lactation; insulin-treated diabetes; diabetes diagnosis in the previous 6 months; glycated haemoglobin (HbA1c) of at least 75 mmol/mol (9.0%); heart problems in the previous 3 months; uncontrolled hypertension; new prescription drug for a chronic disorder in the previous 3 months or change in dose in the previous 1 month; history or presence of cancer, with the exception of completely resected basal or squamous cell carcinoma if treatment completed 6 months before enrolment or if treatment was stable; or participation in another clinical trial in the previous 30 days.</p>
Lighten Up (Jolly)	2011	In addition to 12 vouchers for free entrance to a local leisure centre, participants were randomised to one of 7 intervention groups (all 12 weeks in length): Weight Watchers, Slimming World, Rosemary Conley, Size Down, GP-led one-to-one counselling, pharmacy-led one-to-one counselling, or a choice of any of the six intervention programmes.	12 vouchers for free entrance to a local leisure centre.	<p>Inclusion: Registered with general practices in the South Birmingham Primary Care Trust, aged ≥ 18 years, had a raised BMI recorded in primary care notes within previous 15 months (White Europeans and all ethnic groups apart from South Asians with no comorbidities BMI $30 \geq \text{kg/m}^2$, White Europeans and all ethnic groups apart from South Asians with comorbidities BMI $28 \geq \text{kg/m}^2$, South Asians with no comorbidities $25 \geq \text{kg/m}^2$, South Asians with comorbidities $23 \geq \text{kg/m}^2$).</p> <p>Exclusion: Unable to understand English or were pregnant.</p>

POWeR+ (Little)	2016	<p>Two intervention groups, both consisting of a 24-session web-based weight management programme lasting 6 months.</p> <p>POWeR+F provided three scheduled (and four optional) face-to-face nurse support sessions.</p> <p>POWeR+R included three phone or email contacts and two optional phone or email contacts.</p>	Brief advice web-pages for a healthier diet.	<p>Inclusion: Aged ≥ 18 years and BMI ≥ 30 kg/m² or more (or ≥ 28 kg/m² with hypertension, hypercholesterolaemia, or diabetes).</p> <p>Exclusion: Severe mental health problems, too ill to participate in the study or unable to change diet due to health, pregnant or breastfeeding, perceived inability to walk 100m, another member of household participating, no regular access to the internet.</p>
(Moore)	2003	Intervention was targeted at general practitioners and practice nurses, and the unit of randomisation was primary care practice. The intervention consisted of 3x90-minute sessions that trained the practitioners on a model approach to obesity treatment.	Control practices were asked to provide usual care to patients.	Inclusion: Aged 16-64 years and BMI ≥ 30 kg/m ² .
CAMWEL (Nanchahal)	2012	One-to-one programme delivered across 14 visits over 12 months by advisors trained in obesity causes, diet and physical activity, behaviour change strategies, motivational interviewing and cognitive behavioural therapy techniques.	Usual care.	Inclusion: Aged ≥ 18 years and BMI ≥ 25 kg/m ² .
EDIPS (Penn)	2009	Participants received regular individual advice from a dietitian and physiotherapist trained in	Brief advice and usual care from GP.	Inclusion: Aged >40 years, BMI > 25 kg/m ² , and impaired glucose tolerance of ≥ 7.8 mmol/l and < 11.1 mmol/l.

		<p>motivational interviewing. Participants were also invited to group events, such as 'cook and eat'. Individual sessions were for 30 minutes monthly for the first 3 months and then every 3 months for up to 5 years.</p>		<p>Exclusion: Previous diagnosis of diabetes mellitus, chronic illness that makes participation in moderate physical activity impossible, or on a special diet for medical reasons.</p>
DROPLET (Astbury)	2018	<p>The intervention was a Total Diet Replacement programme, which consisted of weekly behavioural support for 12 weeks and monthly support for 3 months with formula food products providing 810 kcal per day for the first 8 weeks, followed by gradual reintroduction of food.</p>	<p>Behavioural support for weight loss from a practice nurse and a diet programme with modest energy restriction.</p>	<p>Inclusion: Aged ≥ 18 years, BMI $\geq 30\text{kg/m}^2$, and participants' GP determines weight loss would benefit health.</p> <p>Exclusion: Scheduled or previously received bariatric surgery, currently participating in a weight management programme, and contraindications to total diet replacement.</p>
Game of Stones feasibility (Dombrowski)	2020	<p>Two intervention groups. Both intervention groups received narrative text messages for 12 months. The text messages were written from the perspective of a fictional character aiming to lose weight over 12 months and targeted towards men from disadvantaged backgrounds. Between 0 and 5 texts were sent a day over 12 months. In addition to this, one intervention group received financial incentives dependent on meeting weight loss targets.</p>	<p>Wait-list control</p>	<p>Inclusion: Men, aged ≥ 18 years, BMI $\geq 30\text{kg/m}^2$ and/or waist circumference of $\geq 102\text{cm}$, owned a mobile phone capable of receiving text messages, understand English, considered by practice clinical staff as suitable for participation (GP practice recruitment only), for example, no severe medical, terminal or psychiatric illness (in patient or close family member) or no significantly impaired cognitive function.</p> <p>Exclusion: Taking part in a weight loss study, planning or waiting to have bariatric surgery, planning to move within 12 months from study baseline.</p>

ActWELL (Anderson)	2021	Twelve-month long intervention based on COM-B model of behaviour change delivered by Breast Cancer Now volunteers. There were two one-to-one sessions in first 12-weeks of the intervention and 9 x 15-minute support calls over the following nine months.	Brief advice leaflet.	<p>Inclusion: Attending, or invited to attend, routine breast screening clinics (not recall clinics), BMI > 25kg/m², age 50 to 70 years.</p> <p>Exclusion: Undergoing treatment for any malignant condition (excluding certain skin cancers), reported contra-indications to physical activity or weight loss, on a specialised medical diet, diagnosis of T1 diabetes, current use of insulin, no telephone contact, unable to consent.</p>
NULevel (Sniehotta) <i>Weight loss maintenance</i>	2019	Intervention was delivered via a combination of a single face-to face meeting and regular text messaged (at least 1 every 2 days). The text messages consisted of content that was triggered by participants daily self-weighing and questionnaire completion.	Brief lifestyle advice received by text message on 4 occasions, 3 months apart.	<p>Inclusion: Aged ≥ 18 years, BMI ≥ 30kg/m² (≥ 28kg/m² if of South Asian descent) in the 24 months preceding trial, and had lost $\geq 5\%$ of body weight in the preceding 12 months.</p> <p>Exclusion: Lost weight through illness or surgical procedures, pregnant or planning to become pregnant during study period, breastfeeding, unable to understand English, diagnosis of an eating disorder or condition that limits physical activity, or plans to leave geographic area during study period.</p>
LIMIT (Daley) <i>Weight loss maintenance</i>	2019	Over the course of a 12-week weight maintenance programme, participants carried out daily self-weighing, received 3 brief support phone calls delivered by non-specialist call centre staff, and text messages sent every other day for	Brief advice leaflet.	Inclusion: Aged ≥ 18 years, had lost $\geq 5\%$ of their weight by the end of their weight loss programme, owned a mobile or landline phone that could receive text messages, was able to understand English sufficiently to complete study procedures.

		the first 4 weeks and twice weekly for the remaining 8 weeks.		Exclusion: Pregnant or intending to become pregnant during the study period.
WILMA (Simpson) <i>Weight loss maintenance</i>	2015	<p>Two intervention groups, both comprising of a 12-month intervention. Participants in both intervention groups could attend 4 peer group support sessions lasting 1.5 hours for 4 months following the face-to-face sessions.</p> <p>Intensive group – participants received 6 one-to-one face-to-face individually tailored motivational interviewing delivered fortnightly for 3 months (each session lasting around 60 minutes). In the remaining 9 months of the intervention, participants received monthly motivational interviewing calls lasting around 20 minutes.</p> <p>Less intensive group – participants received two face-to-face motivational interviewing sessions two weeks apart and two motivational interviewing phone calls at 6 months and 12 months.</p>	Brief advice leaflet.	<p>Inclusion: Aged 18-70 years, current or previous BMI of ≥ 30 kg/m², and intentionally lost $\geq 5\%$ of body weight in previous 12 months.</p> <p>Exclusion: Previous bariatric surgery (unless reversed), terminal illness, inability to understand study materials in English, living with another study participant, or currently pregnant.</p>

3.5.2 Risk of bias in eligible trials

None of the 19 eligible studies were assessed to be at high risk of bias using Cochrane’s RoB 2 tool (Figure 3-2). Twelve studies were determined to be of low risk of bias,^{204–207,290,219,261,304,332,301,298,334} and seven to have some concerns of risk of bias.^{214,215,217,266,227,233,333} All seven studies scoring some concerns of risk of bias did so because they did not have a retrievable pre-specified analysis plan available.


Study ID	D1	D2	D3	D4	D5	Overall	
1.WRAP	+	+	+	+	+	+	 Low risk  Some concerns  High risk
2.BeWEL	+	+	+	+	+	+	
3.BWeL	+	+	+	+	+	+	
4.10TT	+	+	+	+	+	+	
5.PODOSA	+	+	+	+	+	+	D1 Randomisation process
6.Waste the Waist	+	+	+	+	!	!	D2 Deviations from the intended interventions
7.FFIT	+	+	+	+	!	!	D3 Missing outcome data
8.Jebb 2011	+	+	+	+	!	!	D4 Measurement of the outcome
9.Lighten Up	+	+	+	+	+	+	D5 Selection of the reported result
10.POWeR+	+	+	+	+	+	+	
11.Moore 2003	+	+	+	+	!	!	
12.CAMWEL	+	+	+	+	!	!	
13.EDIPS	+	+	+	+	!	!	
14.NULevel	+	+	+	+	+	+	
15.DROPLET	+	+	+	+	+	+	
16.LIMIT	+	+	+	+	+	+	
17.WILMA	+	+	+	+	+	+	
18.Game of Stones	+	+	+	+	!	!	
19.ActWELL	+	+	+	+	+	+	

Figure 3-2 Risk of bias assessment (Cochrane RoB 2 tool)

3.5.3 PROGRESS-Plus characteristic reporting and harmonisation

Details of the data available from each trial are summarised in Tables 3-2 and 3-3. Across all the trials included in the analyses, there were 7221 participants, of which complete case data were available for 5064 participants; 94% of participants were of a White ethnicity, 57% of

participants were female, the mean age was 54 years, 28% were from the least deprived quintile, and 11% from the most deprived quintile based on the Index of Multiple Deprivation. Participants of a White ethnicity and older participants had greater odds of having complete case data available; there was no evidence of attrition by area-level deprivation or gender.

Table 3-2 Characteristics of eligible (n=19) and included (n=12) studies in the IPD-MA

Study Characteristic	Number (%)
Intervention type	
Weight loss	16 (84)
Weight loss maintenance	3 (16)
Country	
United Kingdom	19 (100)
Individual participant data available	
Weight loss studies	12 (63)
Weight loss maintenance studies	0 (0)
Analyses conducted by collaborator (individual participant data not accessible)	
Weight loss	1 (5)
Weight loss maintenance	0 (0)
Data available	
Weight loss	13 (100)
Weight loss maintenance	0 (0)
Weight change outcome	13 (100)
Attendance	5 (38)
Place of residence	1 (8)
Ethnicity	12 (92)
Occupation	6 (46)
Gender/sex	13 (100)
Religion	0 (0)
Education	8 (62)
Social capital (relationship status)	2 (15)
Socioeconomic status (IMD and Scottish IMD)	11 (85)*
Socioeconomic status (annual household income)	2 (15)
Age	13 (100)*

*One study (10TT) coded SES and age differently from other studies, and it was not possible to harmonise these variables and include 10TT in the meta-analyses for these characteristics

The nature of how each PROGRESS-Plus characteristic was captured in each individual trial is shown in Table 3-3. Following the production of this table, I discussed the capturing of the PROGRESS-Plus characteristics with my supervisors (Dr Amy Ahern, Prof Simon Griffin and Prof Mike Kelly). In these conversations, we discussed how the coding of each characteristic could be harmonised across trials in the most appropriate way – the harmonised coding for each variable is presented in the bottom row of Table 3-3. This involved a trade-off between maximising the amount of data available for each characteristic versus retaining precision by having more subgroups in a variable. For example, I decided the ethnicity harmonised variable was to be coded as binary (White [including White minorities]/Ethnic minority) because 1) I received the data from two studies in this form and 2) there was heterogeneity in the ethnic groups captured between trials that would have made analyses severely underpowered.

There are limitations with this approach; these are discussed in the overall strengths and limitations section in Chapter 8 at the end of this thesis, but primarily concern the fact that there are significant social and cultural differences between different ethnic minority groups that are not reflected when grouping them as ‘ethnic minority’ for analyses. For socioeconomic status (IMD) and age, I decided to exclude one trial (10TT, Beeken et al.,) from the analyses as the data were not categorised in at least quintiles (for IMD) or continuous (for age). For IMD, this meant that the tertiles used in 10TT could not be harmonised with the quintiles or deciles used in the remaining trials. For age, I received this in ten-year increments for 10TT; to replicate this across the remaining trials would have lost some precision and required me to make arbitrary judgements as to decades of age.

Table 3-3 Capturing of PROGRESS-Plus characteristics in each individual trial and overall harmonised variables

Study	Place of residence	Ethnicity	Occupation	Gender/ sex	Religion	Education	Social capital	Socioeconomic status	Plus
Ahern 2017 (WRAP)	-	2011 UK census (White-British/White-Irish/White-Other/Chinese/Asian or Asian-British – Indian/Asian or Asian-British – Pakistani/Asian or Asian-British – Bangladeshi/ Asian or Asian-British – Other/Black or Black-British – Caribbean/Black or Black-British – African/Black or Black-British – Other/Mixed – White and Black Caribbean/Mixed – White and Black African/Mixed – White and Asian/Mixed – Other/Other/ Prefer not to say)	Employment status (Unemployed/Self-employed/ Employed by other/Student/ Retired/Unable to work/Other (carer, home-maker, voluntary work)/Prefer not to say)	Sex (Female/ Male)	-	(None/GCSEs or equivalent/ A-Levels or equivalent/Post secondary study/ University degree/Higher degree	Household member using weight loss programme (Yes/No)	English Indices of Multiple Deprivation [IMD] 2010 (continuous rank) Household income (£0-9999 year/£10000-19999 year/£20000-29999/£30000-39999/£40000-49999/£50000-59999/£60000-69999/£70000+ / Don't know/Prefer not to say)	Age (continuous)
Anderson 2014 (BeWEL)	-	2001 UK census (White/Asian or Asian British/Chinese/Mixed/ Black or Black British/Other ethnic	Employment status (Retired/Employed full time/Student full time/Unemployed/ Employed part	Sex (Female/ Male)	-	(Primary school/ Secondary school/Other professional or technical qualification	Marital status (Single/ Married or cohabiting /	Scottish Index Multiple Deprivation [SIMD] 2012 (Quintiles)	Age (continuous)

Study	Place of residence	Ethnicity	Occupation	Gender/sex	Religion	Education	Social capital	Socioeconomic status	Plus
		group/Do not wish to complete)	time/Student part time/Unable to work/Other)			after leaving school/ University degree/Post-graduate degree)	Widowed or separated or divorced)	Household Income (£280 week /£281-480 week/£481-770 week/£1250 month/£1251-2080 month/£2081-3330 month/<£15000 year/£15001-25000 year/£25001-40000 year/>£40000 year/prefer not to say)	
Aveyard 2016 (BweL)	-	2011 UK census (White/Black Caribbean/Black African/Mixed/Black other/Chinese/Indian/Pakistani/Bangladeshi/ Other Asian/Other)	-	Gender (Female/ Male)	-	-	-	English Indices of Multiple Deprivation [IMD] 2010 (continuous rank)	Age (continuous)
Beeken 2017 (10TT)	Location of primary care physician (Urban vs rural)	Binary (White/ethnic minority)	-	Gender (Female/ Male)	-	-	-	English Indices of Multiple Deprivation [IMD] 2010 (terciles)	Age

Study	Place of residence	Ethnicity	Occupation	Gender/sex	Religion	Education	Social capital	Socioeconomic status	Plus
Greaves 2015 (Waste the Waist)	-	All participants were White	-	Gender (Female/Male)	-	(Up to age 16 or less/Up to age 18/Some additional/Undergraduate degree or higher)	-	English Indices of Multiple Deprivation [IMD] 2000 (continuous rank)	Age (continuous)
Hunt 2014 (FFIT)	-	2001 UK Census (White – British/White – Scottish/White – Irish/White – Any other white background/Mixed – White and Black Caribbean/Mixed – White and Black African/Mixed – White and Asian/Mixed – Any other Mixed background/Chinese/Asian or Asian British – Indian/Asian or Asian British – Pakistani/Asian or Asian British – Bangladeshi/Asian or Asian British – Any other Asian background/Black or Black British – Caribbean/Black or Black British – African/Black or Black British –	Employment status (In paid employment or self-employed (or temporarily away)/Doing unpaid work for a business that you own, or that a relative owns/Waiting to take up paid work already obtained/On a Government scheme for employment training/Looking for paid work or a Government training scheme/Intending to look for work but prevented by temporary sickness or	Gender (Male)	-	(No educational qualifications/Standard grades, O grades, O levels, GCE or GCSEs/Highers, advanced highers, A levels/Vocational qualification (e.g. SVQ/SCOTVEC)/HNC/HND/Degree (e.g. BA, BSc)/Post-graduate qualification (e.g. MSc, PhD)/Other	Marital status (Single (never married)/Married/Separated / Widowed/Divorced/Living with someone as a couple (but not married)/Other (including civil partnership))	Scottish Index of Multiple Deprivation [SIMD] 2009 (quintiles)	Age (continuous)

Study	Place of residence	Ethnicity	Occupation	Gender/sex	Religion	Education	Social capital	Socioeconomic status	Plus
		Any other black background/Other ethnic group – Any other)	injury/Permanently unable to work because of long-term sickness or disability /Going to college or university full-time (including on holiday)/ Retired from paid work/Looking after home or family/Doing something else)						
Jebb 2011	-	2001 UK census (Asian or Asian British – Indian /Asian or Asian British – Other/Black or Black British – African/Black or Black British – Caribbean/Mixed – White & Black African/ Mixed – White & Black Caribbean/Other/White – British/White – Irish/ White – Other)	-	Sex (Female/ Male)	-	-	-	-	Age (continuous)
Jolly 2011 (Lighten Up)	-	2001 UK census (White British or Irish/South Asian/Black British, Caribbean or	Employment status (Full time student/ Home carer/ Intermediate/	Sex (Female /Male)	-	-	-	IMD (continuous rank)	Age (continuous)

Study	Place of residence	Ethnicity	Occupation	Gender/ sex	Religion	Education	Social capital	Socioeconomic status	Plus
		African/Mixed and other)	Managerial or Professional/Never worked or long-term unemployed/ Retired/ Routine and manual / Sick or disabled						
Little 2016 (POWeR+)	-	-	-	Sex (Female/ Male)	-	Age left education (continuous)	-	English Indices of Multiple Deprivation [IMD] 2010 (continuous rank)	Age (continuous)
Nanchahal 2012 (CAMWEL)	-	Non-UK census categories (African/Asian Other/Bangladeshi/ Black Other/Caribbean/ Chinese/Indian/Iran/ Mixed Other/Other/ Pakistani/White and Asian/White and Black African/White and Black Caribbean/Irish White/ White British/White Irish/White Other)	Employment status (Employed/ Unemployed)	Gender (Female/ Male)	-	Highest qualification obtained (None/GCSE or equivalent/A-level or equivalent/ Degree level or higher/Other)	-	English Indices of Multiple Deprivation [IMD] 2010 (quintiles)	Age (continuous)
Penn 2009 (EDIPS)	-	Binary (White/Ethnic minority)	-	Sex (Female/ Male)	-	Educational level (Low/Medium/ High)	-	-	Age (continuous)

Study	Place of residence	Ethnicity	Occupation	Gender/ sex	Religion	Education	Social capital	Socioeconomic status	Plus
Astbury 2018 (DROPLET)	-	2011 UK census (White British/White Irish/White Gypsy or Irish Traveller/Other White background/White + Black Caribbean/White + Black African/White + Asian/Any other mixed or multiple ethnic background/Indian/Pakistani/Bangladeshi/Chinese/African/Caribbean/Other Black, African or Caribbean background/Arab/Any other ethnic group)	-	Sex (Female/ Male)	-	-	-	English Indices of Multiple Deprivation [IMD] 2015 (deciles)	Age (continuous)
Anderson 2021 (ActWELL)	-	2011 UK census (White British/White Irish/ Mixed other/Mixed/ Indian/Pakistani/ Chinese/Asian other/ African Caribbean or Black/Other)	Employment (Retired/Unemployed/ Employed full-time/ Employed part-time/ Student full-time/ Student part-time/ Other)	Sex (Female)	-	Highest qualification obtained (Secondary/ Other professional or technical/ University degree)	-	Scottish Index of Multiple Deprivation [SIMD] 2016	Age (continuous)
Harmonised variable	Urban vs rural	White (including white minorities)/ Ethnic minority	Employed/ Unemployed/ Retired/ Student/ Other (sick or unable to work)	Female/ Male	No data	University degree/ Some additional training/ A-levels or	(Marital status) Single/ Married, civil	Quintiles of IMD (1=most deprived – 5=least deprived)	Age (continuous)

Study	Place of residence	Ethnicity	Occupation	Gender/sex	Religion	Education	Social capital	Socioeconomic status	Plus
						<i>equivalent/ GCSEs, O-levels or equivalent/ No formal qualifications</i>	<i>partnership or cohabiting / Divorced, separated or widowed</i>	<i>Household income: ≥£40,000 / <£40,000</i>	

3.6 Discussion

In this third chapter, I presented the methods used for identifying eligible trials for the IPD-MA. Additionally, I described the eligible trials and which PROGRESS-Plus characteristics each trial collected data on and how these data were harmonised. In the methods section in Chapters 4 and 5 I outline the statistical analyses used for the research questions in each Chapter: Chapter 4 focuses on inequalities in attendance at behavioural weight management interventions; Chapter 5 considers inequalities in the effectiveness of the interventions on weight change.

3.6.1 Strengths and limitations

As previously highlighted, there are several strengths of conducting an IPD-MA in comparison to a conventional meta-analysis. IPD-MAs are particularly useful for considering moderators of intervention outcomes,¹⁷⁹ due to the increased statistical power gained by pooling data (although this is not guaranteed for all moderating variables, as it depends on the available data). Harmonisation of variables across studies means more data can be pooled together, leading to more robust analyses and conclusions. The IPD-MA approach provides a more precise answer on the extent of inequalities in behavioural weight management interventions, especially when compared to previous systematic reviews that used narrative synthesis approaches when considering inequalities in intervention attendance or effectiveness.^{102,145,167,178,187} A further strength of IPD-MAs is that they go beyond published data, which may be limited in the measures reported. Receiving the original trial data also allows for increased data checking and increased validation of previously published results.¹⁸⁰

However, there are also limitations of conducting an IPD-MA. Even though the raw trial data was acquired, analysis was dependent on the measures assessed in each original trial, and may be limited. Data harmonisation that is required to conduct an IPD-MA may lead to some data being excluded from the analyses as it is unlikely to be possible to harmonise all data from different measures of each PROGRESS-Plus characteristic. A further limitation is that the estimates of inequality are influenced by the distribution of characteristics within each study. For example, studies with a narrow age range might not identify interactions between intervention effects and age. Finally, we are only looking at UK-based trials of behavioural

weight management interventions, which may limit the generalisability of these findings to other countries or healthcare systems.

Chapter 4 Inequalities in attendance at behavioural weight management interventions: IPD-MA results

A manuscript containing the results of Chapters 4 and 5 will be submitted for publication with the citation: Birch JM, Mueller J, Sharp SJ, Kelly MP, Damery S, Jones RA, Logue J, Anderson AS, Astbury NM, Aveyard P, Beeken RJ, Craigie AM, Greaves C, Jebb SA, McConnachie A, Nanchahal K, Stuart B, White M, Griffin SJ, Ahern AL. Are there inequalities in the attendance to and effectiveness of behavioural weight management interventions for adults in the UK? An individual participant data meta-analysis

These results will be presented at Society of Social Medicine and Population Health 2023 (oral presentation).

4.1 Contributions

I designed this study with Dr Amy Ahern, Prof Simon Griffin, and Prof Mike Kelly. I conducted all analyses of individual participant data and the subsequent meta-analyses; interpretation of these analyses was conducted in conjunction with Dr Julia Mueller and Mr Stephen Sharp. Individual participant data on attendance were provided for four trials by Dr Amy Ahern (WRAP), Prof Colin Greaves (Waste the Waist), Prof Alex McConnachie (Football Fans in Training), and Dr Nerys Astbury (Jebb 2011 trial). Dr Sarah Damery conducted analyses of individual participant data in the Lighten Up trial and provided me with the results for inclusion in the meta-analysis.

4.2 Background

In the systematic review in Chapter 2 (section 2.5.3.2), I synthesised published analyses of inequalities in the adherence to behavioural weight management interventions. I found some evidence that adherence was higher in groups considered more advantaged (such as those working full time or living in less deprived areas). Most analyses, however, did not find evidence of inequalities in intervention adherence. As highlighted in Chapter 2 (section 2.6.2), most of the trials included in the systematic review would not have been sufficiently powered to detect a difference in intervention adherence should one exist. Consequently, the narrative approach taken in Chapter 2 means there is some uncertainty around the extent of inequalities in attendance at behavioural weight management interventions. Given the heterogeneity in measures of the PROGRESS-Plus characteristics, as well in how adherence was captured, it was not possible to conduct a meta-analysis in the systematic review featured in Chapter 2.

In addition to the systematic review in Chapter 2, two other systematic reviews I have identified also considered inequalities in behavioural weight management intervention attendance. Both these systematic reviews focused on race and ethnicity as the PROGRESS-Plus characteristic of interest. Haughton et al.,¹⁷² found that only 2/60 studies of weight loss interventions conducted analysis of differential attendance by ethnicity. Fitzgibbon et al., included all trials (n=25) that reported including Black women (not only trials of interventions that were targeted towards Black women),¹⁷⁰ and found no evidence of inequalities in intervention adherence.

Both the Haughton et al., and Fitzgibbon et al., systematic reviews only included trials conducted in the USA,^{170,172} the individual participant data meta-analysis [IPD-MA] I present in Chapters 3-5 only includes trials from the UK. Two UK-based trials have published analyses of differential attendance.^{335,336} Using data from the Weight loss Referrals for Adults in Primary care [WRAP] trial, Piernas et al., found that attendance was greater in older participants but there was no evidence of differential attendance by gender, ethnicity, education, or income.³³⁶ Considering socioeconomic status (using Indices of Multiple Deprivation) as a predictor of attendance, using data from the BWeL trial, Graham et al., found that participants from more deprived areas attended fewer interventions sessions

despite participants from more deprived areas being more likely to accept the offer of intervention.³³⁵ This is supported by analyses of tier 2 weight management service data, which found that referrals and enrolments to tier 2 services are highest in people from the most deprived areas but intervention completion was highest in people from the least deprived areas.⁹⁸

In Chapter 3 (section 3.2), I highlighted some of the advantages of an individual participant data meta-analysis [IPD-MA] in overcoming some of these limitations. For example, having access to individual participant data means that data can be recoded and analysed in a uniform way,^{179,180} and synthesising data from multiple trials increases the statistical power to detect differential attendance to behavioural weight management interventions should this exist.^{179,181}

However, an IPD-MA does not overcome all the limitations regarding heterogeneity in how adherence was captured. One such limitation is where there is heterogeneity in intervention design and how adherence is considered within that intervention. Behavioural weight management interventions are broad in intervention design and can be delivered via in-person group sessions, via web platforms, leaflets, and text messages. These are diverse and make it difficult to consider adherence uniformly across trials. Once I had identified UK-based trials of behavioural weight management (shown in Chapter 3, section 3.5.1), I discussed the intervention format with my supervisors and when contacting the trial investigators. I identified that most of the interventions were in-person group services, and most adherence data that I would receive would be in the form of attendance. Hence, I focused the analyses of adherence in this IPD-MA on attendance across the trials I received appropriate data from.

4.3 Aims

The aim of this chapter was to:

- Quantify the extent that attendance at behavioural weight management interventions differed by individual characteristics that stratify health opportunities and outcomes.

4.4 Methods

The process of acquiring the data for this IPD-MA is outlined in section 3.4 in the previous chapter. Here, I describe the outcome of interest (intervention attendance) and the two-stage IPD-MA that was conducted to assess this.

4.4.1 Outcomes

For analysing differences in attendance at behavioural weight management interventions, I defined attendance as the percentage of offered sessions which were attended (in trials where there was more than one in person session).

4.4.2 Statistical analysis

I estimated the association between each PROGRESS-Plus characteristic and attendance using multivariable linear regression. The regression coefficients for each PROGRESS-Plus characteristic sub-category shows the percentage difference in attendance between that sub-category and the reference category. For age, which is a continuous variable, the coefficient shows the percentage difference in attendance for a one-year increase in age at baseline. Estimated exposure/attendance associations were combined across trials using random effects meta-analysis. Heterogeneity was assessed using τ^2 (summarising between-studies variance) and a 95% prediction interval (PI) indicating the range in which 95% of the true effects lie. Inconsistency was assessed using I^2 , indicating the proportion of total variability in the observed effects that was due to heterogeneity.

4.5 Results

I harmonised data on intervention attendance from five trials (Table 4-1).^{204,214,215,217,219} The number of core available sessions in each trial ranged from nine in ‘Waste the Waist’, to 52 in WRAP and Jebb 2011.^{204,214,217}

I did not find evidence of inequalities in intervention attendance by ethnicity, occupation, gender/sex, socioeconomic status (IMD), or age; Table 4-2). I did find some evidence of differential trial attendance by socioeconomic status (annual household income), but the difference was small (i.e., less than one session) and the data came from only a single study.

Table 4-1 Number of sessions and overall percentage session attendance for each trial

Trial (Lead author)	Number of available core sessions	Overall session attendance percentage (percentage attending ≥50% of sessions)
WRAP (Ahern)	12/52 (two trial arms)	12 session arm: 71 (76) 52 session arm: 74 (77)
Waste the Waist (Greaves)	9	66 (70)
Football Fans in Training (Hunt)	12	73 (79)
Jebb 2011	52	73 (92)
Lighten Up (Jolly)	12 (seven trial arms, all of 12 sessions)	Weight Watchers: 44 (70) Slimming World: 44 (62) Rosemary Conley: 45 (50) Size Down: 44 (45) General Practice: 47 (25) Pharmacy: 40 (25) Participant intervention choice arm: 38 (74)

Table 4-2 Percentage difference between groups for intervention attendance

Characteristic	Percentage difference in attendance (95% confidence interval)	I ²	Tau ²	P-value
Ethnicity				
White vs Ethnic minority (Excluding White minorities)	3.47 (-8.46, 15.39)	71.68%	95.42	0.57
Occupation				
Unemployed (vs Employed)	-1.88 (-9.56, 12.92)	0.00%	0.00	0.63
Retired (vs Employed)	-2.30 (-9.17, 4.57)	35.22%	13.10	0.51
Student (vs Employed)	-7.24 (-20.14, 5.65)	0.00%	0.00	0.27
Other (vs Employed)	1.45 (-4.30, 7.20)	0.00%	0.00	0.62
Gender/sex				
Male (vs female)	-1.85 (-5.47, 1.76)	0.00%	0.00	0.31
Education				
Post-secondary (vs University)	-6.05 (-13.68, 1.57)	0.00%	0.00	0.12
A-Levels/equivalent (vs University)	-1.88 (-7.91, 4.15)	0.00%	0.00	0.54
GCSEs/equivalent (vs University)	-0.97 (-6.30, 4.36)	0.00%	0.00	0.72
No formal qualifications (vs University)	-3.66 (-25.08, 17.76)	83.71%	199.97	0.74
Socioeconomic status (IMD)				
IMD 2 (vs 1)	-4.67 (-34.92, 25.57)	98.88%	792.60	0.76
IMD 3 (vs 1)	0.12 (-0.63, 0.87)	0.00%	0.00	0.75
IMD 4 (vs 1)	2.75 (-4.33, 9.82)	54.79	26.10	0.45
IMD 5 (vs 1)	5.82 (-3.05, 14.68)	55.13%	38.85	0.20
Socioeconomic status (annual household income)				
≥£40,000 (vs <£40,000)	6.34 (0.812, 12.62)	n/a*	n/a*	0.04
Social capital (marital status)				
Single (vs married or cohabiting)	-4.28 (-16.87, 8.31)	n/a*	n/a*	0.50
Separated, widowed or divorced (vs married or cohabiting)	-5.61 (-15.90, 4.68)	n/a*	n/a*	0.29
Age				
Continuous (coefficient refers to 1-year increase in age at baseline)	0.12 (-0.14, 0.38)	69.74%	0.05	0.36

* not available as data came from one study

4.6 Discussion

In this chapter, I completed an IPD-MA on attendance at behavioural weight management interventions. I used data from five UK-based trials identified from the systematic search outlined in Chapter 3.

4.6.1 Comparison with existing literature

In not finding evidence of inequalities in the attendance at behavioural weight management interventions, this replicates similar findings from previous systematic reviews of trials of behavioural weight management interventions. These reviews found there was no evidence of differential intervention adherence,¹⁷⁰ which aligns with the lack of evidence of differential attendance shown in this chapter. This could be positive, indicating that these interventions are manageable for patients of all backgrounds. However, the rate of trial attrition being higher in those from an ethnic minority background shown in Chapter 3 (section 3.5.3) also supports the systematic review from Fitzgibbon and colleagues in the US.¹⁷⁰ This suggests that the potentially positive finding that interventions are equally well attended by patients of all backgrounds could stem from the selection biases noted in these trials, and not be generalisable to the wider population. In addition, this suggests that if inequalities are observed in the effectiveness of the behavioural weight management interventions in Chapter 5, that this may be caused by the intervention itself (such as through the content of the intervention) rather than by differential attendance at in-person behavioural weight management interventions.

It should be noted, however, that there is a difference between these results and those observed in routinely collected data from both tier 2 weight management services in the UK. Those data suggest there is a socioeconomic gradient to attendance at behavioural weight management interventions;⁹⁸ those from a less deprived area were more likely to complete a weight management programme than those from more deprived areas. This difference may have been caused by the different measures used between my trial-based research (a continuous measure of attendance) versus that used in the Office for Health Improvement and Disparities' national data tool, which considered those who "completed" rather than a continuous measure. Another contributing factor may be that those who participate in trials are different to those who access behavioural weight management services routinely, and

this could reflect the different findings observed. In two studies of UK primary care data, Booth et al., and Coulman et al., both found that people from more deprived areas were more likely than those from less deprived areas to be referred for weight management intervention;^{199,337} Coulman et al., also found that people of Black (versus White) ethnicity were more likely to have received a weight management referral. These studies highlight that trial participants are different from those who are referred for weight management interventions in routine practice.

4.6.2 Strengths and limitations

To the best of my knowledge, this is the first IPD-MA to consider inequalities in the attendance and effectiveness of behavioural weight management interventions. Accessing individual-level data allowed for harmonisation of the PROGRESS-Plus characteristics and attendance data, which allowed me to include data from more trials in the meta-analysis than would be possible using aggregate data from study publications. This highlights the usefulness of IPD-MA in considering differential effectiveness of interventions, due to the increased statistical power from the harmonisation and synthesis of the PROGRESS-Plus-related data.¹⁷⁹

4.6.3 Conclusion

Across the five trials (out of 13) that had data that could be harmonised on attendance at behavioural weight management interventions, I did not find evidence of inequalities in who attends in-person behavioural weight management interventions. This suggests that if any inequalities are observed in the effectiveness of behavioural weight management interventions, this may be caused by the intervention itself rather than by differential attendance.

Chapter 5 Inequalities in the effectiveness of behavioural weight management interventions: IPD-MA results

A manuscript containing the results of Chapters 4 and 5 will be submitted for publication with the citation: Birch JM, Mueller J, Sharp SJ, Kelly MP, Damery S, Jones RA, Logue J, Anderson AS, Astbury NM, Aveyard P, Beeken RJ, Craigie AM, Greaves C, Jebb SA, McConnachie A, Nanchahal K, Stuart B, White M, Griffin SJ, Ahern AL. Are there inequalities in the attendance to and effectiveness of behavioural weight management interventions for adults in the UK? An individual participant data meta-analysis

These results will be presented at Society of Social Medicine and Population Health 2023 (oral presentation).

5.1 Contributions

I designed this study with Dr Amy Ahern, Prof Simon Griffin, and Prof Mike Kelly. I conducted all analyses of individual participant data and the subsequent meta-analyses; interpretation of these analyses was conducted in conjunction with Dr Julia Mueller and Mr Stephen Sharp. Individual participant data on attendance were provided for 12 trials by Dr Amy Ahern (WRAP), Dr Angela Craigie (BeWEL and ActWELL), Dr Nerys Astbury (BWeL, Jebb 2011 trial, and DROPLET), Dr Rebecca Beeken (10 Top Tips), Prof Colin Greaves (Waste the Waist), Prof Alex McConnachie (Football Fans in Training), Prof Beth Stuart (POWeR+), Dr Kiran Nanchahal (CAMWEL), and Dr Louise Hayes (EDIPS). Dr Sarah Damery conducted analyses of individual participant data in the Lighten Up trial and provided me with the results for inclusion in the meta-analysis. All authors commented on a draft of the results and interpretation.

5.2 Background

As highlighted in Chapter 2, both in the discussion of previous systematic reviews (section 2.2) and the results of my systematic review (section 2.5), systematic reviews of inequalities in the effectiveness of behavioural weight management interventions have taken the form of narrative reviews. My systematic review found inconsistent results of inequalities in the effectiveness of behavioural weight management interventions: in some trials there was evidence that effectiveness was greater in those from the more advantaged groups; in some trials there was evidence that effectiveness that was greater in those from the less advantaged groups; but most analyses did not find evidence of a differential intervention effect. Similar findings were observed by Szinay et al., in a systematic review of the effectiveness of mobile-delivered interventions for weight-related behaviours for age, gender, education, occupation, and geographical location.¹⁶⁷

Other reviews narratively summarised published results of the differential effectiveness of behavioural weight management interventions by a single characteristic.^{125,167,170,174,177} For race and ethnicity, Fitzgibbon et al., and Tussing-Humphreys et al., both found that behavioural weight management interventions were less effective in Black and African American women.^{170,174} For gender or sex, Williams et al., found that interventions were similarly effective in men and women.¹⁷⁷ Olstad et al., found that there was no evidence of differential effectiveness by socioeconomic status.¹²⁵ None of these highlighted systematic reviews included a meta-analysis, meaning – as discussed in Chapter 2 (section 2.6.2), Chapter 3 (section 3.6.1), and Chapter 4 (section 4.2) – these reviews relied on the results of analyses that were unlikely to be sufficiently powered to detect a differential effect of the intervention should one exist.

5.3 Aims

The aims of this chapter were to quantify:

- To what extent does the effectiveness of behavioural weight management interventions differ by individual characteristics that stratify health opportunities and outcomes?
- To what extent do the weight outcomes of those who have participated in a behavioural weight management trial differ by individual characteristics that stratify health opportunities and outcomes?

5.4 Methods

The process through which data were acquired, and exposures coded and harmonised, is outlined in detail in Chapter 3. The methods discussed in this section relate specifically to the coding and analysis of the weight outcome data.

5.4.1 Outcomes

For both aims in this Chapter, the outcome was weight at 12-month follow up controlled for baseline weight.

5.4.2 Statistical analysis

In this two-stage IPD-MA, I performed all analyses in individual trials used multivariable linear regression to determine differences by individual characteristics that stratify health opportunities and outcomes (defined using the PROGRESS-Plus Framework) and controlled for gender/sex, age, and weight at baseline.

For the first aim of this chapter, I analysed differences in the effectiveness of behavioural weight management interventions (defined as the difference in weight change between intervention and control). For each trial, weight at 12 month follow up was used as the

outcome and PROGRESS-Plus characteristic and its interaction with the randomised group (intervention or control) as the exposures in the multivariable linear regression. The interaction regression coefficients show the difference in mean weight differences at 12 months between the sub-category and the comparator sub-category. For age, the interaction regression coefficient shows the difference in mean weight differences at 12 months per 1-year increase in age at baseline. Following the regression analyses, the estimated interaction parameters were then combined across trials using random effects meta-analysis. Heterogeneity was assessed using τ^2 (summarising between-studies variance) and a 95% prediction interval (PI) indicating the range in which 95% of the true effects lie. Inconsistency was assessed using I^2 , indicating the proportion of total variability in the observed effects that was due to heterogeneity.

The analyses for the second aim of this chapter considered differences in the weight outcomes of those who had participated in a behavioural weight management trial (defined as weight change in the overall cohort) the association between the exposure (PROGRESS-Plus characteristic) and weight at 12 month follow up additionally adjusted for assigned intervention (intervention or control). The estimated exposure/weight associations were combined across trials using random effects meta-analysis.

5.5 Results

Overall, being in the intervention group was associated with 2.38kg lower weight at 12-month follow up than the control group (95% CI -3.33, -1.43; $p < 0.001$; $I^2 = 86.45\%$; $\text{Tau}^2 = 2.47$). This ranged from 0.06kg lower weight in the intervention group (95% CI -1.13, 1.26) in the 10TT study to 7.31kg (95% CI 4.93, 9.70) in the DROPLET study.

5.5.1 To what extent does the effectiveness of behavioural weight management interventions differ by individual characteristics that stratify health opportunities and outcomes?

There was evidence of interactions between intervention and gender/sex and between intervention and ethnicity (Figure 5-1). The between-group difference in mean weight at 12 months was greater in males (-2.58kg (95% CI -3.52, 1.64), p -value for interaction = 0.02) than females (-1.71kg (95% CI -2.79, -0.63)). Tau^2 , assessing between-studies variance in the interaction estimates, was 0 (Figure 5-2), and the 95% PI -1.94 to -0.02 (Table 5-1). The proportion of total variability in the observed interaction effects due to heterogeneity (I^2) was 0%. The difference in weight at 12 months was also greater in those of a White ethnicity (-2.74kg (95%CI -4.30, -1.19), p -value for interaction = 0.04) than those from an ethnic minority background (0.03kg (95% CI -1.29, 1.35), $\text{Tau}^2 = 0$, $I^2 = 0\%$, 95% PI -0.52, 4.52) (Figure 5-3).

The intervention had a greater effect in those in the 4th least deprived IMD quintile compared to the most deprived quintile (-1.38kg, 95% CI -2.73, -0.03, $p = 0.05$), although there was not evidence of this when comparing the most and least deprived quintiles (-0.88kg, 95% CI -2.25, 0.49, $p = 0.21$). There was no evidence of a difference in mean weight change between intervention and control by place of residence, occupation, education, socioeconomic status (quintiles 5,3 and 2 versus 1), socioeconomic status (annual household income), social capital (marital status), and age (Appendix 3, Supplementary Material Chapter 5).

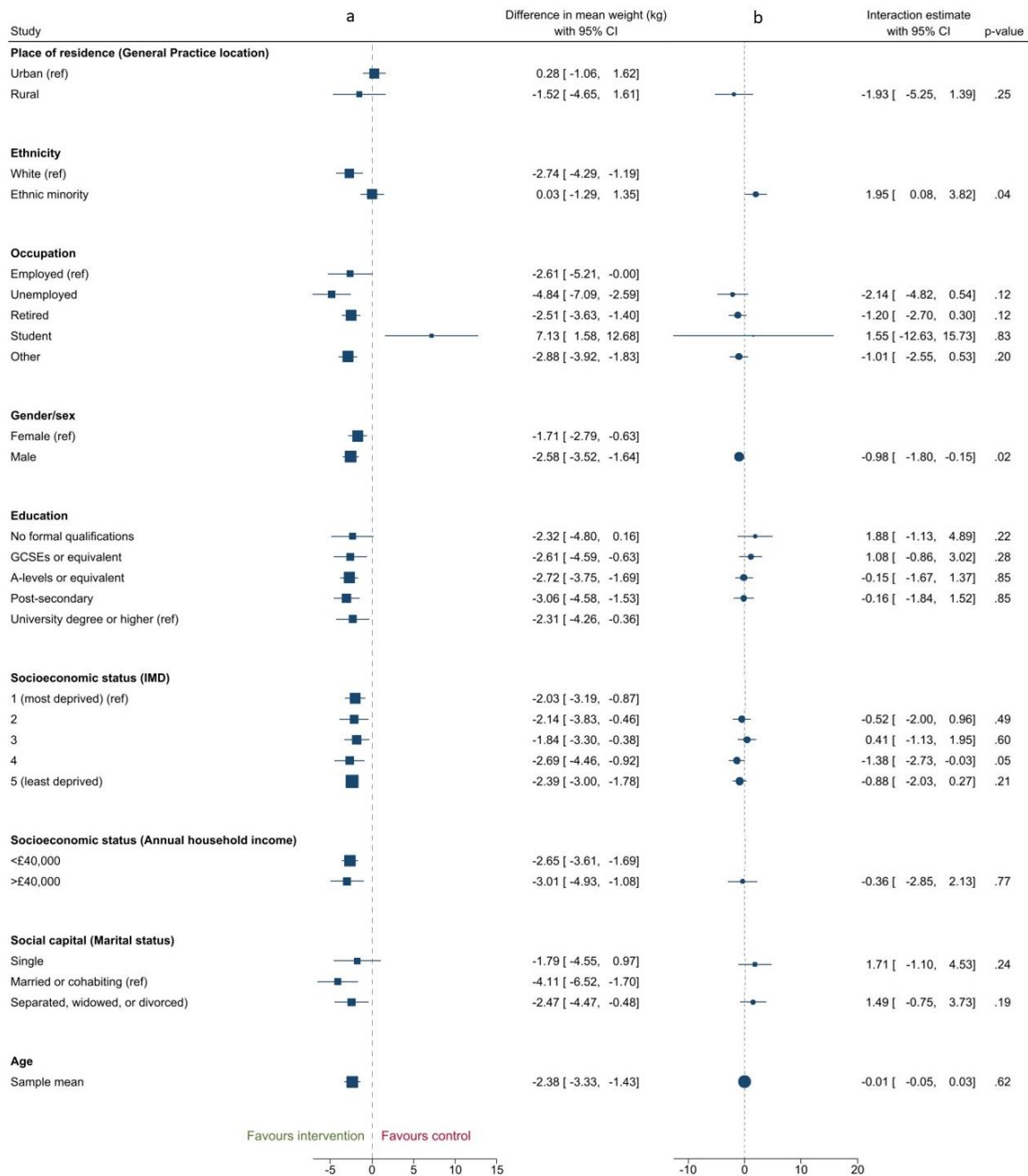


Figure 5-1 Forest plots showing: a) Stratified analyses showing difference in mean weight at 12 months in the intervention group minus control for each characteristic subgroup and b) Estimated interaction coefficients (difference in mean weight differences at 12 months) between intervention and inequality characteristic.

Table 5-1 Estimated interaction parameters from random effects meta-analysis

Characteristic	Estimated interaction (95% confidence interval)	I ²	Tau ² (95% prediction interval of estimated interaction)	p- value
Place of residence (General Practice location)				
Rural (vs Urban)	-1.93 (-5.25, 1.39)	n/a*	n/a*	0.25
Ethnicity				
Ethnic minority (vs White (including White minorities))	1.95 (0.08, 3.82)	0%	0.00 (-0.38, 4.28)	0.04
Occupation				
Unemployed (vs Employed)	-2.14 (-4.82, 0.53)	0%	0.00 (-6.49, 2.21)	0.12
Retired (vs Employed)	-1.20 (-2.70, 0.30)	0%	0.00 (-4.49, 2.09)	0.12
Student (vs Employed)	1.55 (-12.63, 15.73)	79%	163.76 (-61.70, 64.80)	0.83
Other (vs Employed)	-1.01 (-2.55, 0.53)	0%	0.00 (-3.51, 1.49)	0.20
Gender/sex				
Male (vs Female)	-0.98 (-1.80, -0.15)	0%	0.00 (-1.94, -0.02)	0.02
Education				
Post-secondary (vs University)	-0.16 (-1.84, 1.53)	21%	0.79 (-4.10, 3.78)	0.85
A-Levels/equivalent (vs University)	-0.15 (-1.67, 1.37)	8.23%	0.32 (-2.82, 2.52)	0.85
GCSEs/equivalent (vs University)	1.08 (-0.86, 3.02)	0.00%	0.00 (-3.18, 5.34)	0.28
No formal qualifications (vs University)	1.88 (-1.13, 4.89)	2.45%	0.21 (-18.48, 22.24)	0.22
Socioeconomic status (IMD)				
IMD Quintile 2 vs 1 (most deprived)	-0.52 (-2.00, 0.95)	0.00%	0.00 (-2.31, 1.27)	0.49
IMD Quintile 3 vs 1	0.41 (-1.13, 1.95)	12.17%	0.67 (-2.27, 3.09)	0.60
IMD Quintile 4 vs 1	-1.38 (-2.73, -0.03)	0.00%	0.00 (-3.01, 0.25)	0.05
IMD Quintile 5 (least deprived) vs 1	-0.88 (-2.03, 0.27)	0.00%	0.00 (-2.59, 0.83)	0.21
Socioeconomic status (annual household income)				
≥£40,000 (vs <£40,000)	-0.36 (-2.86, 2.13)	31%	1.04 (n/a [^])	0.77
Social Capital				
Single (vs Married/cohabiting)	1.71 (-1.11, 4.52)	0%	0.00 (n/a [^])	0.24
Separated/widowed/divorced (vs Married/cohabiting)	1.49 (-0.75, 3.72)	0%	0.00 (n/a [^])	0.19
Age				
Per 1-year of age at baseline	-0.01 (-0.05, 0.03)	20%	0.00 (-0.06, 0.04)	0.62

The interaction estimates are the difference in the effect of the intervention (vs control) comparing the listed 2 categories of each characteristic or per year of age

*n=1 study, so no meta-analysis performed; ^n=2 studies, so it was not possible to calculate a prediction interval

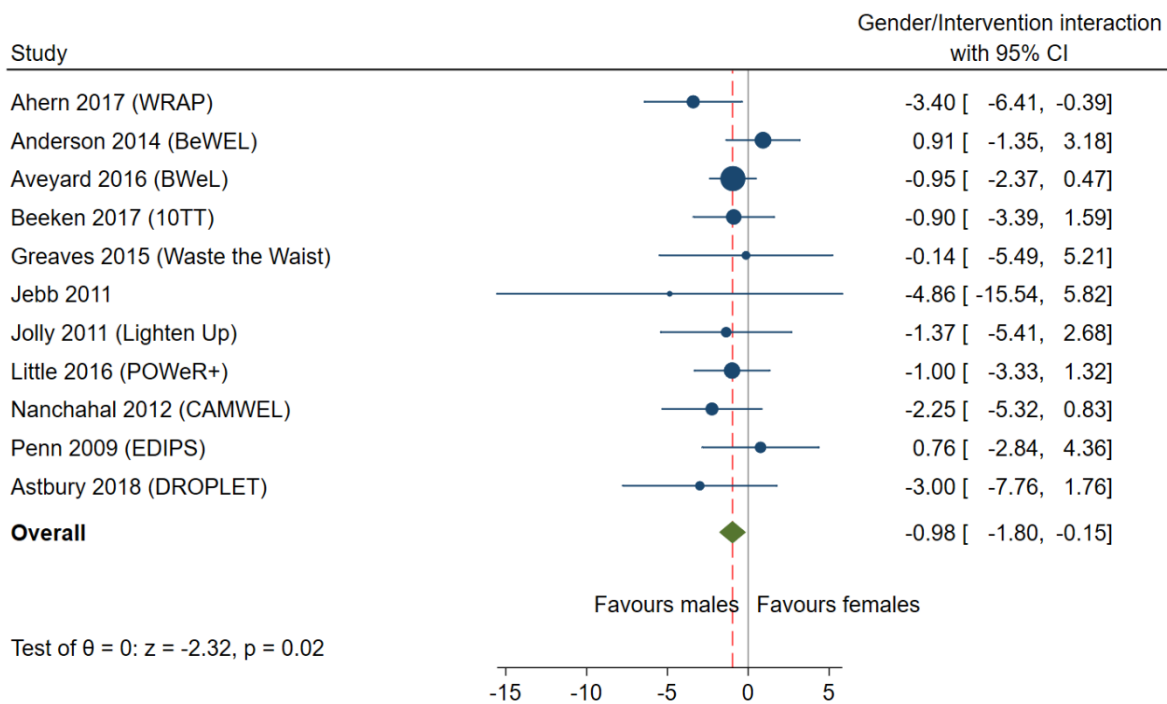


Figure 5-2 Forest plot of the difference (male minus female) in mean differences between the intervention and control groups for gender/sex

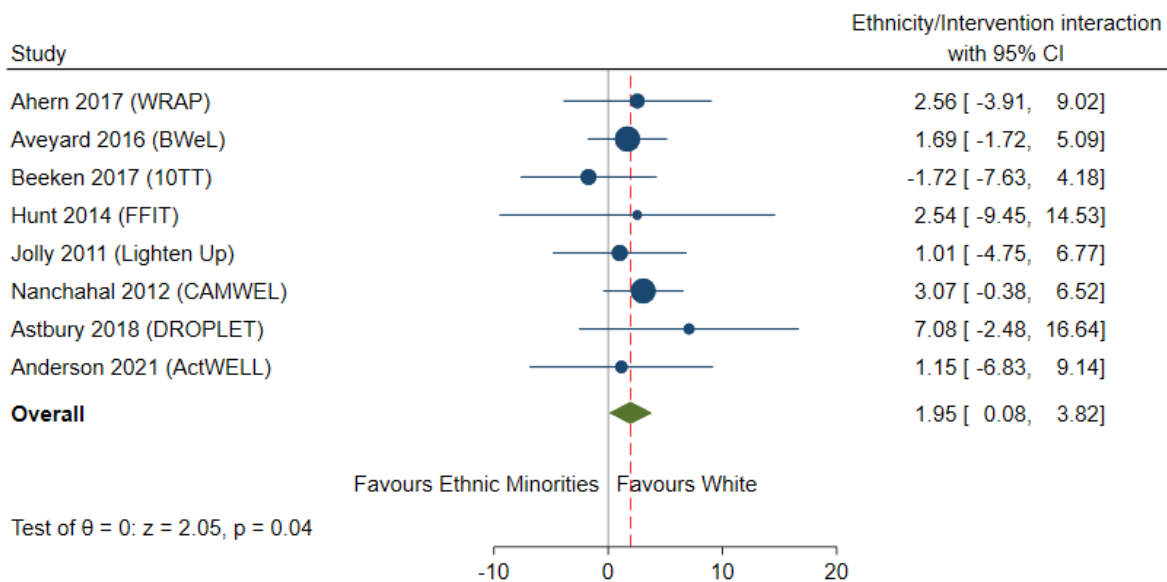


Figure 5-3 Forest plot of the difference (White minus Ethnic Minority) in mean differences between the intervention and control groups for ethnicity

I conducted further post-hoc analyses for gender/sex and ethnicity to understand how these interactions occurred. To understand the interaction between gender/sex and intervention, I examined differences in weight between men and women within each randomised group. I found that males had a 1.27kg (95% CI 0.09, 2.45) higher weight than females at follow up in the control group and a 0.09kg (95% CI -0.65, 0.83) higher weight than females at follow up in the intervention group. For ethnicity, those from an ethnic minority background had a 0.10kg (95% CI -1.03, 0.82) lower weight at follow up than white participants in the control group and a 0.94kg (95% CI -0.94, 2.84) higher weight at follow up than white participants in the intervention group.

5.5.2 To what extent do the weight outcomes of those who have participated in a behavioural weight management trial differ by individual characteristics that stratify health opportunities and outcomes?

In cohort analyses, I found evidence of associations of gender/sex, social capital (marital status), and age, with weight at follow-up (Table 5-2). Being male was associated with a higher weight at 12 month follow up of 0.62kg (95% CI 0.10, 1.15; $p=0.02$; $I^2=27.13\%$; $\text{Tau}^2=0.20$) compared to being female. Being separated, widowed, or divorced was associated with having a higher weight of 1.31 kg (95% CI 0.18, 2.43) at follow up versus those who were married or cohabiting.

Older age at baseline was associated with a lower weight at follow up; a 10-year increase in age at baseline was associated with a lower weight of 0.5 kg (95% CI 0.4, 0.7; $p<0.001$; $I^2=0.01\%$; $\text{Tau}^2=0.00$). There did not appear to be an association between follow up weight and place of residence, ethnicity, occupation, education, or socioeconomic status (IMD and annual household income).

Table 5-2 Difference in weight at 12 months across the cohort of participants in trials of behavioural weight management interventions

Characteristic	Difference in weight at 12 months in kilograms (95% confidence interval)	I ²	Tau ² (95% prediction interval)	p-value of association
Place of residence (General Practice location)				
Rural (vs Urban)	0.22 (-1.43, 1.87)	n/a*	n/a*	0.79
Ethnicity				
White vs Ethnic minority (Excluding White minorities)	0.46 (-0.45, 1.37)	26.73%	0.50 (-1.49, 2.41)	0.32
Occupation				
Unemployed (vs Employed)	-0.64 (-1.86, 0.59)	0.00%	0.00 (-2.64, 1.36)	0.31
Retired (vs Employed)	-0.65 (-1.50, 0.21)	0.00%	0.00 (-2.54, 1.24)	0.14
Student (vs Employed)	2.44 (-0.46, 5.34)	0.00%	0.00 (-3.92, 8.81)	0.10
Other (vs Employed)	1.05 (-0.16, 2.26)	43.41	0.80 (-0.91, 3.01)	0.09
Gender/sex				
Male (vs female)	0.62 (0.10, 1.15)	27.13%	0.20 (-0.56, 1.80)	0.02
Education				
Post-secondary (vs University)	0.35 (-0.35, 1.05)	3.71%	0.03 (-0.91, 1.61)	0.33
A-Levels/equivalent (vs University)	-0.03 (-0.76, 0.7)	9.32%	0.08 (-1.06, 1.00)	0.93
GCSEs/equivalent (vs University)	0.43 (-0.43, 1.30)	0.00%	0.00 (-1.48, 2.34)	0.33
No formal qualifications (vs University)	1.45 (-0.10, 2.99)	21.87%	0.68 (-1.05, 3.95)	0.07
Socioeconomic status (IMD)				
IMD 2 (vs 1)	0.05 (-0.59, 0.70)	0.00%	0.00 (-0.71, 0.81)	0.87
IMD 3 (vs 1)	0.08 (-0.57, 0.72)	0.00%	0.00 (-0.67, 0.83)	0.81
IMD 4 (vs 1)	-0.39 (-1.05, 0.26)	0.00%	0.00 (-1.15, 0.37)	0.24
IMD 5 (vs 1)	-0.26 (-0.98, 0.47)	10.72%	0.15 (-1.12, 0.60)	0.49
Socioeconomic status (annual household income)				
≥£40,000 (vs <£40,000)	-0.38 (-1.29, 0.53)	0.00%	0.00 (n/a [^])	0.41
Social capital (marital status)				
Single (vs married or cohabiting)	0.61 (-0.76, 1.99)	0.00%	0.00 (n/a [^])	0.38
Separated, widowed, or divorced (vs married or cohabiting)	1.31 (0.18, 2.43)	0.00%	0.00 (n/a [^])	0.02
Age				
Continuous (coefficient refers to one-year increase in age at baseline)	-0.05 (-0.07, -0.04)	0.00%	0.00 (-0.06, -0.04)	<0.01

5.6 Discussion

In this IPD-MA, I analysed data from 12 randomised controlled trials of behavioural weight loss interventions. I found that intervention effectiveness was greatest, on average, for people of White ethnicity, suggesting that behavioural weight management interventions may widen existing inequalities in overweight and obesity by ethnicity. Men received a greater benefit of the intervention than women, despite men in the overall cohort losing less weight than women.

5.6.1 Comparison with existing literature

The findings that behavioural weight loss interventions were less effective in women, and those from an ethnic minority background, are similar to those found in an evaluation of the English NHS Diabetes Prevention Programme, which reported that being female and of an Asian or Black ethnicity were associated with lower weight loss.³³⁸ However, unlike my study, this effect was produced by women losing less weight than men (and there was no control group for the intervention group to be compared against). Similarly, I found some evidence that behavioural weight management interventions were more effective in those from less deprived groups, although this evidence was not consistent (i.e., lesser intervention effectiveness compared to the least deprived group was noted in the 4th most but not the most deprived quintiles).

The intervention in English NHS Diabetes Prevention Programme is similar to most of the interventions included in this study, consisting of 13 group-based sessions delivered over at least nine months focusing on weight loss and provides a useful healthcare-based comparison to the results from my study. These similar findings are observed despite differences in the respective populations and trial versus non-trial study contexts; in the evaluation of the English NHS Diabetes Prevention Programme, the proportion of participants who were male was considerably closer to that of the English population than is seen in behavioural weight management interventions, where referral for intervention and enrolment in behavioural weight management trials is more likely among women than men.^{199,309}

Behavioural weight management interventions being more effective in those of a White ethnicity, despite no evidence of inequalities in attendance (as shown in Chapter 4), suggests that the inequalities in the weight outcomes are likely being generated by the intervention

itself. Qualitative research has previously explored how engagement with, and adherence to, an intervention differs by cultural context, and found that the general tailoring of behavioural weight management interventions towards White British participants can present barriers preventing the implementation of intervention content in daily life for participants with different ethnic backgrounds.^{339,340} For example, many behavioural weight management interventions offer dietary advice that is not transferable to typical food preparation methods used in some cultures, or affordable for people on low incomes to implement.³³⁹ Similarly, interventions that use physical activity provision as a component and do not contain access to single-sex spaces to exercise may prevent those of certain cultural backgrounds – such as British Pakistani Muslim women – from accessing such provision.³⁴⁰ Future research should investigate the mechanisms behind the observed inequalities by ethnicity so that people with obesity from minority ethnic groups can be better and supported to manage their weight in ways that are culturally appropriate.

My post-hoc analyses suggested the greater treatment effect observed in males may, in part, have been produced by men doing worse in the control group than women despite having comparable follow up weight in the intervention group. This suggests that when men are only provided with minimal intervention, they may have greater difficulty in managing their weight than women. The comparable outcomes in the treatment group between males and females suggests that despite typically lower uptake of these interventions by men, they achieve similar outcomes to women, and future work could consider how to achieve greater utilisation of these general weight management interventions by men. These generic interventions are particularly useful – especially where gender-tailored weight management programmes towards men (such as Football Fans in Training and Man v Fat Football) may not be available or appeal to some men.^{215,341,342}

My findings about gender/sex and ethnicity align with the findings of previous systematic reviews. For example, my previous narrative systematic review (Chapter 2) found some evidence that effectiveness of behavioural weight management interventions favoured those of a White ethnicity and men, although most trials were not sufficiently powered to explore differential effectiveness.¹⁸⁷ Another meta-analysis also found the effectiveness of weight loss interventions favoured men, albeit the difference was small.¹⁷⁷ For ethnicity, Fitzgibbon and colleagues found that Black women had lower weight loss than other ethnicities.¹⁷⁰

Further, I did not find consistent evidence of inequalities in intervention effectiveness by socioeconomic position or education, which aligns with previous systematic reviews suggesting that individual-level and primary care-delivered interventions are unlikely to increase socioeconomic inequalities in obesity.^{102,125}

5.6.2 Strengths and limitations

There are additional strengths and limitations to consider in addition to those highlighted in sections 3.6.1 and 4.6.2. The estimates of inequality are influenced by the distribution of characteristics within each study. For example, studies with a narrow age range might not identify interactions between intervention effects and age. This may be indicative of the lack of diversity and low inclusion of ‘under-served groups’ in trial samples more generally,^{343,344} where participants are often more likely to be White and more affluent than the general population. Additionally, the lack of inequalities observed across characteristics considered in this study – such as socioeconomic status (IMD) – does not mean that inequalities are not present either among trial participants or in intervention uptake, which we were not able to consider in this study. As all trials included in this study were UK-based, the generalisability of the findings to other countries or healthcare settings may be limited. Finally, there were several PROGRESS-Plus characteristics for which minimal or no data were available (such as place of residence and sexual orientation); future trials may wish to use the PROGRESS-Plus framework when planning data collection relating to baseline characteristics to facilitate analyses of the full range of characteristics that may lead to health inequalities. I did not consider intersectionality between different characteristics in which inequalities occur in this study. It is, however, an important issue for future research to address intersectionality in terms of differential intervention outcomes, as well as building on recent research that explored intersectional differences in prevalence of obesity.^{322–324}

5.6.3 Conclusion

In this chapter, I have shown that behavioural weight management interventions contribute to inequalities in prevalence of obesity by ethnicity, as they were more effective in people of White ethnicity than those from an ethnic minority background. Future research should

investigate the mechanisms behind this, such as exploring how behavioural weight management interventions may be culturally tailored, to better support people with obesity from minority ethnic groups. Furthermore, given the positive intervention effect observed in men, future work should consider how to increase the uptake of behavioural weight management amongst men given the typically lower utilisation of these interventions by men in practice. I did not find consistent evidence of inequalities in intervention effectiveness across the remaining PROGRESS-Plus characteristics, suggesting that behavioural weight management interventions are similarly effective across the demographic range of each characteristic.

Chapter 6 Inequalities in weight change following weight loss intervention

The results presented in this chapter have been published with the following citation: Birch JM, Mueller J, Sharp SJ, Griffin SJ, Kelly MP, Halford JCG, Ahern AL (2022). Association between indicators of inequality and weight change following a behavioural weight loss intervention. Obesity Facts. doi: 10.1159/000528135.³⁴⁵

6.1 Contributions

I planned and designed the study, wrote the statistical analysis plan, conducted the analysis, and led the writing and development of the final manuscript. Julia Mueller, Stephen J Sharp, and Amy L Ahern reviewed the statistical analysis plan. All co-authors contributed to discussions around study design and the published manuscript.

6.2 Background

In the systematic review presented in Chapter 2, I found that most trials did not find evidence of inequalities, especially in the effectiveness of interventions at 12-month follow up. It was not possible to look beyond this time point as few trials of behavioural weight management interventions have followed-up participants for more than 12 months. It is important to consider longer-term weight change post-intervention as the maintenance of weight loss sustains the positive health effects associated with initial clinically significant weight loss, and affects cost-effectiveness¹⁴⁴. However, very few trials have longer-term follow up of participant weight, and consequently there is a lack of evidence on associations between characteristics of inequality (such as those outlined in the PROGRESS-Plus framework as outlined in Chapter 1, section 1.2.2) and long-term maintenance of attained weight loss (i.e. at five-year follow up). This is important to understand as certain sociodemographic groups may require additional support to maintain weight loss achieved through a behavioural intervention.

The Weight Loss Referrals for Adults in Primary Care (WRAP) trial has completed follow-up data collection until the five-year time point, allowing a rare opportunity to study inequalities in weight change following weight loss intervention over an extended time period. All participants in the WRAP trial received a behavioural weight loss intervention (brief intervention information booklet, or vouchers for 12- or 52-weeks of WW [formerly Weight Watchers]). Previous analyses of this trial have found that trial uptake (the number of invited versus recruited participants) was higher in older participants, people from less deprived areas and women (although the proportion of males in WRAP was much higher than seen in similar trials or routine primary care referral);³⁰⁹ intervention attendance was higher in older participants but there was no evidence of inequalities in attendance by any other PROGRESS-Plus criteria;³³⁶ and there was no evidence to suggest that the greater weight loss outcomes observed in the WW groups were affected by gender, education or income level.²⁰⁴ These previous analyses had not considered if uptake or effectiveness differed by ethnicity.

6.3 Aim

The aim of this chapter was to:

- Investigate if there are inequalities in weight change following participation in a weight loss intervention.

6.4 Methods

This study analysed data from the Weight Loss Referrals for Adults in Primary Care (WRAP) trial as a cohort.

6.4.1 The WRAP trial

The WRAP trial is a three-group randomised controlled trial of behavioural weight loss interventions. Full information about the trial design has been published elsewhere.³⁴⁶ Participants were recruited through their general practice and randomised to a brief intervention, 12-week commercial weight loss programme or a 52-week commercial weight loss programme. WRAP was registered with Current Controlled Trials on 15/10/2012 (trial registration: ISRCTN82857232). Ethical approval for WRAP was received from NRES Committee East of England Cambridge East and local approvals from NRES Committee North West Liverpool Central and NRES Committee South Central Oxford.

I identified the WRAP trial as being the most appropriate dataset for this project as it is the only UK-based trial of a behavioural weight management intervention that has completed five-year post-intervention follow-up. No other UK-based trial has completed follow up beyond the 2-year time point; considering weight change from one- to five-year follow up allows greater scope to identify if differential weight regain occurs post-intervention.

6.4.2 Participants

Participants were required to be ≥ 18 years old, residing in the United Kingdom and have a BMI of ≥ 28 kg/m². Participants were not eligible if they were pregnant or had planned pregnancy in the subsequent two years; had previous or planned bariatric surgery; were

following a weight loss programme; did not speak English or had additional communication needs that would preclude them from understanding the study requirements and materials; or the participant's general practitioner considered them ineligible for inclusion (such as history of eating disorders or severe/terminal illness).

6.4.3 Interventions

Participants in the behavioural programmes were given vouchers and asked to attend local WW (formerly Weight Watchers) weekly meetings and access WW web tools at no cost for the duration of the intervention (12-weeks or 52-weeks). Participants allocated to the brief intervention were given a 32-page booklet from the British Heart Foundation that comprised advice and strategies on how to lose weight. Research staff read a scripted introduction that drew attention to each section of the booklet. There were no restrictions on participants in any group accessing other weight management interventions during follow up.

6.4.4 Outcomes

Participants completed outcome assessments at baseline, three months, one year, two years and five years. The primary outcome for this analysis was change in weight between one-year and five-years.

Weight measurements were made at participants' primary care practice or at the research centre by trained clinical or research staff, in line with standard operating procedures and under informed consent. Participants also reported their self-measured weight and we collected weight data from primary care records. At the five-year time point, if clinic-measured weight data were unavailable, the self-reported weight or weight from GP records were used (N=239). Participant demographics were collected via self-report questionnaire at the baseline assessment.

The exposure variables considered for possible association with change in weight between one- and five-years were: 1) ethnic group (*White/Ethnic minorities (excluding White minorities)*); 2) employment status (*Employed/Self-employed/Unemployed/Student/Retired/Unable to work/Other (carer, home-maker,*

voluntary work); 3) sex (*Female/Male*); 4) level of education attained (*University degree or equivalent, or higher/Post-secondary education/A-levels or equivalent/GCSEs or equivalent/No formal qualifications attained*); 5) Indices of Multiple Deprivation (IMD) quintile (*1 (most deprived)/2/3/4/5 (least deprived)*); 6) household income (*<£20 000/£20 000 to £39 999/>£40 000*); 7) member of household participating in a weight loss programme(*Yes/No*); and 8) age (*years*).

6.4.5 Statistical analysis

I analysed data from the WRAP trial as a cohort, rather than consider intervention versus control arms separately to estimate intervention effects. I used Stata v16 (StataCorp. 2019. *Stata Statistical Software: Release 16*. College Station, TX: StataCorp LLC.) to conduct the data analysis. Mean (standard deviation) weight change was calculated within each exposure category. Weight maintenance was defined as having a weight change of 3% or less from the one-year time point³⁴⁷. I used multiple linear regression to estimate the association between each exposure and weight change from one to five years. Each model was adjusted for intervention group, baseline weight, weight change between baseline and one-year, research centre, and source of the five-year weight data. A complete case analysis was performed.

6.4.5.1 Sensitivity analyses

To investigate the impact of missing data on the findings, I performed a sensitivity analysis using Multiple Imputation by Chained Equations (MICE). MICE assumes that data are missing at random conditional on observed participant characteristics. Variables with $\geq 5\%$ and $< 25\%$ missing data had missing values imputed. The number of imputations was set to be the same as the percentage of missing data.

I conducted a further sensitivity analysis to consider if the source of the five-year weight measurement had an impact on the results. The analysis excluded participants whose weight at the five-year time point was collected through GP-records or self-reported information. The final sensitivity analysis, added following peer review feedback, was conducting a single regression model containing all PROGRESS-Plus inequality characteristic variables included in this study to account for potential confounding between them.

6.5 Results

6.5.1 Participant characteristics

A total of 1267 participants were randomised to one of the three groups (211 brief intervention, 528 12-week, 528 52-week intervention). The majority of the recruited participants were women (67.8%) and of White ethnicity (89.7%). Weight data were available for 823 participants at the one-year follow up. At five-year follow up, weight data were available for 871 participants in total. Study-measured weight was available for 632 participants, weight data were extracted from GP-records for 146 participants (11.5%) and were collected by self-report from 93 participants (7.3%). No weight values were available for 396 (31.3%) of participants at the five-year follow up.

Data were available at the one- and five-year follow ups for 708 participants (55.5%, Table 6-1). The participants included in the analyses were more likely to be retired (35.3% vs 21.9% not included), have a university degree (41.6% vs 31.5%), and be older (mean age at baseline of participants included in analysis was 55.7 years old versus 50.0 years old for those not included). Mean weight change between one- and five-years was 3.30 kg (SD 9.10 kg). Mean weight change for each exposure category is presented in Table 6-2. Given the overall mean weight change and standard deviation values, any negative coefficients gained from the regression models (Table 3) would suggest less weight regain, or greater weight loss, in that category.

Where complete data were available, weight at the one-year time point was maintained at the five-year time point by 28.0% of participants, >3% weight loss occurred in 16.5% of participants, and >3% weight gain occurred in 55.5% of participants (Figure 6-1 A histogram of weight change between one- and five-years follow up).

Table 6-1 Sample characteristics by availability of data to calculate weight change

		Complete weight data available n (%)	Complete weight data not available and excluded from analysis n (%)	Chi-square test for association (p-value)
Total participants		708 (55.5)	559 (44.5)	
Ethnicity	White	650 (95.2)	486 (92.6)	3.57 (0.059)
	Ethnic minorities (excluding white minorities)	33 (4.8)	39 (7.4)	
Occupation	Employed	319 (45.8)	287 (53.2)	31.08 (<0.001)
	Self-employed	63 (9.1)	52 (9.6)	
	Unemployed	27 (3.9)	34 (6.3)	
	Student	5 (0.7)	10 (1.8)	
	Retired	246 (35.3)	118 (21.9)	
	Unable to work	22 (3.2)	21 (3.9)	
	Other (carer, home-maker, voluntary work)	14 (2.0)	17 (3.2)	
Gender	Female	471 (66.5)	388 (69.4)	1.19 (0.275)
	Male	237 (33.5)	171 (30.6)	
Education	University degree or equivalent, or higher	267 (41.6)	156 (31.5)	16.91 (0.002)
	Post-secondary education	20 (3.1)	14 (2.8)	
	A-levels or equivalent	147 (22.9)	111 (22.4)	
	GCSEs or equivalent	181 (28.2)	182 (36.8)	
	No formal qualifications attained	27 (4.2)	32 (6.5)	
IMD	1 (most deprived)	72 (10.2)	83 (14.8)	11.40 (0.022)
	2	88 (12.4)	86 (15.4)	
	3	150 (21.2)	117 (20.9)	
	4	190 (26.8)	135 (24.2)	
	5 (least deprived)	208 (29.4)	136 (24.3)	
Household income	<£20 000	174 (31.2)	154 (37.4)	3.45 (0.178)
	£20 000 to £39 999	195 (35.6)	130 (31.6)	
	≥£40 000	178 (32.5)	128 (31.1)	

Other family members participating in weight loss	Yes	25 (5.0)	17 (4.8)	0.03 (0.874)
	No	475 (95.0)	340 (95.2)	
Age at baseline	Mean years (SD)	55.7 (12.5)	50.0 (14.4)	<i>Logistic regression</i> (<0.001)
Intervention group	Brief intervention	107 (15.1)	104 (18.6)	2.93 (0.231)
	12-week	297 (41.9)	231 (41.3)	
	52-week	304 (42.9)	224 (40.1)	

Table 6-2 Mean (SD) weight change by each exposure category

Exposure characteristic (number of observations)	Category	Mean weight change in kg (SD)
Ethnicity (n=683)	White	3.31 (9.24)
	Ethnic minorities (excluding white minorities)	3.48 (7.27)
Occupation (n=696)	Employed	3.76 (9.77)
	Self-employed	3.11 (7.07)
	Unemployed	3.45 (9.24)
	Student	-3.64 (17.48)
	Retired	3.09 (7.45)
	Unable to work	2.34 (17.04)
Gender (n=708)	Other (carer, home-maker, voluntary work)	2.43 (7.10)
	Female	3.19 (9.63)
Education (n=642)	Male	3.52 (7.97)
	University degree or equivalent, or higher	3.43 (8.63)
	Post-secondary education	4.45 (7.57)
	A-levels or equivalent	3.84 (8.90)
	GCSEs or equivalent	2.62 (10.47)
Socioeconomic status Indices of Multiple Deprivation (n=708)	No formal qualifications attained	2.28 (9.25)
	1 (most deprived)	4.46 (9.35)
	2	2.62 (7.02)
	3	2.87 (9.17)
	4	4.19 (10.27)
SES Household income (n=547)	5 (least deprived)	2.69 (8.57)
	<£20 000	3.05 (9.27)
	£20 000 to £39 999	2.54 (10.57)
Other family members participating (n=500)	≥£40 000	3.58 (8.03)
	Yes	2.67 (8.59)
Age (n=708)	No	3.32 (9.22)
	≤55 years old	3.97 (10.72)
	>55 years old	2.72 (7.37)

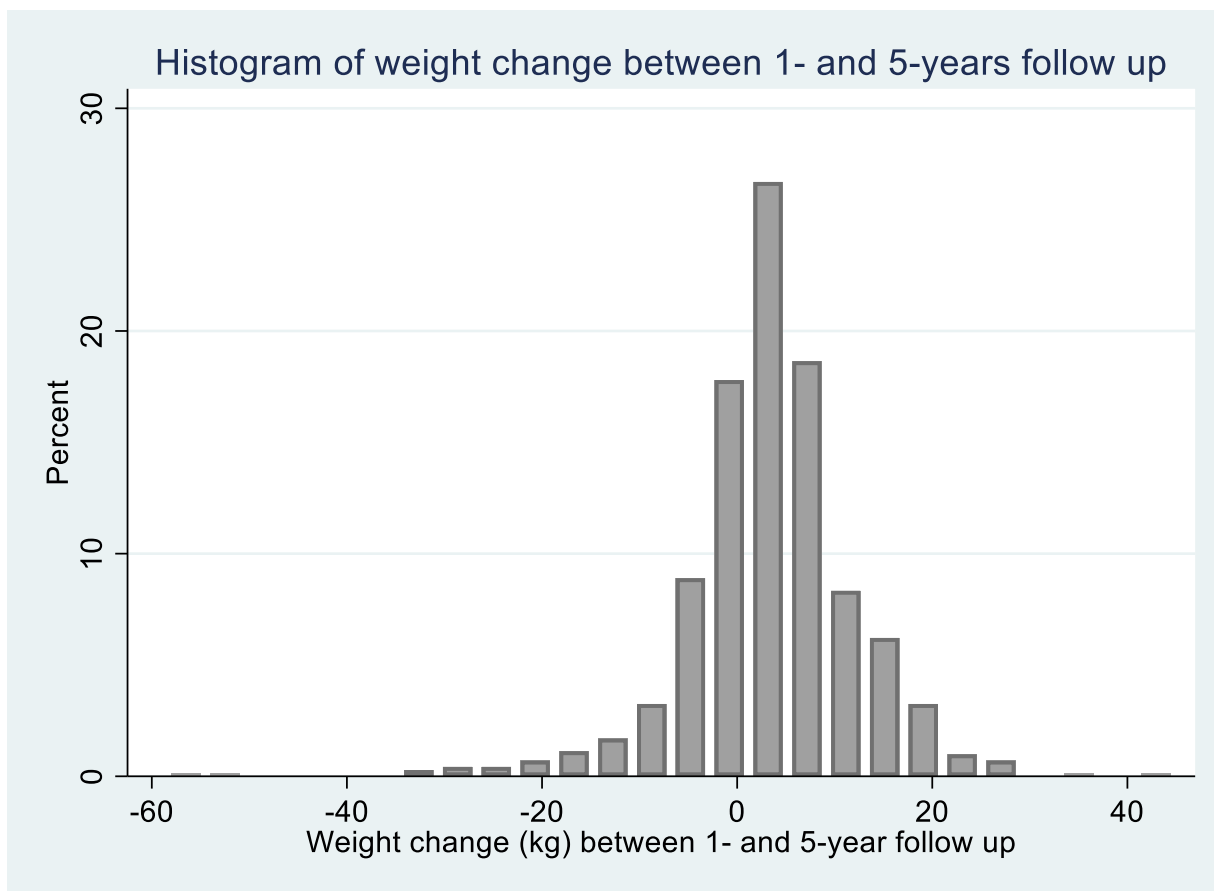


Figure 6-1 A histogram of weight change between one- and five-years follow up

6.5.2 Association between PROGRESS-Plus criteria and weight change from one- to five-years

Being one-year older compared to other participants at baseline was associated with experiencing 0.11kg less weight regain, or greater weight loss ((95%CI 0.06, 0.16), $p < 0.001$). When considering occupation as the independent variable, being retired was associated with a 1.67kg lower weight regain compared to being employed ((95%CI 0.27, 3.08), $p = 0.020$, Table 3). Subsequently, I performed a *post-hoc* analysis of occupation as the independent variable controlling for age, given the differences in age distribution between occupational categories. In this analysis, being retired was no longer associated with weight change between one- and five-year follow up (coefficient 1.15, 95%CI -0.79, 3.09, $p = 0.246$; full results presented in Supplementary Table 2). No other category of occupation, when compared to being employed, was associated with weight change between one- and five-years in either analysis.

There was no evidence of association between ethnicity, gender, education, IMD, household income, and other family members participating in a weight loss programme and weight change between one- and five-years.

6.5.3 Sensitivity analyses

Only one variable, education, met the conditions for performing MICE to impute missing data (between 5% and 25% missing data). The observed results using 11 imputed datasets were comparable to the primary analysis, and no associations were identified (Supplementary Table 3).

In the sensitivity analysis using only study-measured weight at the five-year follow up (Supplementary Table 1), being older at baseline remained associated with lower weight regain or greater weight loss, but the effect size was smaller (coefficient -0.092 (95%CI -0.15, -0.04), $p=0.001$). Being retired, compared to being employed, was not associated with weight change when we included only study-measured weight, neither when not controlling for age (coefficient -0.95 (95%CI -2.48, 0.59), $p=0.226$) nor when controlling for age (coefficient 1.66 (95% CI -0.46, 3.78), $p=0.125$).

Table 6-3 Association between PROGRESS-Plus characteristics and weight change from one- to five-years

Exposure characteristic (number of observations)	Category	Adjusted coefficient (95% CI)	P-value
Ethnicity (n=683)	White	Ref	-
	Ethnic minorities (excluding white minorities)	1.19 (-1.79, 4.17)	0.434
Occupation (n=696)	Employed	Ref	-
	Self-employed	-0.27 (-2.54, 2.00)	0.816
	Unemployed	-0.05 (-3.356, 3.26)	0.978
	Student	-5.33 (-12.75, 2.08)	0.158
	Retired	-1.67 (-3.08, -0.27)	0.020
	Unable to work	-0.67 (-4.32, 2.99)	0.720
	Other (carer, home-maker, voluntary work)	-4.09 (-8.62, 0.43)	0.076
Gender (n=708)	Female	Ref	-
	Male	1.15 (-0.24, 2.54)	0.103
Education (n=642)	University degree or equivalent, or higher	Ref	-
	Post-secondary education	2.41 (-1.46, 6.28)	0.221
	A-levels or equivalent	0.81 (-0.92, 2.53)	0.358
	GCSEs or equivalent	-0.65 (-2.27, 0.97)	0.432
	No formal qualifications attained	-2.20 (-5.58, 1.18)	0.202
Socioeconomic status Indices of Multiple Deprivation (n=708)	1 (most deprived)	Ref	-
	2	-1.61 (-4.31, 1.08)	0.240
	3	-1.30 (-3.86, 1.26)	0.319
	4	-0.07 (-2.83, 2.69)	0.961
	5 (least deprived)	-1.70 (-4.61, 1.22)	0.253
SES Household income (n=547)	<£20 000	Ref	-
	£20 000 to £39 999	-0.50 (-2.37, 1.18)	0.509
	≥£40 000	0.34 (-1.51, 2.19)	0.718
Other family members participating (n=500)	Yes	Ref	-
	No	0.95 (-2.46, 4.35)	0.585
Age (n=708)	N/A	-0.11 (-0.16, -0.06)	<0.001

A multivariable model was performed to assess the association between the exposure PROGRESS-Plus characteristic and weight change. Each model was adjusted for intervention group, baseline weight, weight change between baseline and one-year, research centre, and source of the five-year weight data.

The final sensitivity analysis was of all independent variables included in a single model, which adjusted for intervention group, baseline weight, weight change between baseline and one-year, research centre, and source of the five-year weight data (full results available in Supplementary Table 4). In this model, older age at baseline remained associated with lower weight regain or greater weight loss (coefficient -0.15 (95% CI -0.25, -0.04), $p=0.008$). The remaining results from this model were broadly consistent with the primary analyses, with the exception that being male was associated with greater weight regain or lower weight loss (coefficient 2.05 (95% CI 0.02, 4.08), $p=0.048$) and being unable to work (compared to being employed) was associated with lower weight regain or greater weight loss (coefficient -5.59 (-10.86, -0.32), $p=0.038$).

6.6 Discussion

In this study, I explored inequalities in weight change following participation in a weight loss intervention using data from the WRAP trial. Given that 55.5% of participants regained weight between the one- and five-year follow up time points, the coefficients produced from the regression analyses were interpreted as indicating either less weight regain or greater weight loss compared to the reference group. I found that age at baseline was correlated with weight change between one- and five-years, showing that older participants experienced less weight change, and this effect was consistent across models that only used study-measured data and a model controlling for all other PROGRESS-Plus characteristics. No association was observed in the primary analysis between weight change between one- and five-years and other PROGRESS-Plus characteristics (ethnicity, occupation, sex, education, indices of multiple deprivation, household income) included in the WRAP trial, although in a sensitivity analysis controlling for all PROGRESS-Plus characteristics being male was associated with greater weight regain or lesser weight loss.

6.6.1 Comparison with existing literature

As shown in Chapter 2 (systematic review), and Chapters 3-5 (IPD meta-analysis), inequalities have previously been considered in trial participation and intervention uptake, intervention adherence, and at one-year follow up both in the WRAP trial and other UK-based trials of behavioural weight management interventions ¹⁸⁷. This study is the first to consider inequalities in weight change in the longer term (i.e., at the five-year time point).

In Chapter 5, I found that behavioural weight management interventions had a greater effect in men (versus women) and people of White (versus ethnic minority) ethnicity. I did not find evidence that age predicted intervention effectiveness; however, I did find evidence that older age at baseline was associated with lower weight at 12-month follow up in the overall trial cohort. This may suggest that the findings in this chapter are a continuation of that trend.

There may be several reasons why older participants regained less weight than younger participants. First, in WRAP, older participants tended to have better attendance at intervention sessions ³⁴⁸. As higher levels of attendance are more likely to lead to clinically significant weight loss ^{349,350}, this increased level of attendance may lead to longer lasting

effects of the intervention. Second, healthcare behaviour patterns of older people are generally different to those of younger people. Older adults experience fewer barriers in accessing primary care ¹⁹⁷, meaning they are more likely to have regular consultation with healthcare professionals and may have greater healthcare need to focus on behaviours that could affect their weight. Further, specifically in terms of weight management, older people are more likely to be offered access to a weight management intervention in routine practice ¹⁹⁹. Third, biological factors related to ageing could affect long term weight loss maintenance following participation in a weight loss trial. As participants reach an age of 65 years and older, a reduction in appetite and increased rate of loss of muscle tissue has been observed ^{351,352}. This may partly explain the lesser weight regain in older participants in the WRAP trial, especially as the mean age at baseline was 55.7 years old; at the five-year follow up the average participant age is above 60. Finally, factors associated with being an older person may make it easier to attend or maintain behaviours associated with maintaining weight loss. For example, older adults may be less likely to be currently raising children or have a full-time job.

6.6.2 Strengths and limitations

This study is the first to consider if there are inequalities in weight loss maintenance following participation in a weight loss trial at the five-year follow up time point. The demographics of the WRAP trial sample are similar to that of the UK-population in terms of socioeconomic status and ethnicity ³⁴⁸, whereas the demographic makeup of research trials is often more affluent than that of the population.

A limitation of this study is the large amount of missing data for the primary outcome; complete outcome data were available for 55.5% of the total sample ³⁵³. This level of missing data is common in trials of weight management interventions – the estimated retention rate in a systematic review of these trials at the one-year time point is 63%, and was 65% in WRAP ²⁰⁴. Despite this, those with and without missing data were similar with regards to the PROGRESS-Plus characteristics, indicating the sample was unlikely to have been biased by the missing data. Furthermore, the results of my sensitivity analyses conducted to test the robustness of the data were consistent with the primary analyses.

A further limitation of this study is the homogeneity of the sample, especially regarding ethnicity. The majority (94%) of the participants were self-described as White British, which limited the extent I could explore inequalities in weight change by ethnicity. This is reflective of the issue of diversity in clinical trials; those of ethnicities other than white are typically underrepresented^{354–356}. The sensitivity analyses conducted broadly supported the results of the primary analyses, with the exception that when all PROGRESS-Plus inequality characteristics included in the study were controlled for, associations between gender and a category of occupation (unable to work) were identified.

6.6.3 Conclusions

Despite obesity being socially patterned, I did not find consistent evidence of inequalities in weight regain, or weight loss, following weight loss intervention, with the exception of age. This may represent evidence of an absence of inequalities in who regains weight following weight loss intervention or may be indicative of the analyses being conducted in a single trial. Younger participants of behavioural weight management interventions may need additional support to maintain weight loss following intervention. However, overall, these findings support the continued use of behavioural weight management interventions as part of a systems-wide approach to reducing obesity and related diseases without widening existing health inequalities. Such an approach would also include population level interventions that could support all people with obesity in maintaining weight after treatment.

Chapter 7 Inequalities in the outcomes of a web-based guided self-help intervention to support weight management during COVID-19 (SWiM-C)

The results presented in this chapter and will be submitted for publication with the citation: Birch JM, Mueller J, Sharp SJ, Kelly MP, Griffin SJ, Ahern AL. Inequalities in the outcomes of a web-based guided self-help intervention to support weight management during COVID-19 (SWiM-C).

7.1 Contributions

I co-designed the baseline demographics survey that participants completed in the SWiM-C trial. I planned and designed this secondary analysis study, wrote the statistical analysis plan, conducted the analysis, and led the writing and development of the manuscript. Julia Mueller, Stephen J Sharp, Michael P Kelly, Simon J Griffin, and Amy L Ahern reviewed the statistical analysis plan. All co-authors contributed to discussions around study design and the draft manuscript.

7.2 Background

As highlighted in Chapter 1 in section 1.5.1, randomised controlled trials (RCTs) are often considered the ‘gold-standard’ in evaluating the effectiveness of interventions and hold prominence in informing evidence-based healthcare.¹⁶⁰ They provide an opportunity to consider the equity-impact of interventions before they are widely implemented. However, they are not always designed or reported in a way that is conducive to informing consideration of health inequalities in intervention effectiveness. The differential effectiveness of the impacts of interventions are often not reported,¹⁵⁹ and the data relevant to the characteristics in the PROGRESS-Plus framework are often not collected at baseline.^{159,162} Demographic data at baseline are typically used to assess successful randomisation and to adjust for baseline imbalances rather than to investigate potential effect modification.¹⁵⁹ Reviews of how many trials consider equity or differential effectiveness of the studied intervention have frequently found that fewer than half of RCTs report any subgroup analyses by the characteristics included in the PROGRESS-Plus framework.^{160,163,164}

I identified a similar pattern in the systematic review of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions in adults in Chapter 2 of this thesis.¹⁸⁷ Particularly given the known inequalities in the prevalence of obesity, such as by ethnicity or socioeconomic status,^{94,95} it is important to consider if there are differential impacts of weight management interventions. To achieve this, it is important that RCTs have equity considerations ‘baked into’ them at the outset to ensure appropriate data across a range of characteristics in which social disadvantage may occur are collected and differential impacts can be considered.³⁵⁷

Inequalities in the prevalence of obesity and the differential effectiveness of public health interventions are known to occur across a broader range of characteristics captured in the PROGRESS-Plus framework. For example, the prevalence of obesity is higher in those who experience food insecurity (an alternative measure of socioeconomic status) or in those who have fewer years of formal education.^{107,358} A contributing factor to few trials considering differential effectiveness across a broader range of the PROGRESS-Plus characteristics has been a lack of data collection across these characteristics at study baseline. In the Supporting Weight Management during Covid-19 (SWiM-C) trial, I used the PROGRESS-Plus framework

when developing the baseline questionnaire to ensure a broad range of characteristics were captured.

In addition to weight, weight management interventions may also impact on other health outcomes. These outcomes may be determinants of weight, but it is also important to consider if the intervention impacts on these outcomes as the intervention could have an adverse unintended impact on outcomes that are not the primary focus of an intervention. These outcomes include physical activity, eating behaviour traits, and mental health.¹⁸⁶

The SWiM-C intervention was developed to support those living with overweight or obesity to manage their weight at a time when many in-person weight management services were paused or moved online due to Covid-19 lockdown restrictions on in-person gatherings. SWiM-C was a web-based, acceptance and commitment therapy (ACT)-based self-help intervention to help adults with overweight and obesity to manage their weight, eating behaviour, physical activity, and mental wellbeing during the Covid-19 pandemic.^{359,360} Whilst difference in weight from baseline to four and 12 month follow up was comparable between SWiM-C and the control group, being in the SWiM-C intervention was associated with increased physical activity at 12 months and a reduction in uncontrolled and emotional eating at four and 12 months compared to the control group.

There are features of the SWiM-C intervention that may make it susceptible to generating inequalities. Digitally delivered interventions require technological literacy, which is often lower in those who are older, with fewer years of education, and with certain cultural backgrounds.^{167,361} Furthermore, the intervention requires health literacy for the intervention content to be understood; health literacy is patterned by several of the PROGRESS-Plus characteristics including education, socioeconomic status (financial deprivation), and age.³⁶² Therefore, it is important to consider if inequalities are generated by interventions that are digitally delivered and requiring high health literacy to take effect.

7.3 Aims

The primary aim was to:

- Identify if there are inequalities in the effectiveness of the SWiM-C intervention on weight change.

The secondary aims were to:

- Identify if there are inequalities in the effectiveness of the SWiM-C intervention in outcomes that are determinants of an individuals' weight.
- Identify if there are inequalities in the effectiveness of the SWiM-C intervention in outcomes where there was a significant intervention effect at four or 12 months.

7.4 Methods

This study analysed data from the Supporting Weight Management during Covid-19 (SWiM-C) trial.

7.4.1 The SWiM-C trial

The SWiM-C trial is a two-armed randomised controlled trial that compared an acceptance and commitment therapy intervention for preventing weight gain to a brief advice wait-list control group. SWiM-C was pre-registered with ISRCTN on 28/05/2020 (ISRCTN12107048). Participants were recruited online via social media advertisements and mailing lists accessed through local weight management services, obesity and weight management organisations, and a volunteer database from a previous trial.³⁵⁹

The SWiM-C trial was initiated during my PhD and its development was led by my primary supervisor and other researchers within the team I conducted my PhD in. I designed the baseline demographics survey which contributed to the primary data collection in the trial. Hence, I was able to ensure a comprehensive range of data on the inequality characteristics were collected to enable the analyses presented in this chapter. The overall results at 4- and 12-month follow up have been published.^{359,360}

7.4.2 Participants

To be eligible for participation in the trial, participants were required to: be adults (≥ 18 years old) with overweight or obesity (body mass index ≥ 25 kg/m²), reside in the UK, have a good standard of written English, be willing to be randomised to either the SWiM-C or the brief advice wait-list control intervention, be able to complete online outcome assessments, and own a set of bodyweight scales. Participants were ineligible for inclusion if they had received bariatric surgery in the two years prior to the study.

7.4.3 Intervention

Participants randomly assigned to the SWiM-C intervention received a web-based, ACT-based, guided self-help intervention designed to support adults living with overweight or obesity to prevent weight gain during the Covid-19 pandemic. The intervention focused on helping participants to manage their eating behaviours, increase their physical activity, and protect their mental wellbeing. Twelve weekly 'SWiM sessions' were delivered via an online platform and participants were able to complete these at their own pace. These sessions included psychoeducation (learning about mental health and wellbeing), reflective exercises, and behavioural experiments. Automated email reminders to log in and complete sessions were sent weekly. There was one semi-structured scripted telephone call of around 20 minutes in length, with a SWiM coach. The coaches were trained non-specialists (i.e., with no specialist qualifications or registration for weight management) who had received online training about the principles of ACT and guided self-help. Participants were encouraged to weigh themselves weekly throughout the intervention and to complete reflective and behavioural exercises between intervention sessions. More details on the intervention and its development have been previously published.^{359,360,363}

Those randomised to the brief advice wait-list control received standard advice in a leaflet produced by the European Association for the Study of Obesity on diet, physical activity, and mood during the Covid-19 pandemic. This leaflet was tailored to those living with overweight or obesity.

7.4.4 Randomisation

A 1:1 block randomisation (block size 6) stratified by BMI classification 25–<30, 30–<40, 40+ kg/m²) and sex (male, female) was used to allocate participants to study arms. The randomisation sequence was computer-generated by the trial statistician and incorporated into the trial database by the trial manager; this sequence was unknown to all other personnel involved in the study.

7.4.5 Outcomes

The primary outcome was self-reported weight (kg) at 12 month follow up.

Secondary outcomes were cognitive restraint (control of food intake), uncontrolled eating (losing control over eating when feeling hungry or exposed to external stimuli), and emotional eating (propensity to overeat in response to negative mood; scores 0-100, assessed using the Three-Factor Eating Questionnaire);³⁶⁴ physical activity (total volume of physical activity in MET-mins per week assessed using International Physical Activity Questionnaire (IPAQ));³⁶⁵ depression symptoms (Patient Health Questionnaire (PHQ-8),³⁶⁶ scored 0-24 with lower scores indicating better mental health); anxiety symptoms (Generalised Anxiety Disorder-7 (GAD-7),³⁶⁷ scores 0-21 with lower scores indicating better mental health); wellbeing (ICECAP-A, a score between 0 and 1 with a higher score indicating higher wellbeing);³⁶⁸ and experiential avoidance (defined as “attempts to control or change unwanted internal experiences when doing so causes harm”; AAQW-R, scores 10-70 with lower scores indicating less experiential avoidance and more psychological flexibility).³⁶⁹

The PROGRESS-Plus characteristics informed the baseline data collected from participants, and I have considered all the characteristics data were collected on as potentially interacting with intervention group across all outcomes under consideration in this study.

For each characteristic, I identified survey questions that reflected both the definitions of the PROGRESS-Plus characteristics outlined by O’Neill and colleagues³¹ and the contemporary situation of the Covid-19 lockdown measures that were in place when this trial was initiated (such as restrictions on socialising, work and travel). The final survey is included in Appendix 3, Supplementary Material (Chapter 7).

For 'Place of residence', I chose two variables (access to private or communal garden and time to nearest park) to reflect the urban versus rural nature of the PROGRESS-Plus characteristic definition and, given the restrictions on travel and outdoor socialising and the association between green space and wellbeing, people's local access to green space.³⁷⁰

I similarly chose two questions about occupation to include, reflecting both the participant's usual occupation and to consider what their current work situation was, as many people had the nature of their jobs changed due to the pandemic – for example, working from home rather than an office. It was not possible to collect postcodes to calculate IMD due to data management restrictions; instead, I used the Food Insecurity Experience Scale.³⁷¹ I chose this because the prevalence of food insecurity is increasing in the United Kingdom³⁷² and it gives an indication of self-perceived socioeconomic status.

There are known associations between social support and outcomes of public health interventions (greater positive social support associated with greater intervention effect); therefore, I chose to capture this in two forms. First, data on marital status was collected to capture participants' romantic relationships and consider if this impacts upon intervention effect. Second, perceived social support was collected using the F-SozU K-6 questionnaire due to the nature of the Covid-19 lockdowns in preventing in-person socialising.³⁷³ The remaining characteristics considered (ethnicity, sex, education, and age) are frequently captured in public health trials and are known to be correlated with both obesity and effectiveness of some interventions.^{92–95}

These variables were coded in the analyses using the below categories; the reference group for each characteristic is in bold:

- Place of residence: Access to private or communal garden (**Yes**/No)
- Place of residence: Time to nearest park (1-5 mins/6-10 mins/11-20 mins/21-30 mins/More than 30 mins, *treated as **continuous** for interaction analyses*)
- Race/ethnicity: Ethnicity (**White (including White minorities)**/Ethnic minority)
- Occupation: Usual Occupation (**Employed full-time or self-employed**/Employed part time/Full-time education/Retired/Sick or disabled/Unemployed or other)

- Occupation: Covid work situation (**Travelling to place of work**/Usual occupation but working from home/Furloughed or unable to carry out usual occupation/Retired/Sick or disabled/Unemployed or other)
- Gender/sex: Sex (**Female**/Male)
- Education: Education (**Below post-secondary (up to and including A-levels)**/Post-secondary)
- Socioeconomic status: Food insecurity (assessed using the Food Insecurity Experience Scale, coded as **No food insecurity**/Some food insecurity)
- Social capital: Marital status (**Single**/Married, civil partnership or cohabiting/Widowed or separated or divorced)
- Social capital: Perceived social support (assessed using F-SozU K-6; average scores 1-5 across six questions. Higher average scores indicate greater perceived social support; *treated as **continuous** for interaction analyses*)
- Plus: Age (*treated as **continuous** (in years) for interaction analyses*)

7.4.6 Statistical analysis

Data were analysed using Stata v17 (StataCorp 2021, Stata Statistical Software: Release 17. Statacorp LLC., College Station, TX, USA). For each outcome, I used multivariable linear regression to estimate the interaction between randomised group and each PROGRESS Plus characteristic on that outcome, adjusting for the baseline value of the outcome, age, and sex. The intervention effect (versus control) and 95% confidence interval were presented within each PROGRESS-Plus characteristic subgroup, together with the interaction estimate, 95% confidence interval and p-value for the interaction. Participants with missing data were excluded from the analysis.

As this study is exploratory in nature, I decided to not adjust for multiple analyses.³⁷⁴ Given the many analyses presented in this study, there is an increased risk of multiplicity (a Type I error – rejecting the null hypothesis incorrectly) as the chance of obtaining p-values of less than 0.05 is increased due to the number of tests being performed. Performing adjustments, such as the Bonferroni correction, may inadvertently increase the risk of Type II errors (where the null hypothesis is not rejected when it is false).³⁷⁵ The issue of multiplicity can be

addressed by having a clear rationale based in evidence or theory for each performed test across the outcome measures of interest.^{375,376} Furthermore, it is suggested that adjusting multiplicity should be conducted in confirmatory trials, rather than exploratory analyses such as those presented in this study.³⁷⁴ Instead, caution is taken when interpreting the results of the interactions between the inequality characteristics and randomised group. Qualitative judgement is used when interpreting results to consider patterns across the outcomes and inequality characteristics.

7.5 Results

A total of 388 participants were randomised to the SWiM-C intervention or the brief advice wait-list control; 266 (69.3%) participants had weight data available at 12 months. Previous analyses have showed that those with missing weight data at twelve months were similar to those without missing data for sex, ethnicity, education, marital status, and age; although participants with obesity were more likely than those without to have missing weight data at 12 months.³⁶⁰

Table 7-1 shows the baseline PROGRESS-Plus characteristics of the participants by randomised group. Mean age was 50.3 (SD 13.8) years, and most participants identified as White (94%), employed full-time or self-employed (59%), female (78%), having post-secondary education (73%), having no food insecurity (67%), and being married, in civil partnership, or co-habiting (72%).

Table 7-1 Sample characteristics of the SWiM-C trial by trial arm

Characteristic	Standard advice (n=196) n (%)	SWiM-C (n=192) n (%)	Total sample (N=388) n (%)
Access to private or communal garden (Place of residence)			
Yes	170 (87)	166 (87)	336 (87)
No	26 (13)	26 (13)	52 (13)
Time distance to nearest park (Place of residence)			
1-5 mins	84 (43)	78 (41)	162 (42)
6-10 mins	59 (30)	56 (29)	115 (30)
11-20mins	33 (17)	36 (19)	69 (18)
21-30mins	9 (5)	13 (7)	22 (6)
More than 30mins	10 (5)	8 (4)	18 (5)
Don't know	1 (1)	1 (1)	2 (1)
Ethnicity (Race/ethnicity)			
White (including white minorities)	183 (93)	182 (95)	365 (94)
Ethnic minority	11 (6)	9 (5)	20 (5)
Prefer not to say	2 (1)	1 (1)	3 (1)
Usual occupation (Occupation)			
Employed full-time or self-employed	114 (58)	116 (60)	230 (59)
Employed part-time	30 (15)	18 (9)	48 (12)
Full-time education	3 (2)	8 (4)	11 (3)
Retired	27 (14)	34 (18)	61 (16)
Unable to work due to sickness or disability	5 (3)	5 (3)	10 (3)
Unemployed or other	17 (9)	11 (6)	28 (7)
Covid work situation (Occupation)			
Travelling to place of work	35 (18)	43 (22)	78 (20)
Usual occupation but working from home	88 (45)	81 (42)	169 (44)
Furloughed/unable to carry out usual occupation	21 (11)	15 (8)	36 (9)
Retired	30 (15)	33 (17)	63 (16)
Unable to work due to sickness or disability	6 (3)	4 (2)	10 (3)
Unemployed or other	16 (8)	16 (8)	32 (8)
Sex (Gender/sex)			
Female	152 (78)	151 (79)	303 (78)
Male	43 (22)	41 (22)	84 (22)
Prefer not to say	1 (1)	0 (0.0)	1 (0)
Education (Education)			
Below post-secondary (up to and including A-levels)	50 (26)	50 (26)	100 (26)
Post-secondary	142 (73)	140 (73)	282 (73)

Other	3 (2)	2 (1)	5 (1)
Prefer not to say	1 (1)	0 (0)	1 (0)
Food insecurity (<i>Socioeconomic status</i>)			
Mean (SD)	0.74 (1.4)	0.64 (1.2)	0.69 (1.3)
Range	0-8	0-6	0-8
No food insecurity	128 (65)	131 (68)	259 (67)
Some food insecurity	68 (34)	61 (32)	129 (33)
Marital status (<i>Social capital</i>)			
Single	36 (18)	31 (16)	67 (17)
Married, civil partnership or co-habiting	140 (71)	140 (73)	280 (72)
Widowed or separated or divorced	18 (9)	21 (11)	39 (10)
Prefer not to say	2 (1)	0 (0)	2 (1)
Perceived social support (<i>Social capital</i>)			
Mean (SD)	3.81 (1.0)	3.82 (0.9)	3.81 (1.0)
Range	1-5	1.3-5	1-5
Age (<i>Plus</i>)			
Mean (SD) years	49.9 (13.2)	50.7 (14.3)	50.3 (13.8)

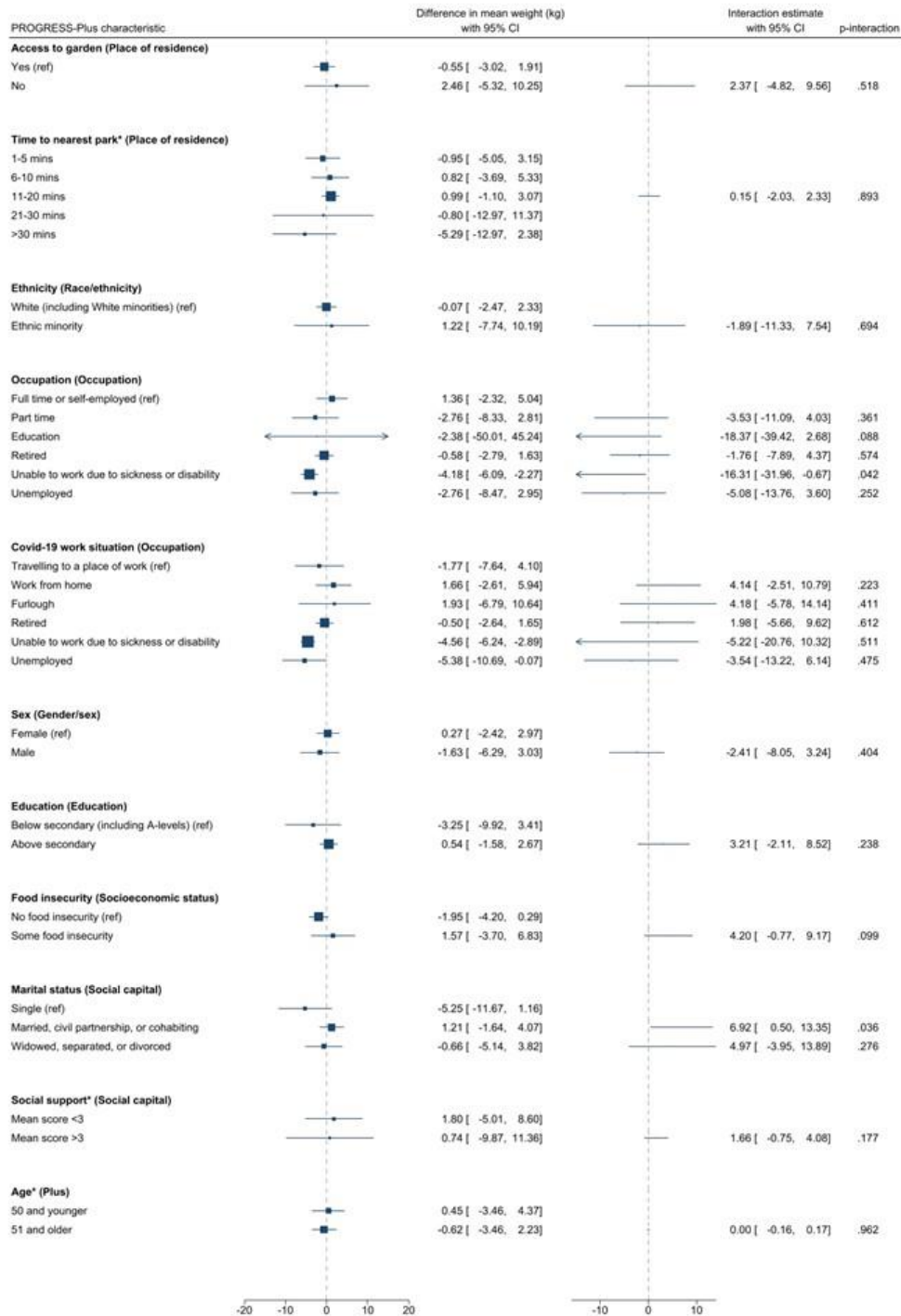
7.5.1 Primary outcome: weight at 12 months

I found some evidence to suggest there may be inequalities in the effectiveness of SWiM-C on weight at 12 months (Figure 7-1).

For usual occupation, the intervention had a greater effect (i.e., lower weight at follow up) on those who were unable to work due to sickness or disability (-4.18, 95% CI -6.09, -2.27) when compared to those who were working full-time or self-employed (1.36 kg, 95% CI -2.32, 5.04, p-interaction=0.042). The intervention also had a greater effect on weight in those who were single (-5.25, 95% CI -11.67, 1.16) than in those who were married, in a civil partnership or co-habiting (1.21kg higher weight at follow up, 95% CI -1.64, 4.07, p-interaction=0.036). I did not find evidence of an interaction by access to garden, time to nearest park, ethnicity, Covid-19 work situation, sex, education, food insecurity, social support, or age.

a)

b)



*denotes characteristic analyses as continuous

Figure 7-1 a) Stratified analyses showing difference in mean weight at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

7.5.2 Secondary outcomes: determinants of weight

I considered if there were inequalities in effect of the intervention on three eating behaviour traits (cognitive restraint, uncontrolled eating, and emotional eating), physical activity, depression symptoms, and anxiety symptoms. I found evidence of a differential intervention effect on the three eating behavioural traits (cognitive restraint, uncontrolled eating, and emotional eating) by marital status but not by the other PROGRESS-Plus characteristics considered.

The intervention had a greater effect on cognitive restraint (Figure 7-2) in those who were single (6.64 points higher at follow up, 95% CI -0.74, 14.01) versus those who are married, in a civil partnership or co-habiting (-0.42 point reduction at follow up, 95% CI -3.59, 2.75, p -interaction=0.045). This was also observed for uncontrolled eating (Figure 7-3); the intervention had a greater effect in those who were single (-12.6 point change at follow up, 95% CI -20.72, -4.50) versus those who were married, in a civil partnership or co-habiting (-3.65, 95% CI -6.66, -0.64, p -interaction=0.044). For emotional eating (Figure 7-4), I found the intervention had a greater in those who were single (-24.12 point reduction at follow up, 95% CI -37.36, -10.88) versus those who were separated (12.87, 95% CI -4.39, 30.12, p -interaction=0.002). There was suggestion that the intervention had a greater effect in those who were single when compared to those who were married, in a civil partnership, or cohabiting (-6.22 point reduction at follow up, 95% CI -11.49, -0.96, p -interaction=0.103) but the evidence was not conclusive.

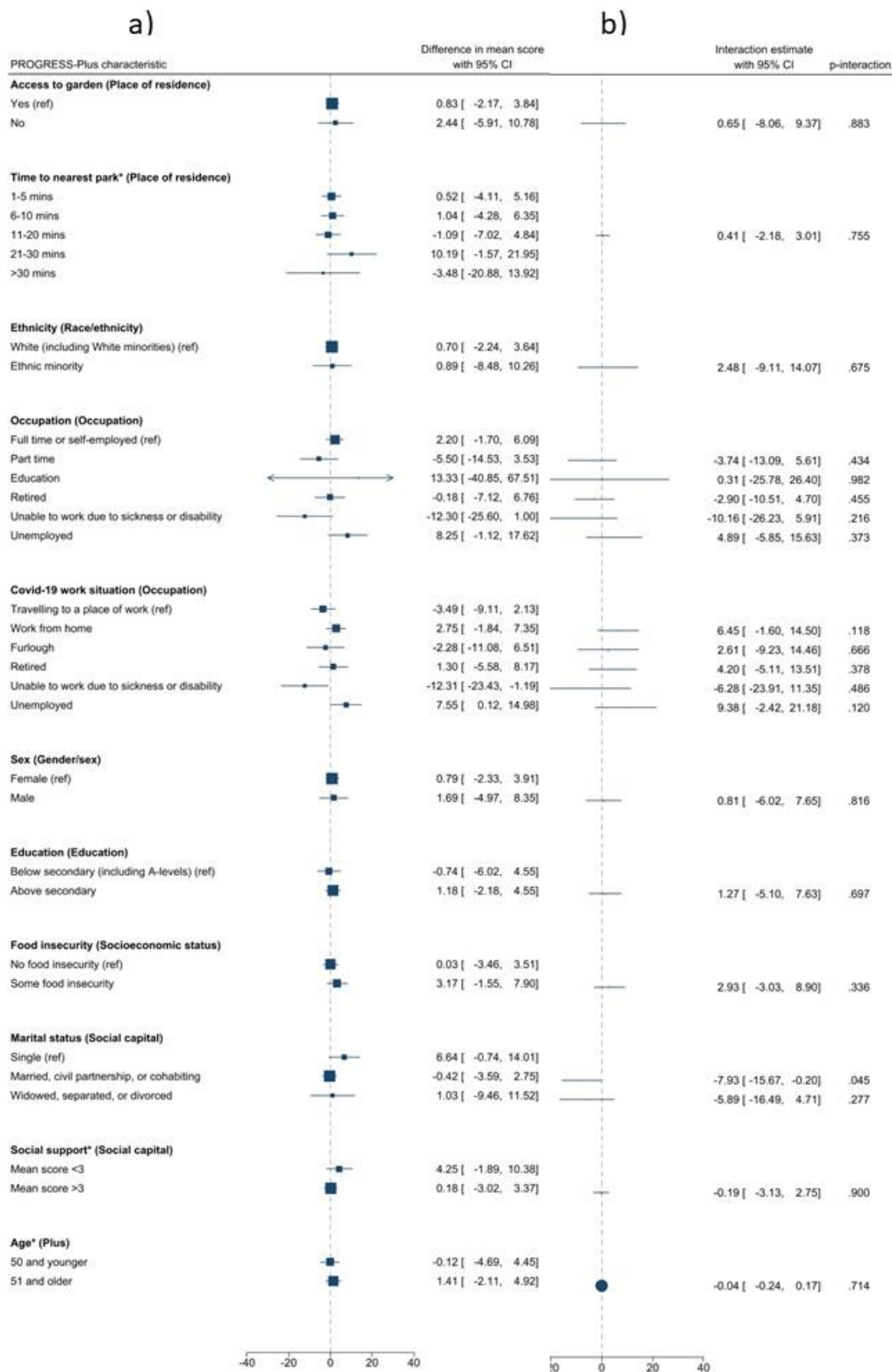


Figure 7-2 a) Stratified analyses showing difference in mean cognitive restraint at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

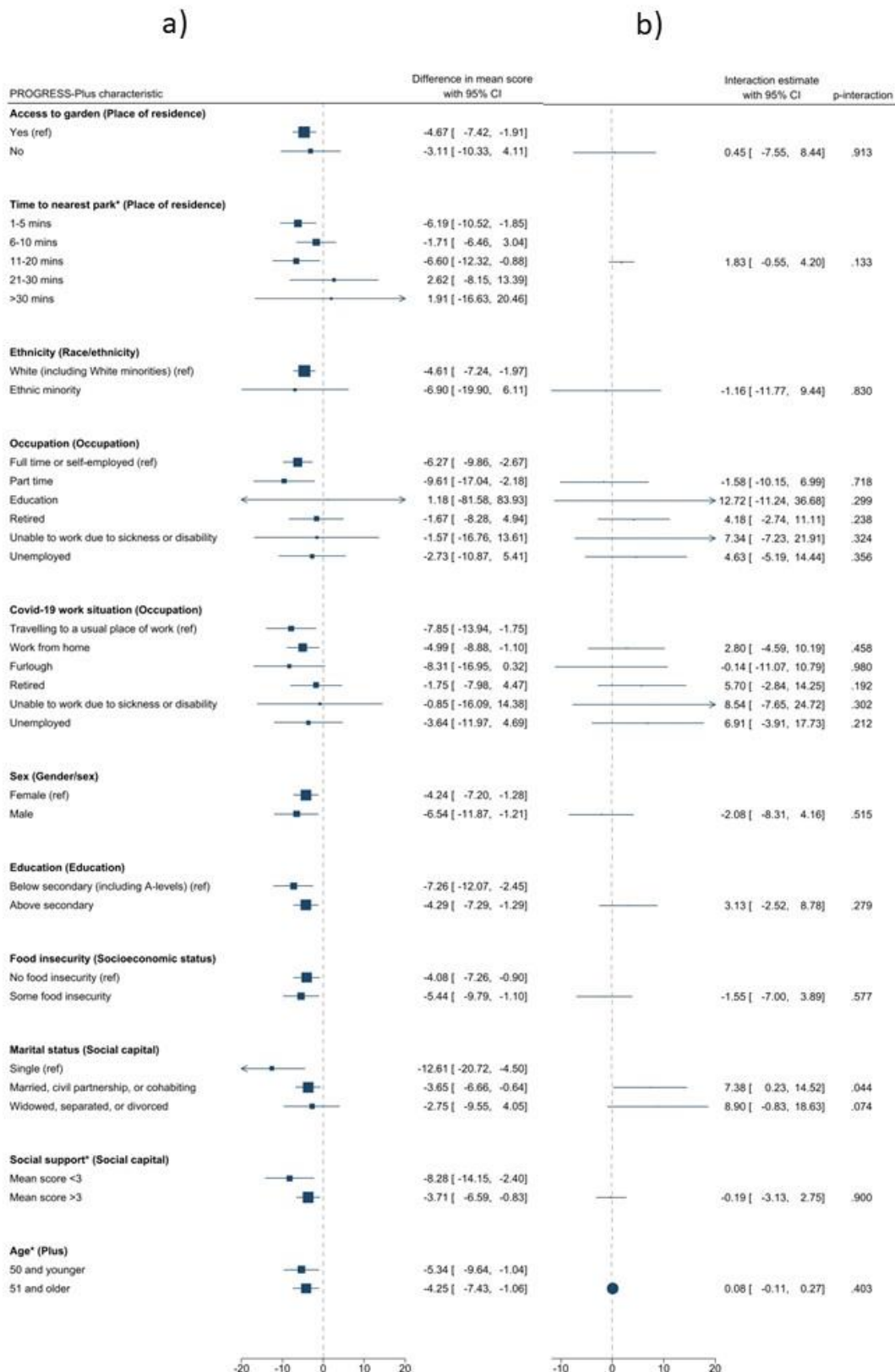


Figure 7-3 a) Stratified analyses showing difference in uncontrolled eating at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

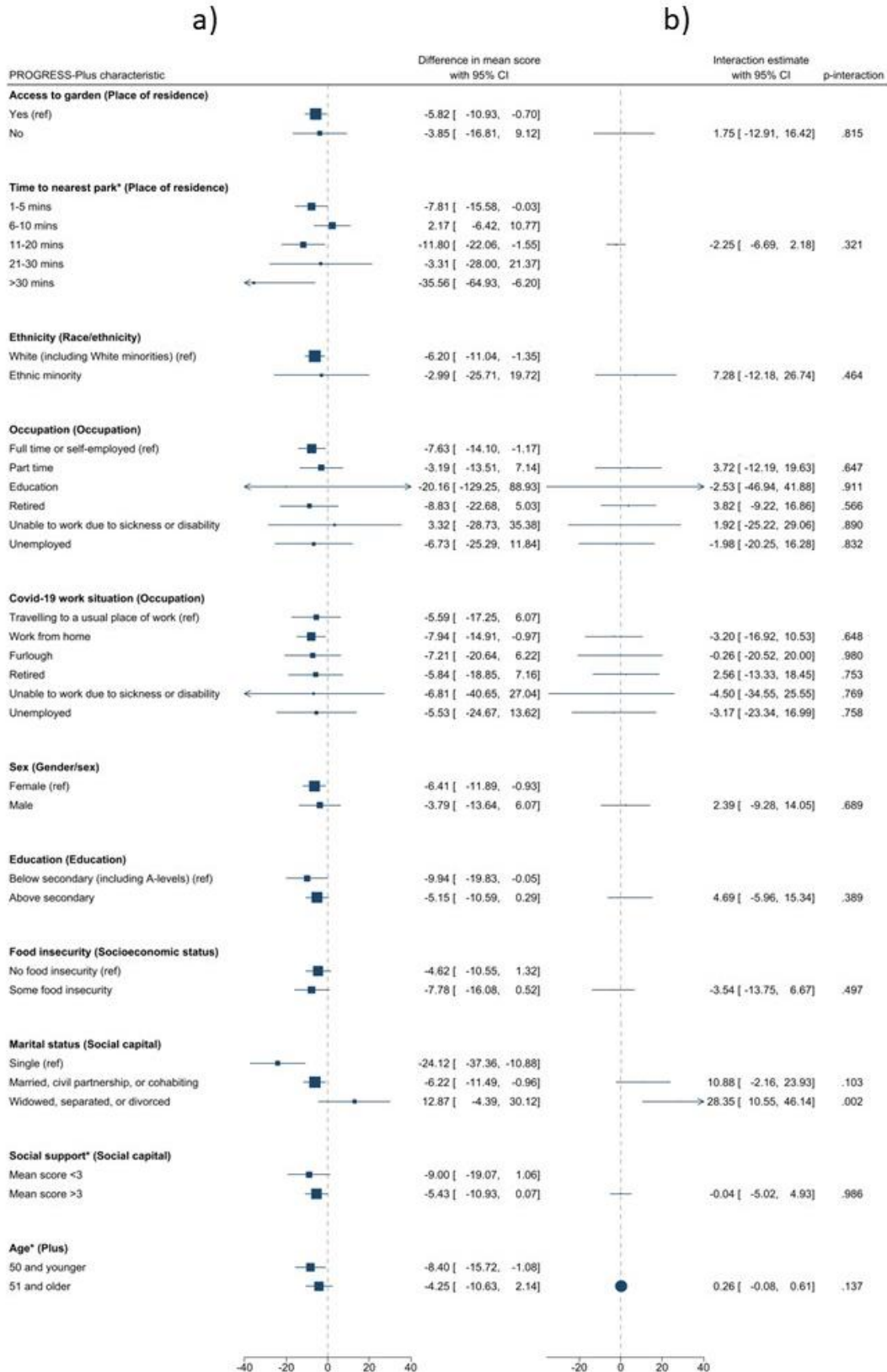


Figure 7-4 a) Stratified analyses showing difference in emotional eating at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

I did not find conclusive evidence of a differential effect of the SWiM-C intervention by the PROGRESS-Plus characteristics on physical activity (Figure 7-5). There was a suggestion that the intervention had a greater effect on physical activity in those who experienced some food insecurity (24.43 more MET-mins of physical activity at follow up, 95% CI 4.45, 44.42) versus those who experienced no food insecurity (3.06, 95% CI -7.54, 13.66, p-interaction=0.051).

There was evidence of differential effect of the intervention on depression symptoms (Figure 7-6) and anxiety symptoms (Figure 7-7). The intervention had a greater impact on depression symptoms for those who were single (-3.76 point reduction at follow up, 95% CI -7.35, -0.17) versus those who were married, in a civil partnership, or co-habiting (0.26, 95% CI -0.86, 1.38, p-interaction=0.025). There was also some suggestion that the intervention had a greater effect on depression symptoms in those with below secondary education (-1.77, 95% CI -3.68, 0.14) versus above secondary education (0.20, 95% CI -0.97, 1.37, p-interaction=0.073) and in those with less social support (1-point increase in social support associated with a lesser intervention impact of 0.89 points [95% CI -0.13, 1.91, p-interaction=0.088]). For anxiety symptoms, I found evidence of a greater intervention effect in those in those who were retired (1.77, 95% CI 0.43, 3.12) versus travelling to a place of work as their Covid-19 work situation (2.29, 95% CI -0.12, 4.70, p-interaction=0.029), below secondary education (-1.66, 95% CI -3.45, 0.12) versus above secondary education (0.89, 95% CI -0.16, 1.95, p-interaction=0.015), and being single (-2.59, 95% CI -5.96, 0.79) versus being married, in a civil partnership, or co-habiting (0.80, 95% CI -0.21, 1.81, p-interaction=0.047).

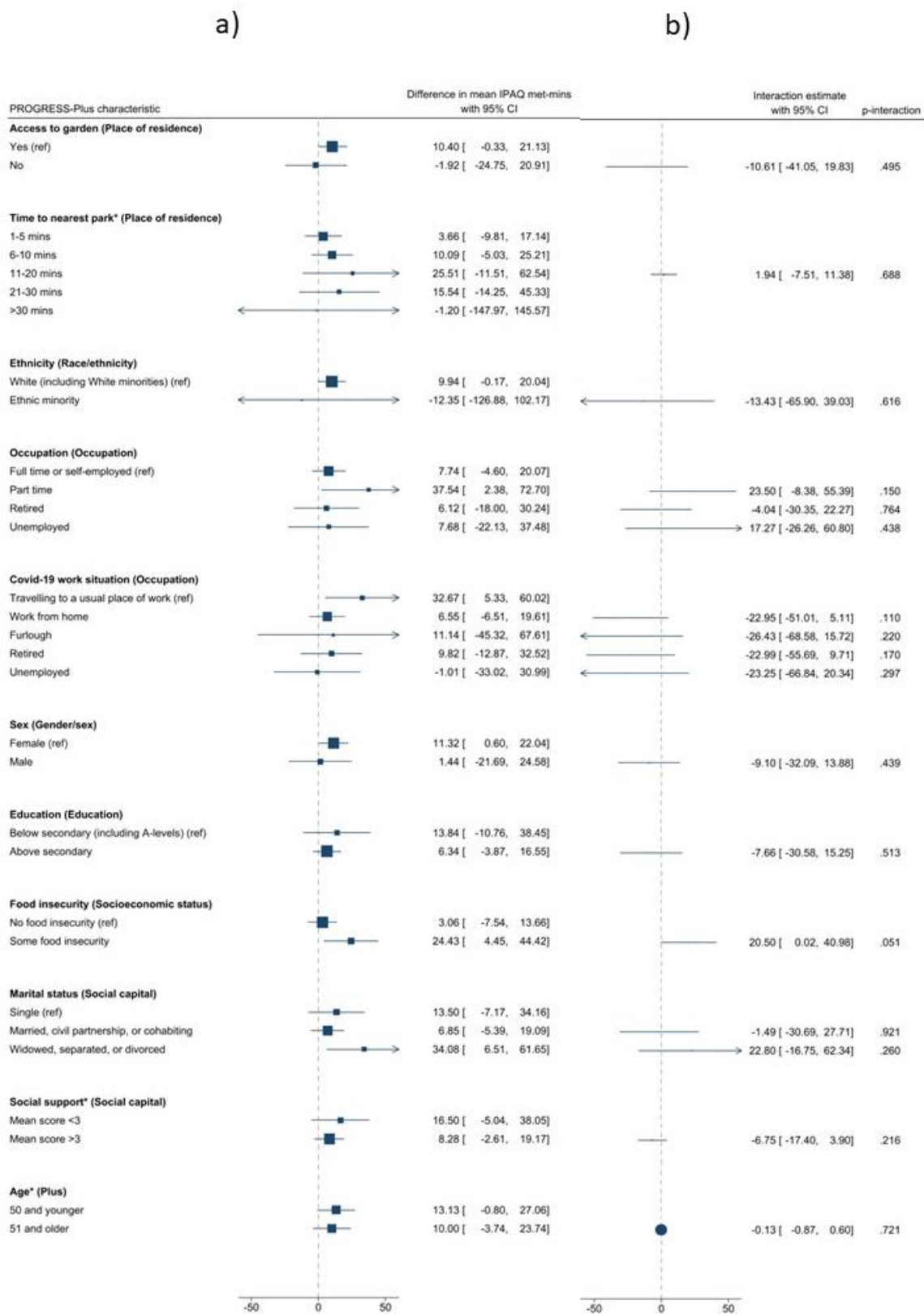


Figure 7-5 a) Stratified analyses showing difference in mean physical activity in MET-mins at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

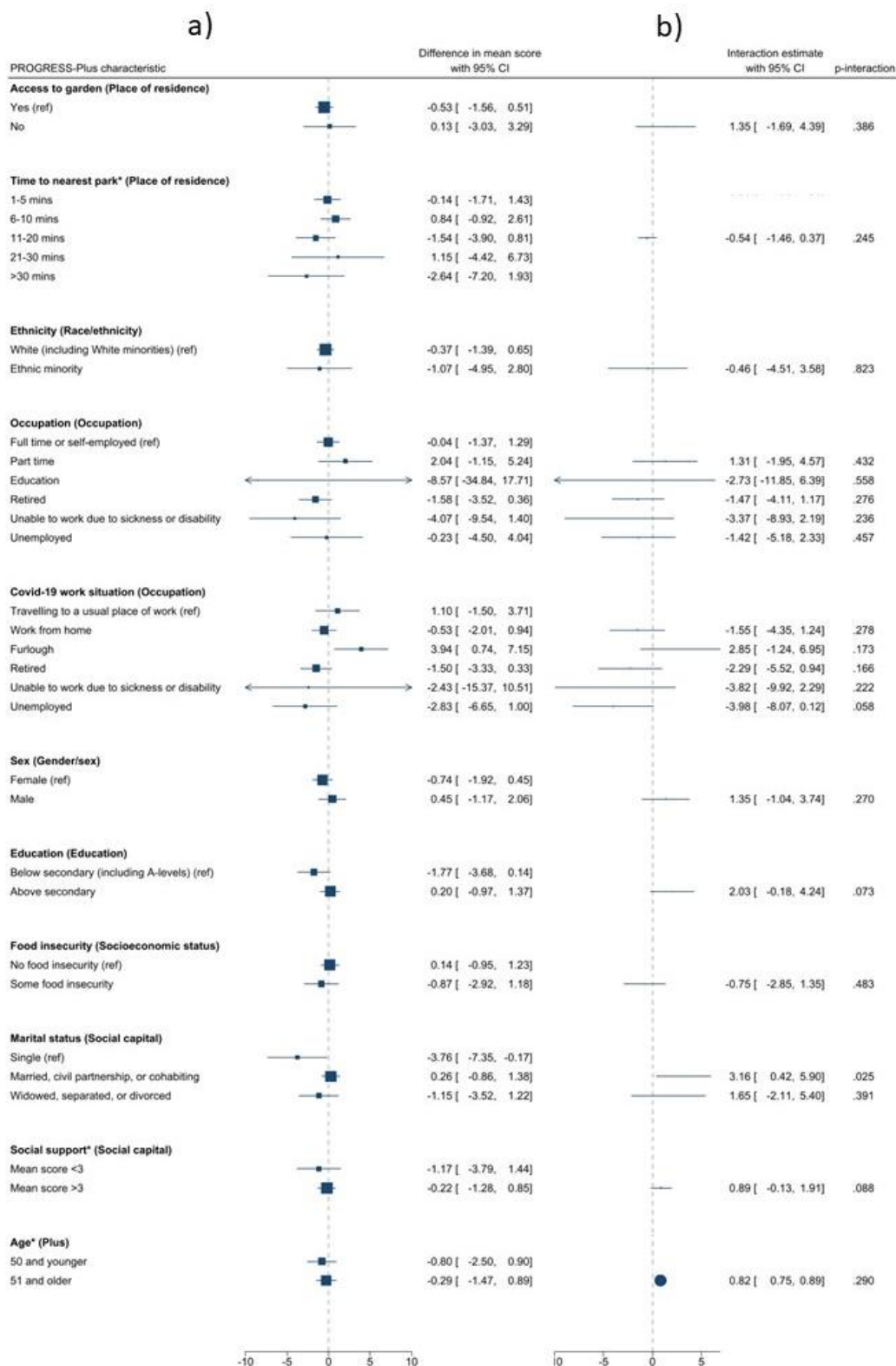


Figure 7-6 a) Stratified analyses showing difference in mean depression symptoms at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

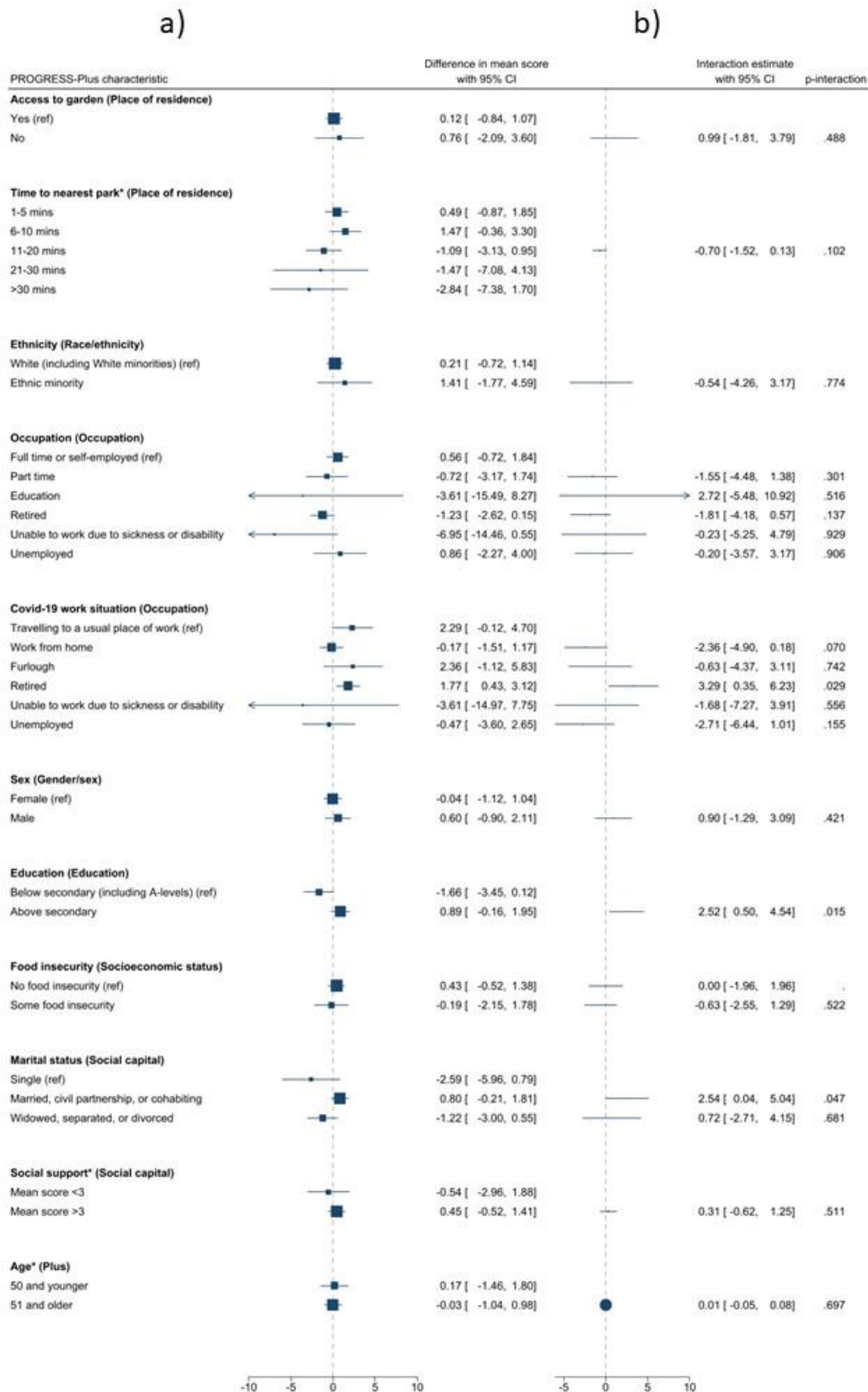


Figure 7-7 a) Stratified analyses showing difference in mean anxiety symptoms at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

7.5.3 Secondary outcomes: outcomes with an overall significant intervention effect

There was evidence of a differential effect of the SWiM-C intervention on wellbeing (assessed using ICECAP-A, Figure 7-8). At follow up, those who were unemployed as their Covid-19 work situation had more improvement in wellbeing (0.15 point higher score at follow up, 95% CI -0.02, 0.32) than those who were travelling to their usual occupation (-0.02, 95% CI -0.10, 0.07, p -interaction=0.02). The intervention had a greater impact on the wellbeing on those with below secondary education (0.06 point higher score at follow up, 95% CI -0.01, 0.13) than on those with above secondary education (-0.01, 95% CI -0.04, 0.03, p -interaction=0.034). There was also a suggestion that the intervention may have had a greater impact on the wellbeing of those who were single (0.10 point higher score at follow up, 95% CI -0.02, 0.22) versus those who were married, in a civil partnership, or co-habiting (0.00, 95% CI -0.03, 0.03, p -interaction=0.075).

There was suggestion that the intervention had a greater impact on experiential avoidance (Figure 7-9) in those who were single (-8.73 point lower score at follow up, 95% CI -16.27, -1.20) versus those who were married, in a civil partnership, or co-habiting (-1.98, 95% CI -4.84, 0.88, p -interaction=0.090). However, the confidence interval around the interaction estimate included zero.

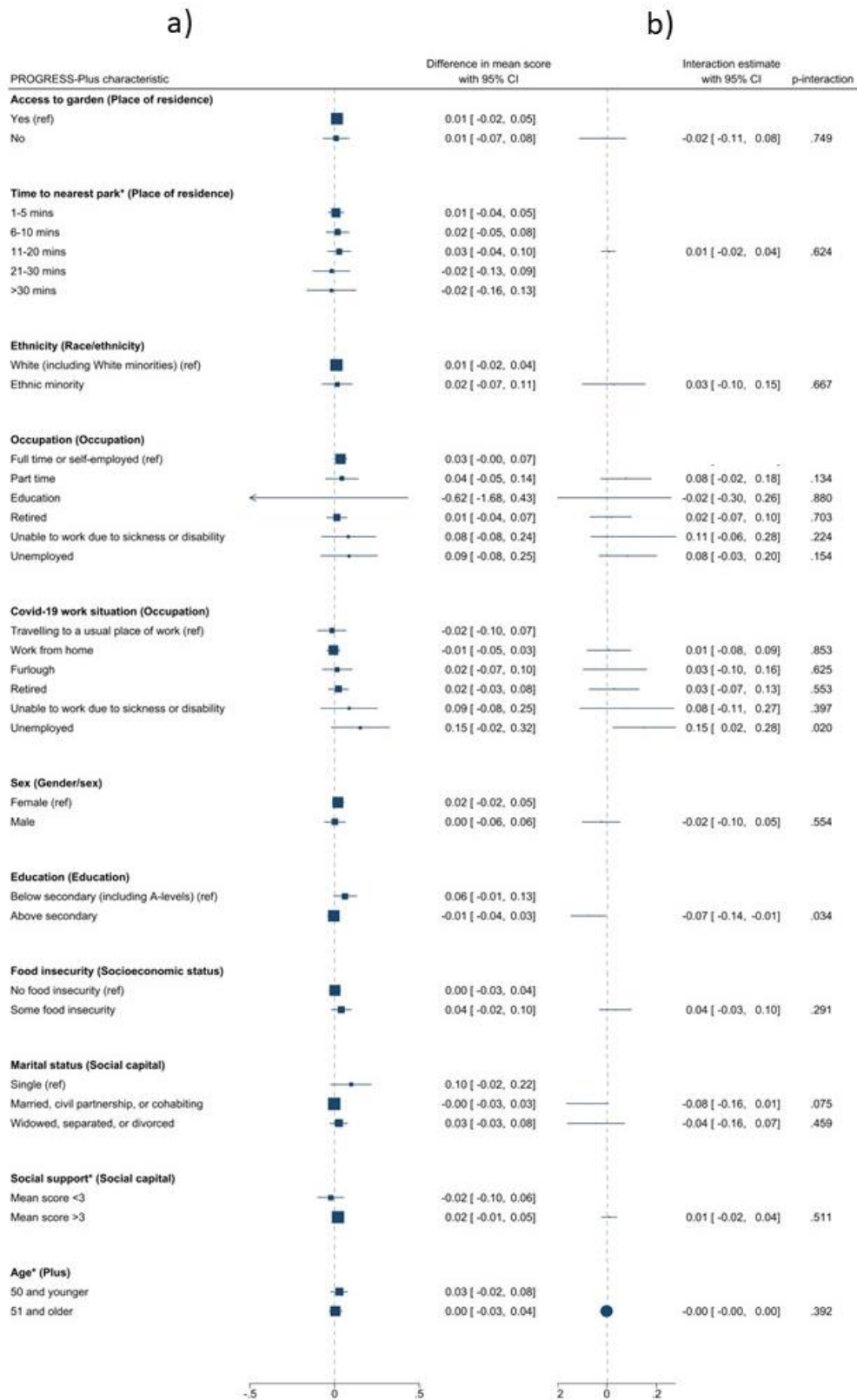


Figure 7-8 a) Stratified analyses showing difference in mean wellbeing at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

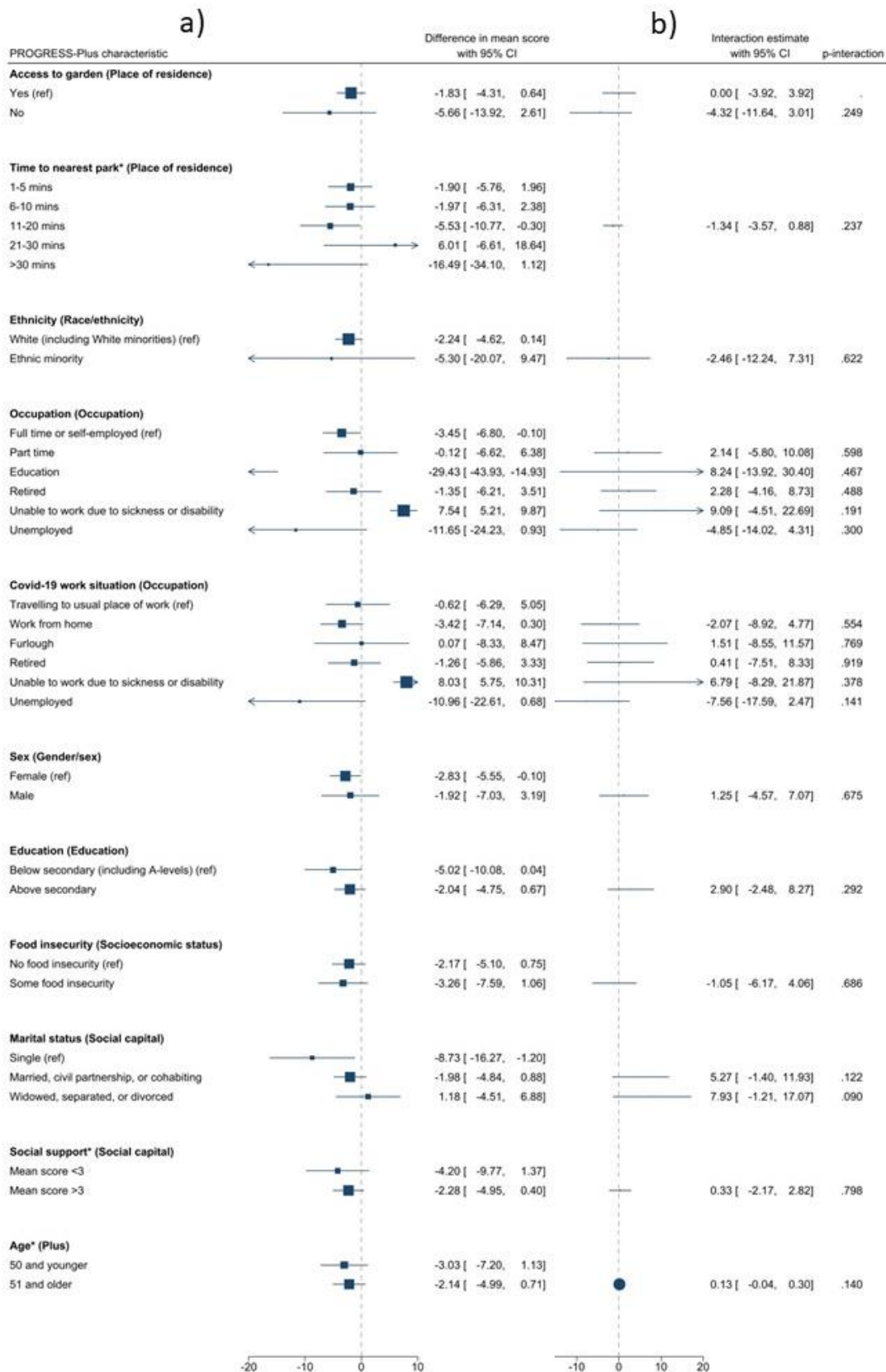


Figure 7-9 a) Stratified analyses showing difference in mean experiential avoidance at 12 months (intervention group minus control) for each characteristic subgroup. b) Estimated interaction i.e. difference in effect of intervention comparing each category of the inequality characteristic with the reference category for that characteristic.

7.6 Discussion

In this exploratory study, I considered if there were differences in the effect of the SWiM-C behavioural weight management intervention across the social gradient. I found some indication the intervention had a greater effect on weight, cognitive restraint, uncontrolled eating, depression symptoms, and anxiety symptoms in single people (versus those who were married, in a civil partnership or co-habiting). There was some evidence of differential effects of the intervention by other characteristics, such as by occupation for weight and education for anxiety symptoms, but these were not consistent across outcomes and should be interpreted cautiously given this is an exploratory study with a large number of analyses. I did not find evidence of a differential intervention effect for most of the PROGRESS-Plus characteristics for which data were collected.

7.6.1 Comparison with existing literature

Previous systematic reviews have highlighted that few studies of behavioural weight management interventions have considered if there is a differential intervention effect by someone's marital status.^{187,377} The two behavioural weight loss and one weight loss maintenance trials that did consider if there was a differential intervention effect by marital status did not find evidence of a difference.^{215,234,378} There has been exploration in the literature about how social support can impact someone's weight and weight management. This social support, especially in romantic relationships and also with wider family, can be beneficial and lead to a greater intervention effect,^{379,380} but it is not always positive. Someone's efforts to manage their weight may be detrimentally affected if they are discouraged from healthier eating, accessing support, and being more physically active by their partner,^{381,382} or have to consider the diet of their family when making their own dietary choices, and this could explain why I observed a consistent difference in health outcomes by marital status in this study. It may be that those who are living as single do not have the same barriers to engaging and enacting intervention content as some people who are living with their partner. These findings are supportive of the literature that explores how to ensure spousal support for weight management is positively harnessed.^{381,383}

It is also likely that, given this study was conducted during the Covid-19 pandemic, factors associated with the restrictions on movement and socialising that were in place at the time may have impacted on who the intervention was effective for. The restrictions that were in place at the time included school closures, travel restrictions, and physical distancing including not being allowed to enter other people's homes.^{384,385} It is likely that these restrictions would have impacted differently depending on someone's marital status. Those who were married, in a civil partnership or cohabiting may be more likely to have children or caring responsibilities. During lockdown restrictions, these caring responsibilities were additional to the usual workloads people had – for example, many people had to home school their children whilst also working full time. These responsibilities may have impacted on actions people who were married, in a civil partnership or cohabiting could take for their own health and could explain why the SWiM-C intervention was less effective in this group.

Across the remaining PROGRESS-Plus characteristics in this study, the analyses suggest that the SWiM-C intervention has a similar effect across all groups. There were some exceptions; I found evidence of a greater intervention effect on weight in those unable to work due to sickness or disability as their usual occupation and on anxiety symptoms and wellbeing in those with above secondary education. These interactions were not consistent across outcomes, unlike the marital status findings, so should be interpreted with caution given the number of analyses I conducted and the resulting increased chance of a Type I error (rejecting the null hypothesis when it is true). Therefore, these results suggest that SWiM-C is unlikely to generate inequalities in weight or other related outcomes through the intervention effect. This is similar to my findings in a previous systematic review, where I found that most individual trials of behavioural weight management interventions did not find evidence of inequalities in intervention effectiveness.¹⁸⁷

7.6.2 Strengths and limitations

A strength of this study is that I was able to consider if there was a differential effect of the SWiM-C intervention across a large number of characteristics in which health inequalities are known to occur. This was possible due to the integration of the PROGRESS-Plus framework when designing the baseline demographics survey, which ensured I could explore if there

were inequalities in the intervention effectiveness across a broad range of characteristics. There are limitations to be noted in this study. Weight and physical activity were self-reported, meaning they may be subject to bias. Commonly, self-reported weight is underestimated and self-reported physical activity has a low-to-moderate correlation with objectively measured physical activity.^{386–390} Additionally, the SWiM-C trial was designed to detect an overall difference between the intervention and control groups on weight, not to detect if there was an interaction between characteristics in which inequalities occur and intervention group. Hence, some of the subgroups did have very small sample sizes. Furthermore, as highlighted in the CONSORT-Equity extension, reporting and publishing such findings is beneficial to systematic reviewers in future who may be able to synthesise published data from several studies when considering health equity in trials in future.¹⁶² Finally, the ability to detect differential effects may be limited by the distribution of that characteristic in the study sample. For example, I analysed ethnicity as a binary variable (White versus Ethnic Minority) due to the number of ethnic minority participants. This may have led to differential effects in some ethnicities not being detected should they exist.

7.6.3 Conclusion

I found that across several outcomes related to weight management there was a greater effect of the SWiM-C intervention in those who were single versus those who were married, in a civil partnership or co—habiting. I found the effect of the SWiM-C intervention to be comparable across the remaining PROGRESS-Plus characteristics, suggesting that this intervention is unlikely to be exacerbating existing health inequalities.

Chapter 8 Discussion

8.1 Introduction

The overall aim of my thesis was to examine the nature and extent of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions in adults. This aim was addressed across five chapters (Chapters 2-7), incorporating a systematic review, an individual participant data meta-analysis (IPD-MA), and two secondary analyses – one using data from a UK trial with extensive five-year follow up data, and one which analysed a trial which used an innovative web-delivery format of an acceptance and commitment therapy-based intervention.

Prior to this thesis, consideration of the differential effects of behavioural weight management interventions was limited to narrative systematic reviews or analyses in individual trials across a small range of characteristics that were inconsistently captured. My comprehensive systematic review in Chapter 2 highlighted these limitations in previous research. It found that most trials did not report whether inequalities were present in intervention uptake, adherence, attrition, or outcomes. A likely reason for this that is individual trials were not sufficiently statistically powered to detect differential effects should they exist.

This limitation was addressed in Chapters 3-5 in the IPD-MA, where data from 13 UK-based trials of behavioural weight management interventions were harmonised to provide the first quantitative synthesis of inequalities in the attendance at, and effectiveness of, behavioural weight management interventions in adults. I did not find evidence of inequalities in attendance or adherence, but I did find evidence that these interventions have a greater effect on those of a White ethnicity (versus ethnic minority groups) and on men (versus women).

Chapters 6 and 7 focused on areas where there was a significant research gap not covered by existing literature. In Chapter 6, I conducted the first analysis of inequalities in weight loss maintenance up to 5 years after a weight management intervention. I found that older age was associated with less weight regain (or greater weight loss) at the five-year follow up timepoint, but did not identify any inequalities by ethnicity, gender, education, IMD, or

household income. In Chapter 7, I examined a more comprehensive range of characteristics in which inequalities may occur than is considered in previous literature and I examined the impact on outcomes other than weight. I found that an acceptance-based intervention to prevent weight gain had a greater effect in those who were single versus those who were married, in a civil-partnership or co-habiting, but did not find evidence of differential effectiveness by place of residence, ethnicity, Covid-19 work situation, sex, education, food insecurity, social support, or age. The analyses I completed in Chapters 6 and 7 are likely underpowered due to the trials not being designed to capture differential intervention effects, but they 1) provide valuable data that has not yet been reported elsewhere, 2) demonstrate a template that can be adopted by other researchers when considering inequalities in trials, and 3) are reported in a way that facilitates future evidence synthesis.

Here in Chapter 8, I discuss the key contributions to the literature made by this thesis (section 8.2), the strengths and limitations of the thesis approach (8.3), the implications for public health policy and practice (8.4), and the implications for research (8.5). In section 8.6 I discuss reflexivity in relation to this thesis and how my pre-PhD experiences informed the development of this thesis, and in 8.7 I highlight the impact of the Covid-19 pandemic on my research. This chapter finishes with the overall conclusion of the thesis (section 8.8).

8.2 Key contributions of thesis and comparison to previous literature

In the discussion section of each individual chapter, I have compared the findings of that study to the wider literature. Here, I discuss the broader contributions this thesis as a whole makes to the literature.

These contributions fit into four themes. First, I have identified several characteristics (ethnicity, gender/sex, and marital status) in which there is evidence of inequalities in the effectiveness of behavioural weight management interventions. There was also evidence of differential post-intervention effect maintenance by age. Second, there were characteristics and intervention stages that I did not find evidence of inequalities by or in. Third, I have provided a comprehensive overview of the reporting of inequality-related data and analyses

in trials of behavioural weight management interventions conducted in economically developed countries, with a greater focus on the UK. Fourth, this thesis advances the field by exploring questions previously unaddressed or under-addressed, such as considering inequalities by a comprehensive range of characteristics, inequalities in web-based interventions, and inequalities in long-term weight maintenance in the years following a weight management intervention.

In Table 8-1, I map where I found evidence of inequalities in behavioural weight management interventions against where there are inequalities in the prevalence of overweight and obesity by the PROGRESS-Plus characteristics. It is important to consider the four contribution themes my thesis makes to the literature within the wider public health context of inequalities in overweight and obesity prevalence. Between January 2007 and June 2020, 3% of adults with a recording of overweight or obesity in their primary care records in England were referred to a weight management programme.³³⁷ This highlights that any inequalities observed in the uptake of, adherence to, or effectiveness of behavioural weight management interventions may be unlikely to be contributing to the overall inequalities in overweight and obesity prevalence observed in the population, given the overall low access of these interventions. Therefore, the importance of addressing such observed inequalities is more focused on addressing and preventing healthcare inequalities and individual-level health inequalities, rather than using behavioural weight management interventions to address inequalities in population-level obesity prevalence.

In sections 8.2.1 to 8.2.4 I outline how each of the chapters in this thesis contributed to each of these four themes and relate this to existing literature. Implications for future research resulting from these contributions are discussed in section 8.5.

Table 8-1 Summary of inequalities in overweight and obesity; prevalence and in the uptake of, adherence to, and effectiveness of behavioural weight management interventions

PROGRESS-Plus characteristic	Overweight and obesity prevalence data (% of population with obesity)	Evidence of inequalities in effectiveness of behavioural weight management interventions presented in thesis (Chapters 2-7)
Place of residence	Regions with highest prevalence (based on Sport England Survey data) ⁹⁸ : North East, North West, East Midlands and West Midlands Regions with lowest prevalence: London and South	<i>No data available</i>
Ethnicity	Asian (57.6) Black (70.8) Chinese (33.1) Mixed (60.1) Other (59.4) White British (65.2) White Other (59.1)	Greater weight loss in those from White (versus ethnic minority) ethnicities (Chapters 2 and 5)
Occupation	Unemployed (65.8) Employed (65.3)	<i>Absence of evidence of inequalities by education observed in the studies conducted for this thesis.</i>
Gender/sex	Female (58.4) Male (69.1)	Interventions were more effective in men than women (Chapters 2 and 5). In Chapter 5, I showed that this difference was likely produced by men in the minimal intervention control groups gaining weight on average, rather than men in the intervention groups losing more weight.
Religion	<i>No data available</i>	<i>No data available</i>
Education	No formal qualifications (71.0) Level 1 and below (lower GCSE, 68.1) Level 2 (GCSEs or equivalent, 68.3) Level 3 (A-Levels, 67.3) Level 4 (Higher education, 60.1)	<i>Absence of evidence of inequalities by education observed in the studies conducted for this thesis.</i>
Socioeconomic status	Indices of multiple deprivation: Most deprived quintile (70.8) Least deprived quintile (59.1)	Interventions had a greater effect in those from the 2 nd least deprived (versus most deprived) quintile (Chapter 5).
Social capital	<i>Data for marital status not available</i>	In an acceptance and commitment therapy-based weight gain

		prevention intervention, the intervention had a greater effect on a range of weight-related outcomes on those who were single (versus married, in a civil partnership, or cohabiting, <i>Chapter 7</i>).
Plus (age)	18-24 (36.9)	Older participants had higher trial uptake and adherence and lower trial attrition than younger participants (<i>Chapter 2</i>).
	25-34 (56.2)	
	35-44 (64.3)	
	45-54 (69.6)	
	55-64 (72.8)	
	65-74 (70.8)	
	75-84 (71.4)	
Plus (disability)	Lives with a disability/disabled (72.2)	<i>No data available</i>
	No disability (61.7)	

8.2.1 Evidence of inequalities in the effectiveness of behavioural weight management interventions

Across Chapters 2, 5, and 7, I found evidence of inequalities in the effectiveness of behavioural weight management interventions by several PROGRESS-Plus characteristics. These characteristics were ethnicity and gender/sex in Chapters 2 and 5 and marital status (as an indicator of social capital) in Chapter 7. I also found evidence of inequalities in weight change between one- and five-years post-intervention by age in Chapter 6. I discuss the contributions this thesis makes to the literature by each of these characteristics in this section.

8.2.1.1 Ethnicity

In Chapters 2 (narrative systematic review) and 5 (IPD-MA) I found evidence that behavioural weight management interventions are more effective in those from White ethnic groups versus those from minority ethnic groups at the 12-month follow up time point. I did not find further evidence in either Chapter 6, which considered if there were inequalities in weight loss maintenance up to five years follow up in the WRAP trial, or in the analyses of a weight gain prevention interventions presented in Chapter 7. However, this may be due to the study design used in these chapters (e.g., analyses in single trials that may not be sufficiently powered to detect a difference in intervention effect by ethnicity).

Relating to other literature, it is likely these inequalities are generated by social and cultural factors rather than genetic and biological variation that occurs between people of different ethnicities. Analysis of cohort studies have found that once the social determinants of health are controlled for, observed inequalities in premature mortality between White and ethnic minority people disappear.³⁹¹ This suggests that it is sociocultural and sociodemographic factors associated with ethnicity that are causing health inequalities by ethnicity.³⁹¹ Ultimately, a large driver of health inequalities by ethnicity is systemic racism and how this affects ethnic minority people. Systemic racism affects someone's socioeconomic conditions – their income,⁴³ education,⁴⁴ job prospects,⁴⁵ where they live,⁴⁶ access to health and other services,^{47,48} and social opportunities.⁵⁰ The stress associated with these conditions have a direct impact on mental and physical health,⁶⁶⁻⁶⁸ including increased activation of the sympathetic nervous system leading to release of cortisol from internalised stress.⁶³ This stress may contribute to an environment where behaviours associated with stress and obesity, such as increased consumption of foods high in fat, sugar and salt,^{392,393} are more likely to occur as a coping mechanism. This highlights that systemic racism may be a cause of why inequalities in health are observed by ethnicity even when socioeconomic status is controlled for; in Chapter 5 I found that controlling for area-level deprivation did not significantly alter the observed inequalities by ethnicity.

Where the literature has explored why these inequalities may be produced in weight management interventions, it is in terms of cultural tailoring of weight management services. There have been two qualitative studies conducted in the UK that offer insight into why the inequalities in intervention effect I found evidence of, exist. Coupe et al., found that facilitators of weight loss groups did not think they had the knowledge or time to sufficiently tailor intervention content to culturally diverse intervention groups.³³⁹ In particular, facilitators felt they were unable to sufficiently tailor intervention content to those who had moved to the local area from outside the UK, such as refugees and asylum seekers, and how they prepared their food. For example, much of the advice given in this intervention was around moving from highly processed food to more home-cooked meals; for those from outside the UK, it appeared they already prepared their own food but it was the food preparation methods that made the food unhealthy and high in fat, sugar and salt. Furthermore, in a study of British Pakistani Muslim women, Iqbal et al., found that many

facilities that are often utilised as part of weight management – such as gyms and exercise classes – were not available in a way that made them truly available to the women interviewed in the study.³⁴⁰ Similar barriers have also been identified in interventions focused on modifying the diet of people with or at high risk of type 2 diabetes mellitus and South Asian ethnicity.³⁹⁴ Therefore, to prevent the inequalities in intervention effectiveness I have identified, it may be that greater intervention tailoring needs to be completed prior to delivering the intervention to some ethnic minority people.

In the overall introduction to the thesis (section 1.5), I highlighted several previous systematic reviews of inequalities in the effectiveness of behavioural weight management interventions. Two of these systematic reviews were of interventions specifically tailored for people from ethnic minority backgrounds in the USA; one was of interventions targeted towards Latino adults, and one tailored for African American women.^{168,169} These systematic reviews found that tailored interventions were feasible and effective for these groups; though it is worth noting that evidence from the USA may not be directly applicable to the UK (where most of my thesis is focused). In Chapter 2, I identified one UK-based trial (PODOSA) where the intervention was targeted towards South Asian individuals (and their families) in the UK.²⁹⁰ In this trial, the authors did find the intervention effect to be effective – providing some UK-based evidence that culturally tailoring weight management interventions could be one avenue to reducing the inequalities in obesity these interventions are currently producing.

8.2.1.2 Gender/sex

In Chapters 2 and 5, I found evidence that the effect of behavioural weight management interventions was greater in men than women. I demonstrated in Chapter 5 that a significant contributor of this was that men actually gained weight in the control group; weight loss in the intervention group was similar in men and women.

A mechanism driving the observed difference could be that, given the difference in intervention effect I observed by gender/sex was due to men gaining weight in the control group, men may be more likely to lack the tools pre-intervention to help them manage their weight. For example, it may be that men are less likely to try weight management interventions outside of a trial context by themselves.³⁹⁵ Many men perceive weight

management services to be “feminised spaces” and to have limited options outside of these spaces that would help them to manage their weight.³⁹⁶ However, I could not identify other literature that explored this further, which is an implication for future research that is further discussed in section 8.5.2. Given the lower rates of uptake of these interventions by men, it could be that those men who attend are a self-selecting, non-representative group, who have extra motivation for attending, resulting in increased intervention effectiveness. This could be because generic weight management interventions are typically designed for, and used by, women, so men may have had to already overcome certain barriers associated with gender in order to attend in the first place.

As the difference in intervention effect by gender/sex observed in the IPD-MA was produced by men gaining weight in the control group on average, it means that this differential effect is not likely to be evidence of lesser effectiveness of behavioural weight management interventions in women. Further evidence of this is women are over-represented in the trials of behavioural weight management interventions, and in real-world contexts women are also more likely than men to be referred to behavioural weight management interventions by their primary care practitioner (and more likely to accept the referral).^{199,337} Similarly, there is a perception that these interventions are better suited to women and that weight loss interventions outside of the healthcare setting, such as some of the commercially-delivered interventions included in Chapters 2-6 of this thesis, have often been designed and targeted for women rather than men.^{204,206,217,219} This is counter to a common problem in healthcare, which is that women are a disadvantaged group in terms of access to and benefit from health care interventions, as well as less consideration of women in the development and evaluation of treatments (as highlighted in section 1.4.3 in Chapter 1).^{128,135–139}

Further, given that the observed difference in intervention effect was produced by men gaining weight in the control group, and there being similar weight loss in the intervention group in men and women, it suggests that the difference in intervention effect is not produced by men having a higher starting weight. Male participants in weight loss trials may have a higher starting weight,³⁹⁷ meaning they have greater scope to lose more weight than women. Had the differential effect been produced by men losing more weight in the intervention arm, then differences in average starting weight may have been a plausible contributor to a differential effect favouring men being observed.

8.2.1.3 Evidence of inequalities by other characteristics

In addition to ethnicity and gender/sex, I also found some evidence of differential effectiveness of behavioural weight management interventions by area-level deprivation (socioeconomic status), marital status (social capital), and age.

In the IPD-MA of inequalities in effectiveness of behavioural weight management interventions in Chapter 5, I found that those who lived in the fourth most deprived quintile (assessed using area-level IMD) lost less weight than who lived in the least deprived quintile, although there was not a statistically significant difference in weight loss between the most and least deprived quintiles. This is comparable to an evaluation of the NHS Diabetes Prevention Programme, where in an evaluation of national service-level data in England, Valabhji et al., found that weight loss was less in those from socioeconomically deprived areas.³³⁸ Although my finding of there being differential intervention effectiveness by area-level deprivation is not consistent across the deprivation gradient, it may suggest that there are some barriers to losing weight that are associated with living in an area of high deprivation. For example, there is a higher density of unhealthy fast food and takeaway outlets in areas of higher area-level deprivation,^{398,399} and that exposure to fast food and takeaway outlets leads to marginally higher consumption of these foods and greater odds of obesity.⁴⁰⁰ Similarly, qualitative research has found that those living in more deprived areas may face extra difficulties – such as a lack of sufficient public transport – when accessing more affordable supermarkets, which present additional difficulties when attempting to purchase and prepare healthier foods that will help weight loss.³³⁹

For marital status, there was some suggestion in the systematic review in Chapter 2 that trial uptake and intervention adherence was higher in those who were married (versus unmarried), but there were few analyses conducted to consider if marital status predicted trial or intervention uptake, adherence, or effectiveness. In Chapter 7, for most of the outcomes I considered (weight, eating behaviour, and mental health outcomes), those who were single gained greater benefit from the intervention than those who were married, cohabiting, or in a civil partnership. I reflected on why this may be the case in section 7.6.1 of Chapter 7; people who are living with their partner may face additional social barriers to

changing behaviours associated with weight management (such as being dissuaded from changing their diet) compared to those who are single.

Unlike marital status, age was one of the most explored predictors identified in my systematic review. In two of my studies (Chapters 2 and 6), I found that older age was a likely predictor; in Chapter 2, I found that older participants had higher trial uptake and adherence and lower trial attrition than younger participants and in Chapter 6 I found that older age was associated with less weight regain or greater weight loss than younger participants. Exploration of potential mechanisms of why these differences in intervention effect may have occurred was discussed in Chapter 6 (section 6.6.1) for age and Chapter 7 (section 7.6.1) for marital status. Generally, these findings show an advantage of using the PROGRESS-Plus criteria to consider in which inequalities occur in intervention effectiveness, as these characteristics may not be typically considered by researchers.

8.2.2 Absence of inequalities for some intervention stages and PROGRESS-Plus characteristics for effectiveness

There were several characteristics I did not find consistent evidence of inequalities in behavioural weight management interventions across Chapters 2-7. In particular, this was the case for education, occupation, and socioeconomic status (when measured using annual household income). This was also partly the case for socioeconomic status where area-level deprivation (IMD) was used to indicate someone's socioeconomic position, though in Chapter 5 there was some evidence to suggest that those living in more deprived areas lost less weight than those living in the least deprived areas.

Given the correlation between occupation, education, and income, and how in some studies education and occupation are used directly as indicators of socioeconomic status, it is not necessarily surprising to have observed similar results across these characteristics. This may show, given I did not observe evidence of inequalities in the attendance at or effectiveness of behavioural weight management interventions by socioeconomic status (annual household income), education, and occupation, that these interventions are similarly effective across the socioeconomic gradient. Therefore, when linked to data showing that those from deprived areas are more likely to be offered behavioural weight management intervention in

practice,⁹⁸ this suggests that these intervention may play a role in narrowing the inequalities seen by deprivation in the prevalence of obesity – although the suggestion of inequality by IMD in Chapter 5 (and as discussed in section 8.2.1.3) warrants further research to ensure that this is the case. This highlights that, as suggested in Chapter 1 (section 1.2.2), it is important to consider how socioeconomic status is assessed, as the different measures that can be used (such as IMD and annual household income in the IPD-MA in Chapters 3-5 and food insecurity in Chapter 7) capture different aspects of someone’s socioeconomic status.

Further, I did not find evidence of inequalities in the attendance at behavioural weight management interventions in the IPD-MA in Chapter 4. This highlights that, within a trial context, that attendance at in-person interventions was similar across the inequality gradient, suggesting that the inequalities in intervention effectiveness may be produced by adherence to the intervention (such as having the resource to afford and prepare healthier food, or the time to complete specific intervention components), rather than being able to attend. However, this is contrary to data provided by commissioned services; data from the Office for Health Improvement and Disparities shows that despite greater referral to behavioural weight management interventions in people from more deprived areas, it is those from the least deprived areas who are most likely to complete a behavioural weight management intervention.⁹⁸ This may reflect differences in who participates in trials versus the wider population who access weight management services more generally, or that factors associated with participating in a trial may make people more likely to attend an intervention versus when behavioural weight management interventions are offered more routinely.

8.2.3 Assessment of representativeness of trial participants and reporting of

inequality related data in trials of behavioural weight management interventions

Across all my studies in this thesis, I have been able to reflect on the reporting of demographic characteristics in trials of behavioural weight management interventions. Generally, I found that the trials included had a lack of sociodemographic diversity and representativeness compared to the populations they were sampled from. This is an issue that appears ubiquitous in the literature in high income countries regardless of the intervention that is being assessed and is particularly an issue for ethnicity and socioeconomic position of the

participants. For example, clinical trials (such as of cancer treatments and of vaccinations)^{401,402} typically have an under-representation of people from minority ethnic groups.⁴⁰³⁻⁴⁰⁶ It is, therefore, unsurprising that in the studies across Chapters 2- 7 in this thesis, a higher proportion of participants are White than is observed in the general population. This is further compounded by poor reporting of inequality characteristics such as ethnicity and socioeconomic status when trials are reported, which I also identified in the systematic review outlined in Chapter 2 of this thesis.⁴⁰⁷⁻⁴⁰⁹ This is the opposite of age and gender/sex which is reported in almost all studies (e.g., in one review of studies published in 'high-impact' medical journals, 99% of studies reported age and 97% reported gender or sex).⁴⁰⁸ Even if characteristics such as age are widely reported, the lack of diversity within that characteristic may hide inequalities in intervention uptake or effectiveness that could occur. For example, the narrow age range of participants included in trials of behavioural weight management interventions prevents assessment of how effective these interventions may be for those outside of this age range.

8.2.4 Contributing data to the field where there was a previous paucity of data
In this thesis, I used the PROGRESS-Plus criteria as a framework for considering inequalities in behavioural weight management interventions. This ensured I considered a wide range of characteristics in which health inequalities are known to occur for some conditions and treatments, but the evidence base has not yet considered whether inequalities exist by these characteristics in the attendance and effectiveness of behavioural weight management interventions.

This approach has been beneficial across all the studies I have conducted for this thesis; in Chapters 2-6 I was able to reflect on the range of characteristics that were and were not captured in published research (Chapter 2) and collected in previously conducted trials (Chapters 3-5 (IPD-MA) and Chapter 6 (analyses in WRAP trial)). Where this approach was particularly beneficial in shaping my research was in Chapter 7, where I was able to influence data collection of a broad range of PROGRESS-Plus characteristics by designing the baseline demographics survey used in the SWiM-C trial. This allowed me to examine characteristics I had not been able to examine in other studies, such as marital status. I identified that those

who were living as single gained a greater benefit from the intervention consistently across several outcomes (including weight, eating behaviour, and mental health outcomes). As suggested in the Discussion section of Chapter 7, to the best of my knowledge this was the first study to find such an association, which may be due to most trials not considering whether marital status modifies intervention effectiveness. Therefore, I suggest my thesis contributes a model for considering whether inequalities occur in public health intervention across a broad range of characteristics, such as marital status as an indicator of social capital.

A further contribution of my thesis in this theme is that it presents some inequality analyses that have yet to be presented in the literature, particularly in Chapters 6 and 7. In Chapter 6, I present the first analyses of inequalities in weight regain between one- and five-year follow up following behavioural weight management intervention; in Chapter 7, I present the first analyses of inequalities in outcomes other than weight following a weight management (in the case of SWiM-C, a weight gain prevention) intervention. Whilst the studies I presented in Chapters 6 and 7 may not have been statistically powered for the analyses I completed, they provide much needed insight into the equity of behavioural weight management interventions in the post-intervention period (Chapter 6) and in their impact on outcomes other than just weight (Chapter 7). These findings could in future be synthesised with other studies.

Similarly, this thesis adds further evidence to be considered around the concept of ‘intervention agency’ I introduced in the overall thesis introduction. In 1.4.2, I highlighted that one mechanism that intervention-generated inequalities could occur through is the amount of ‘agency’, which is the amount of personal resource required for an intervention to take effect.^{18,123,124} A systematic review published as a preprint in 2023 found that intervention agency is correlated with equity (i.e., the greater the agency required for an intervention to take effect, the less equitable it is) but not overall effectiveness.⁴¹⁰ Whilst this review did not highlight behavioural weight management interventions specifically, it was earlier suggested by Adams et al., that behavioural weight management interventions are a high agency intervention and are, therefore, likely to be inequitable across the socioeconomic gradient.¹²³ In the evidence produced through the studies conducted for this thesis, I found some evidence of lesser effectiveness in those from more socioeconomically deprived areas (in Chapter 5), though this was not consistent across the socioeconomic gradient – i.e., I only

found evidence of a difference in effectiveness between the second most deprived group by IMD and the least deprived, this did not appear across a gradient. This may highlight that further research is needed to identify which interventions are susceptible to being inequitable due to agency, or whether that for behavioural weight management interventions, evidence from routine data – rather than RCTs – is needed to fully consider if they are susceptible to being inequitable due to agency.

Whilst this thesis focused on behavioural weight management interventions specifically, the findings may provide useful information for other similar behaviour change interventions – such as those for promoting healthier diets or increasing physical activity. Reviews in these areas faced similar limitations I found of the systematic review I conducted in Chapter 2 of this thesis; even though most studies collect PROGRESS-Plus relevant data, few studies report analyses which would allow differential effects to be considered. McGill et al., focusing on socioeconomic status, found that that most interventions to promote healthy eating did not consider if differential effectiveness was present.¹⁵¹ In some of the counselling-type interventions included in the review – most similar in nature to the behavioural weight management interventions explored in this thesis– there was some evidence susceptible to widening inequalities, although this was not consistent. In a systematic review of primary care-based physical activity interventions, that used the PROGRESS-Plus characteristics, Attwood et al., found that most trials did not report if differential intervention effects were present; where these analyses were presented, they were mostly neutral (i.e., did not find evidence of differential effectiveness by the PROGRESS-Plus characteristics).³² These systematic reviews also have the same limitation as the systematic review I presented in Chapter 2, in that the included analyses of differential effects were underpowered to have detected a true difference should one have existed. The only individual participant data meta-analysis I could identify around inequalities in diet and physical activity interventions was one that considered the effectiveness of and compliance to workplace health promotion programmes in the Netherlands. In that paper, Coenen et al., found that the effectiveness and compliance did not differ by educational attainment.⁴¹¹ As no similar review for diet or physical activity interventions exists in a UK context, the findings of my thesis may provide useful data those with an interest in if a differential effect may exist in interventions targeting diet and physical activity.

8.3 Strengths and limitations

8.3.1 Internal validity

8.3.1.1 Study design and confounding

The chapters in this thesis use different study designs: including a systematic review with Harvest plots to narratively synthesise published findings from RCTs; analysis of unpublished data from RCTs in an IPD-MA; and new analyses of data from novel RCTs. A common feature across these chapters is they all use data from RCTs, so it is particularly important to reflect on the internal validity of RCTs and the strengths and limitations that come from using them as a data source.

RCTs are considered a rigorous and robust method of evaluating the effectiveness of interventions.^{412,413} This is primarily due to the randomisation process in RCTs, which balances confounding variables between the intervention and control groups.⁴¹⁴ Importantly, this means that the differences in outcomes between the intervention and control groups can be attributed to the intervention itself and causality of effect established.^{412,415} Together with detailed inclusion and exclusion criteria for participants in RCTs, this suggests that RCTs are generally considered to have high internal validity.⁴¹² However, this is not a universal view in the field. Cartwright suggests that the characterisation of RCTs as rigorous is not based on any real definition of 'rigour'.⁴¹⁶ Cartwright suggests that, instead, many forms of diverse evidence should be considered as part of a making causal claims, and a causal-process-tracing theory of change should be created with this evidence for establishing causality.

Moreover, causality cannot necessarily be established in analyses of differential effects of interventions where subgroup analyses are conducted. These analyses took the form of statistical test of differences in subgroups in Chapter 4 and interaction analyses in Chapters 5 (IPD-MA inequalities in weight loss outcome) and 7 (inequalities in the effectiveness of the SWiM-C intervention). These included studies did not use stratified randomisation for all the subgroups of the PROGRESS-Plus characteristics I included in this thesis. This means that participants in each subgroup may not be balanced across each trial arm, meaning that confounders may be unbalanced between the trial arms.^{417,418} As a result, it cannot be completely ruled out that confounding could explain the observed presence, or lack of,

inequalities observed,⁴¹⁹ as these subgroup analyses are observational in nature.^{165,420} It is suggested by Griffin that subgroup analyses of intervention effectiveness should be hypothesis generating rather than forming the basis for policy change and practice.⁴²¹ In the conclusions made in each individual chapter and in this Discussion chapter, I recommend that future work should be undertaken to understand the mechanisms underpinning the inequalities that have been observed, rather than suggest a change in behavioural weight management provision in the UK, which is in line with this recommendation.

It is also important to consider the issue of internal validity in the context of systematic reviews, which form the basis of Chapters 2-5. There are decisions taken at several stages of a systematic review (defining search strategy, deciding inclusion/exclusion criteria, title/abstract and full text screening) which could affect the internal validity. For example, I adapted the search strategy used in a United States Preventive Services Taskforce [USPSTF] review and discussed with a librarian from the University of Cambridge Clinical School to ensure as many relevant studies as possible would be captured. Similarly, calibrating the inclusion/exclusion criteria with my co-authors who co-conducted literature screening reduced subjectivity in this process, ensuring internal validity was maximised.

8.3.1.2 Chance

Frequently, p-values of less than 0.05 are used to indicate statistical significance.⁴²²⁻⁴²⁵ This binary threshold has been extensively discussed in the literature and may lead to Type II errors (failing to reject a null hypothesis that is actually false) where no difference is concluded when the p-value is greater than 0.05.^{422,423} In this thesis, I reported all p-values together with confidence intervals and refrained from stating whether there was an association just based on whether the p-value was less than 0.05.

Given the number of analyses presented in this thesis, there may be an increased chance of multiplicity (a Type I error occurring; rejecting a null hypothesis that is actually true). This is particularly pertinent in Chapter 7, where I conducted more than 100 statistical tests. In consultation with a statistician, I did not adjust for multiple comparisons (such as using a Bonferroni correction). Performing such adjustments may inadvertently increase the risk of Type II errors.³⁷⁵ The issue of multiplicity can be addressed by having a clear rationale for analyses based in evidence or theory for each performed test,^{375,376} which I have presented through the PROGRESS-Plus criteria and outcomes related to weight management that I have

considered. Furthermore, the analyses presented in this thesis are broadly exploratory – identifying the characteristics and intervention stages of behavioural weight management interventions in which inequalities may occur – rather than confirmatory. It is suggested that adjusting for multiplicity should only be performed in confirmatory trials,³⁷⁴ which was not an aim of this thesis. Rather, I used qualitative judgement – particularly in Chapter 7 – when interpreting results to consider consistency in patterns across outcomes and inequality characteristics.

8.3.1.3 Measurement error

8.3.1.3.1 Outcome measurement

A strength of this thesis is that the majority of weight data presented has come from validated scales and measurements conducted by research staff who were blinded to which trial arm participants were assigned to. This minimises the risk of social desirability and recall bias, which often leads people underestimating their weight when they self-report.^{387,426} However, this was not uniform across all the trials included in this thesis. This was primarily due to difficulties in collecting data from participants via study visits. In Chapter 6, I used data from the WRAP trial – where participants who were not able to attend a study visit had weight data retrieved from primary care records or self-reported by the participant themselves. To mitigate this, I controlled for data source (study measured, primary care recorded, or self-reported) of the weight data in the analyses and conducted sensitivity analyses excluding self-reported data. There was no real difference in the results of the analyses conducted with and without self-reported data. For the SWiM-C trial, analysed in Chapter 7, all weight data was self-reported as clinic visits were not possible due to lockdown restrictions in place during the Covid-19 pandemic.

8.3.1.3.2 Exposure measurement

The exposures considered in my thesis are the variables used to capture the PROGRESS-Plus characteristics. There was heterogeneity in how these characteristics are captured across the trials included in each of the chapters in this thesis, the extent of which differed across the characteristics. The most uniformly measured characteristics were age, gender/sex, and ethnicity. Age was captured as age in years in across all trials, although in the IPD-MA (Chapters 3-5) it was not shared as a continuous variable for one trial. Gender/sex was captured as female/male or women/men. There was inconsistency about whether gender or

sex was recorded, though this has limited implications for this thesis as most studies assessing gender did not capture it as a spectrum but rather as a female/male binary. There are similar limitations around the capturing of ethnicity in the trials included in this thesis. In the UK-based trials included in Chapters 2-7, ethnicity was predominantly collected using the UK census categories applicable to when data collection was initiated in each trial. However, this did not equate to (in Chapters 3-5) data being shared in this format; some data management teams only shared ethnicity as White/minority ethnic group binary. Even where sufficient granularity in ethnicity data was present (as in Chapters 6 and 7), the number of people of in each ethnicity category made conducting meaningful analysis not possible. This means that the ethnicity analyses presented in this thesis lack precision, as they do not highlight which minority ethnicities these interventions may not work for, which has implications for future research as discussed in 8.4.2.

Measures of the remaining PROGRESS-Plus characteristics were more variable in nature and how these characteristics were captured affects the internal validity. For most characteristics, despite the variation in how they were captured, internal validity was maintained because the measures do accurately capture that characteristic as they were collected at an individual level. For example, education was captured in some studies as number of years of education completed, and in others as highest qualification achieved. Socioeconomic status, considered in this thesis as area-level deprivation and annual household or individual income, had more variability, of which some measures may have poor internal validity. In UK-based trials, socioeconomic status was often captured using IMD (in England) or Scottish IMD. IMD is an area-level indicator of deprivation that provides an indicator of an individual's socioeconomic position but may be subject to ecological fallacy (where the area level deprivation does not reflect an individual's deprivation). McCartney et al., found that area-based deprivation indices (English IMD, Scottish IMD, and Welsh IMD) had low sensitivity and specificity for detecting income- and employment-deprived individuals.⁴²⁷ This impacts upon the internal validity as this measure may not be truly capturing an individual's socioeconomic position; hence, the variable may not be measuring what it set out to capture. An alternative measure of socioeconomic status is household or individual income, which was used in some of the UK-based trials in Chapters 2-5 and non-UK trials in Chapter 2. This may have higher internal validity than IMD, but still may not truly capture an individual's socioeconomic status as it is

not relative to the cost of living of the location they are based, and it is possible to be wealthy but have little current income.

A final factor affecting the internal validity of the exposures considered in this thesis is that the capturing of the PROGRESS-Plus characteristics is cross-sectional and primarily collected at trial recruitment or baseline. For characteristics that are static, such as ethnicity, this will not have an impact on internal validity. However, for characteristics that are more susceptible to change – such as co-habitation status or socioeconomic status (where individuals may move to areas of different deprivation or have a change of income) – using the baseline status may impact the internal validity, especially in Chapter 6 which looked at longer term follow up.

8.3.2 External validity

8.3.2.1 Selection and attrition bias and generalisability

Selection and attrition bias in studies impacts upon the generalisability of observed findings. Selection bias is where there are differences in the characteristics between who takes part in a study and in the population the recruited sample should represent.⁴²⁸ Attrition bias is where the characteristics of those who are not followed up in a study are different to the characteristics of the sample as a whole.⁴²⁹ Generalisability is the extent findings of a study can be applied to contexts outside of the one it was conducted in.⁴³⁰

Behavioural weight management interventions, both in trials and in real-world settings, are susceptible to selection bias, as there are some differences in the characteristics of those who typically take part. This thesis has highlighted that trial participants were more likely be female, to have received more years in formal education, be from areas of lower socioeconomic deprivation, be of a White ethnicity, and be older than the population of those living with overweight or obesity in the UK. This means that these trials were not entirely representative of the population and that this could have an impact on the results observed. For example, underrepresentation of minority groups may lead to differential effects of an intervention not being detected should they truly exist. This selection bias may suggest that behavioural weight management interventions could actually increase health inequalities, even if there are no inequalities observed during a trial.

Furthermore, there are elements of selection bias in trials that are not easily captured and that may make the participants who take part different to that group in the population more broadly. In Chapter 5, I found that behavioural weight loss interventions had a greater intervention effect in men than women despite the greater uptake of the intervention, both in trials and in the population generally, by women.^{199,337} It may be that the gap between those who participate in a weight management intervention and those with overweight or obesity in the general population is greater for men than women, and in ways that were not captured in the studies reported in this thesis.

Where I found evidence of inequalities in intervention effectiveness in Chapter 5, such as by ethnicity and gender/sex, there was low heterogeneity in the corresponding meta-analyses. This suggests that the observed differential impacts of behavioural weight management interventions are consistent despite differences in the design of the interventions included and that the observed inequalities by ethnicity and gender/sex may be true for most types of behavioural weight management intervention.

8.3.3 Use of PROGRESS-Plus characteristics as a framework for conceptualising and defining health inequalities

In Table 1-1 in Chapter 1 of this thesis, adapted from a table included in paper by Attwood et al.,³² I outlined definitions and examples of the PROGRESS-Plus characteristics. As highlighted in 8.3.1, the variables used to capture the PROGRESS-Plus inequality characteristics could impact the internal validity of the studies included in this thesis (such as using area-level deprivation to indicate an individual's socioeconomic status). Here, I reflect on the strengths and limitations of using the PROGRESS-Plus characteristics as a framework for conceptualising and defining health inequalities.

I found that the PROGRESS-Plus characteristics provided a useful framework to ensure I considered whether inequalities were present in behavioural weight management interventions across a range of characteristics in which there is evidence of health inequalities occurring. Whilst the characteristics should not be used as a “shopping list” for deciding which subgroup analyses to perform,¹⁶⁵ they are particularly useful for exploratory analyses where there is a lack of evidence of inequalities by some characteristics. For example, the social

capital characteristic encouraged me to include a variable on marital status when designing the baseline demographics questionnaire for the SWiM-C trial I analysed data from in Chapter 7. To prevent over-interpretation of a spurious association, I looked for trends of inequality across the PROGRESS-Plus characteristics rather than focusing on single significant associations. In doing this, I identified if an association was present by a characteristic across two or more outcomes together with the direction of the association. If the direction of associations matched, then I considered this as a trend. As a result, this provides stronger evidence for future research to consider the role of marital status in behavioural weight management interventions to consider what mechanisms may have caused this differential intervention effect. A further strength of adopting the PROGRESS-Plus framework is that it provided some distinction between the many characteristics that typically make up 'socioeconomic status'. Someone's education and occupation are also used in some literature as an indicator of someone's socioeconomic status alongside individual or household income and area-level deprivation. Considering them separately from each other reflects that each characteristic (occupation, education, and socioeconomic status) is likely to impact someone's health, and ability to attend or adhere to interventions, in different ways. For example, having less educational attainment may present challenges in adherence to intervention content, whilst someone having a full-time occupation may limit the time they can spend to make dietary changes in response to an intervention.

A limitation of using the PROGRESS-Plus characteristics however is that the framework itself does not provide guidance in what measures are most appropriate for each characteristic. It is likely that this is deliberate so that the framework is appropriate across different high-, middle-, and low-income countries. This means that even within a single country – as shown in Chapters 3-5 in the IPD-MA I conducted – there is variation in how each of the characteristics are captured in trials, which limits the scope of synthesising data from multiple trials to address equity-focused questions.

8.3.4 Synthesising data from multiple sources to explore inequalities in interventions

A key strength of this thesis is the novel evidence synthesis approaches I adopted in using Harvest plots (in Chapter 2) and conducting an IPD-MA (Chapters 3-5). Data on the differential impact of interventions, together with evidence of existing health inequalities in disease prevalence is particularly important for policymakers and those who commission interventions to have available, but these data – particularly from systematic reviews – are often lacking.⁴³¹⁻⁴³⁵ Individual RCTs are not powered to detect differential effects of an intervention, meaning that when inequality-focused analyses are conducted they are underpowered to detect an association should one exist. Further, where these analyses are reported, there is heterogeneity in the variables used to capture inequality characteristics. In the narrative systematic review presented in Chapter 2, I was able to overcome the limitation of heterogeneity by using Harvest plots to visually synthesise the published results of the equity effects of interventions – however, this approach was unable to overcome the limitation of statistical power. Instead, this limitation was overcome in the IPD-MA presented in Chapters 3-5, where I harmonised data across the PROGRESS-Plus characteristics to conduct analyses that were more likely to detect inequalities, should they be present, than is possible in individual trials.

I presented analyses of inequalities in intervention effectiveness (Chapter 7) and intervention effect maintenance (Chapter 6) from two individual trials. These trials are not statistically powered to moderation of the intervention effect by different characteristics, which means they may not detect inequalities that are truly present. However, I have presented them completely and in a way that facilitates more traditional meta-analysis approaches, should others publish similar studies in future. Reporting studies in this way may enable considerations of inequalities in a timelier and less resource intensive manner than was possible in the IPD-MA presented in this thesis.

8.3.5 Evidence of absence versus absence of evidence of inequalities

A limitation of my thesis is that, where I did not find evidence of inequalities, it is difficult to establish whether the null results suggest evidence of absence of inequalities in intervention

effect for that characteristic, or a methodological limitation of the studies I conducted or of the data I used (an absence of evidence). The latter is particularly likely for my thesis chapters that relied on analyses from single trials – the systematic review in Chapter 2, analyses of the WRAP trial in Chapter 6, and analyses from the SWiM-C trial in Chapter 7. Given the data largely existed prior to me developing the hypotheses and research questions assessed throughout this thesis, it is difficult to judge the statistical power of the analyses. I did not conduct post-hoc power calculations as they have several fundamental limitations. Primarily, post-hoc power calculations are flawed because they test for the observed power of a study in a way that is, according to Hoenig and Heisey, a 1:1 function of the p-value.⁴³⁶ This means that post-hoc power calculations often suggest that an analysis is sufficiently powered if it finds evidence to reject the null hypothesis and an analysis is insufficiently powered if evidence is not found to reject the null hypothesis.^{437,438} Essentially, post-hoc power calculations present the observed p-value in a different way,⁴³⁹ meaning they offer no additional information to that provided by the p-value and confidence interval.^{440,441} A strength of this thesis is that I provided the 95% confidence intervals for all observed associations, rather than relying solely on p-values. This allows qualitative judgement of the power to detect an association; a wider confidence interval may indicate less statistical power.

There are other factors, in addition to statistical power, that inform considerations about whether the null results observed are convincing evidence of absence of inequalities. One example is differential attrition, where inequalities in intervention effect are hidden due to those who are more disadvantaged not being followed up. Whilst this is common in trials,^{187,442,443} in the IPD-MA presented in Chapters 3-5 there was evidence of differential attrition by ethnicity and age but not gender/sex or socioeconomic status (considered using area-level deprivation). This makes it unlikely that the observed lack of inequalities by characteristics such as occupation, education, and socioeconomic status are due to differential attrition. Another example is inequalities in trial uptake, related to selection bias discussed in 8.3.1. I was only able to explore inequalities in trial and intervention uptake in the systematic review (Chapter 2) and not in subsequent chapters. This is a limitation of the thesis, and of using data from RCTs, as this information – on who is approached to take part in a trial but declines in particular – is often not reported or collected and is difficult to

capture. However, these data are vital for converting trial efficacy into real-world effectiveness, in an equitable way. These analyses have been conducted by other researchers, such as Booth et al., and Coulman et al.,^{199,337} so some information is available for policymakers, and the work on the other stages of an intervention presented in this thesis can be considered complementary. Both these studies found that referral to weight management interventions in primary care was higher in women (as is the case of the participants in the trials included in this thesis), but also in those from areas of high socioeconomic deprivation. Data from RCTs, in terms of accepting an offer to participate in the trial, is more mixed. In three UK-based trials included in Chapters 2-5 of this thesis, two (the BWeL and DROPLET trials) found that trial uptake of the intervention was higher in those from deprived areas (supporting the findings of Booth et al., and Coulman et al.),^{280,335} and one (the WRAP trial) found that uptake was higher in those from less deprived areas.³⁰⁹

8.4 Implications for public health policy and practice

Across the results and data limitations outlined in this thesis, there are several implications that should be considered for public health policy, practice, and research. Most of the recommendations in this section are focused on the policy and healthcare system of the UK as this was the primary focus of this thesis.

8.4.1 Policy and practice

Data on many aspects of an intervention provide useful insight to commissioners around what services to implement, maintain, or change in the population they serve. Specifically for weight management interventions, these aspects include who: has obesity, is referred for weight management services, accesses interventions, adheres, and who achieves desired outcomes in the short- and long-term. It is also important to understand where there may be inequalities in these aspects, and what interventions could mitigate against these. At an overall level, these data are available via surveillance tools (such as the Office for Health Improvement and Disparities' tier 2 weight management services national dataset), analyses of primary care data (particularly for referrals), and data from RCTs and meta-analyses on the effectiveness of interventions.

Where data have previously been lacking, however, concerns whether there are inequalities in different aspects or stages of an intervention. This is particularly important for commissioners as, in England, there is statutory duty for the public sector and healthcare commissioners to reduce inequalities in outcomes that occur from disadvantage from protected characteristics such as ethnicity and gender/sex.^{29,30} Outcomes include 'hard' health outcomes, such as disease prevalence, as well as access to services. Much of the data required to tackle health inequalities has not been available to commissioners and policymakers. Particularly, data on the differential effectiveness of public health interventions has historically not been available to policymakers.^{431,434}

This thesis provides vital insight for commissioners on inequalities in three key intervention stages of a behavioural weight management intervention: adherence to behavioural weight management interventions, effectiveness at 12-month follow-up, and weight regain up to five-years post-intervention baseline. It provides high-quality data that has not previously been available, highlighting certain characteristics that the interventions are not as effective in.

For example, given the known inequalities in obesity prevalence and its complications by ethnicity, and my finding that behavioural weight management interventions are more effective in people of White ethnicity than in ethnic minority people, commissioners may look to implement more culturally tailored interventions to mitigate the inequalities ethnic minority people face. For gender/sex, I found that the interventions had a greater effect in men – primarily due to men doing less well with minimal intervention in the control group. However, data from this thesis, as well as surveillance and primary care data, suggests a significantly higher utilisation of generic behavioural weight management interventions by women. Consequently, commissioners may additionally focus their efforts on increasing uptake of these generic-style interventions in men to complement existing effective gender-tailored interventions.

A further benefit of this thesis for public health policy and practice is that the analyses I present on differential intervention effectiveness provide crucial data for others to model if the long-term differential impact of these interventions in different subgroups of the PROGRESS-Plus characteristics. These data can be integrated in modelling of QALYs (quality

adjusted life years) and cost-effectiveness, ensuring that estimates produced from these models are more reflective of the populations they are being applied to.

As highlighted in 1.3.1, public health interventions are targeted towards “high-risk” groups or a population as a whole. Behavioural weight management interventions are targeted towards high-risk groups, as they are designed to be delivered to people who already have overweight or obesity. Interventions targeted towards populations for overweight and obesity, such as the soft drink industry levy or restrictions on marketing and price promotions for unhealthy foods, tend to be more focused on primary prevention (i.e., to stop someone from getting obesity). Obesity was first recognised as a public health challenge by the UK Government in 1991;⁴⁴⁴ between 1992 and 2020, there have been 689 policies to address obesity in 14 UK Government strategies.⁴⁴⁵ As discussed by Theis and White, many of these policies were never implemented, and the ones that were implemented were rarely evaluated.⁴⁴⁵ Whilst the effectiveness of behavioural weight management interventions in practice is difficult to establish, RCT-based evidence fills this gap somewhat and shows that these interventions are effective for weight loss and are cost-effective for healthcare providers.^{145,446}

There are two areas where this thesis is unable to provide original contribution for policy. First, it does not provide original insight into who accesses or is offered behavioural weight management intervention, and if there are inequalities at this point in the intervention process. However, data from RCTs – central to this thesis – are not the best way to inform this policy issue. Instead, data from primary care (as conducted by Booth et al., and Coulman et al.,)^{199,337} considers who has typically been offered behavioural weight management intervention, whilst surveillance data from the Office for Health Improvement and Disparities (provided by local governments in England) offers insight into who is accessing behavioural weight management interventions.⁹⁸ Second, this thesis does not provide original insight to policymakers and commissioners for preventing inequalities in the prevalence of obesity from occurring. The intervention of interest in this thesis, behavioural weight management interventions, are targeted towards ‘high-risk’ groups (i.e., those already living with overweight or obesity). It is possible for these interventions to mitigate against some of these inequalities – for example, I did not find evidence of a gradient in effectiveness by socioeconomic status, so if more people from deprived areas were to access behavioural weight management interventions, then this inequality could be somewhat mitigated against.

To make more significant progress on preventing the inequalities in prevalence from occurring in the first place, then more action would need to be taken “upstream”, focusing on population-level interventions which have a greater potential to achieve this.

8.5 Future research recommendations

There are several recommendations for future research arising from the findings of this thesis.

8.5.1 Further explore inequalities in intervention effectiveness by ethnicity

I found that behavioural weight management interventions are more effective in White participants than in ethnic minority participants. However, as noted in 8.3.1.3.2, I explored ethnicity as a binary variable given how it is frequently reported in the published (in Chapter 2), how the data are shared (Chapters 3-5), and due to lack of diversity in the ethnicity of participants (in Chapters 6 and 7). Whilst I could have explored ethnicity in greater granularity in the studies I had individual participant data for, this would have led to several very small groups and therefore low power. It is important to state that minority ethnic groups are not homogeneous.

Given the known differences in the prevalence of obesity in different ethnic groups and in the comorbidities associated with obesity (e.g., type II diabetes mellitus occurs at a lower BMI level in people of South Asian ethnicities), I recommend that future work builds on my findings to confirm which minority ethnic groups will experience less benefit from non-tailored behavioural weight management interventions. Part of this will require ensuring greater diversity and representativeness of trials, which I discuss further in section 8.5.3. Future work should also seek to evidence the mechanisms that produce the inequalities in intervention effectiveness I have identified in this thesis and identify which intervention features could be producing these inequalities.

There has been some work on this in the field previously in the UK-context. In a qualitative study, Coupe et al., found that group facilitators of generic behavioural weight management interventions did not feel they could offer culturally appropriate advice on diet and food preparation to those who had moved to the North West of England from another country.³³⁹ Furthermore, Iqbal et al., interviewed British Pakistani Muslim women living in Bradford in the Yorkshire region of England and found that some of the services people living with obesity utilise to help manage their weight – such as exercise classes and gyms – were not available in a way that made them appropriate to access given the requirements of their religion.³⁴⁰ For example, even where female-only exercise classes were available, they were organised in

venues where men could see the participants taking part in the classes. This research, together with the quantitative findings presented in this thesis, suggests that future work should explore how to create more culturally appropriate spaces, as the current lack of such provision is having an impact on health outcomes.

Similarly, future research should further explore whether there is a gradient in the effectiveness of behavioural weight management interventions by deprivation, given that I found inconsistent evidence of inequalities in effectiveness by area-level deprivation but no evidence of inequalities by occupation or education.

8.5.2 Increasing uptake of non-gender tailored interventions in men

Much of the current research about gender in behavioural weight management interventions has focused on tailoring interventions for men, typically using male-only groups to deliver the intervention. Many of these have used sport as a platform to tailor the intervention content towards (e.g., using ‘coaches’ to deliver intervention content – this has been successfully conducted across several sports and countries, including football (UK, Germany, Netherlands, Norway, Portugal, and Sweden),^{215,341,447–449} ice hockey (Sweden, Canada and USA),^{449,450} Australian rules football (Australia),⁴⁵¹ and rugby (New Zealand).⁴⁵² These have achieved good results and are very useful in providing an option for men who may not feel comfortable in the generic interventions (such as those delivered by commercial weight management organisations) that have typically greater attendance by women. However, the evidence presented in my thesis has shown that these generic-style interventions are effective for the men who attend. Therefore, I suggest that future research should also explore how to increase uptake of these interventions by men, particularly in areas where the gender-tailored interventions are not available.

8.5.3 Take actions to reduce differential trial participation and attrition

Future studies should consider how participants who may be considered disadvantaged, in relation to health inequalities, can be recruited into and retained in RCTs. Achieving this would make data more representative of the population and improve opportunities to consider the

differential effects of an intervention. Providing financial incentives for participation in trials may provide one avenue for improving the representativeness and reducing attrition in trial participants.^{453,454} As shown in a systematic review by Halpern et al., the evidence base for the effectiveness of incentives on enrolment in trials is mixed (e.g., in some trials it increased enrolment but in others it did not have an impact).⁴⁵⁵ Therefore, more work is required – such as using realist evidence review methods – to understand the contextual factors of who incentives work for, and when this is the case.

Otherwise, it may be through the explicit consultation of under-represented groups when establishing research projects that could establish steps to reduce the inequalities in who participates and is retained in trials. There are further examples of this work that is underway to address the under-representation of certain groups in research in addition to incentivisation; it is important that researchers and practitioners sufficiently engage with it to ensure the theory and findings of the work translate into practice. In the UK, the INCLUDE frameworks for ethnicity and socioeconomic position aid trialists to design trials that are more representative and have improved inclusion of under-served groups.^{343,456–458}

8.5.4 Possible role of incentives in behavioural weight management interventions

Use of financial incentives have been shown have some effect in promoting behaviour change to improve health; Mantzari et al., found that financial incentives increased behaviour change generally until 18 months from baseline and this effect was greater in those with high deprivation, but only at the 6-12 month from baseline time point.⁴⁵⁹ It is less clear if incentives may reduce inequalities by ethnicity, however. This is particularly pertinent issue, where, as highlighted in the UK in this thesis and in the US by the USPSTF in relation to the US healthcare system,⁴⁵³ there are particular issues of inequitable healthcare. Therefore, future research should explore the use of incentives specifically in the context of narrowing health inequalities by ethnicity.

8.5.5 Data sharing in research

This thesis contribution also has implications for data sharing. In the systematic review presented in Chapter 2 of this thesis, I found that most trials do not consider inequalities in trial or intervention uptake, intervention adherence, or trial outcomes. This limitation was overcome somewhat in Chapters 3-5; it was, however, a time-consuming process to acquire the individual-level data. I coordinated with data and contract specialists to get 14 datasets from nine universities; some of the datasets taking 18-24 months to acquire. This limited the scope of my IPD-MA – as outlined in the protocol, I originally intended to perform the same analyses presented in Chapters 4 and 5 on trials of behavioural weight loss maintenance interventions in addition to those presented in this thesis,⁴⁶⁰ but this ultimately was not possible due to barriers and resistance towards data sharing. Platforms for publishing data and conducting open science exist but are under-utilised, especially for data from weight management trials – none of the datasets included in this thesis were openly available.

Ideally, these datasets would be published open access, giving equity-focused researchers the opportunity to conduct uniform analyses which can then be synthesised. However, there are few incentives that reward the resource required to publish data and overcome the barriers that exist. These barriers include knowledge barriers (about the process of publishing data), concerns around data will be reused inappropriately, not having the necessary participant and institutional consent to publish data, and a lack of time and financial incentive for making data open access.⁴⁶¹ An alternative to making data available open access is to conduct better and more consistent reporting of equity-specific analyses in individual trials, even where those individual trials are not sufficiently powered for such analyses, would allow for traditional meta-analyses of aggregate data to take place.

8.5.6 Consider if there are inequalities in other weight management interventions

Over the course of completing this PhD, the landscape of weight management interventions has shifted. There has been extensive media coverage of new pharmacological interventions for obesity, in particular liraglutide and semaglutide,^{462–466} that have become available for those living with obesity. These drugs typically lead to significantly greater weight loss than is

attained through behavioural intervention alone; in a trial of once-weekly injected semaglutide, the researchers found the majority of participants achieved a weight reduction 10%, and half achieved weight loss of 15% or greater.⁴⁶⁷ This has led to a change in best-practice guidelines in England, where the National Institute for Health and Care Excellence recommend (since February 2022) semaglutide be offered to adults with at least one weight-related condition and a body mass index (BMI) of at least 35 kg/m², and exceptionally, to people with a BMI of 30.0 kg/m² to 34.9 kg/m².⁴⁶⁸ From an equity perspective, there are gaps in the evidence base in support of these medications. For example, data on the differential effectiveness by PROGRESS-Plus characteristics have not been published, and whilst the primary trial of semaglutide has relatively good diversity by ethnicity than is typical of trials of weight management interventions,⁴⁶⁷ it may still not be fully representative of the population in terms of socioeconomic status.

Furthermore, in healthcare systems such as the NHS in the UK, medications are sometimes susceptible to the “postcode lottery” and are not always universally available even if a person meets the eligibility criteria to receive such treatment. There are also inequalities in who is able to advocate for their own healthcare, with those from a socioeconomically deprived or minority ethnic group often less able or likely to do so.^{469–471} This is an example of the ‘inverse care law’, where those most in need of healthcare are least likely to utilise it.⁴⁷² In addition, these drugs are available privately – whilst there are supply issues for the NHS in England, these drugs remain available for those who are able to afford to pay for private healthcare.⁴⁷³ Hence, future research could consider if differential effectiveness is present in these pharmacological interventions, which may be likely given they require concurrent lifestyle intervention for them to be effective, in addition to the aforementioned reasons.

8.5.7 Explore the effects of multiple disadvantage in terms of overweight and obesity

In this thesis, I have considered the effects of a disadvantage in terms of the PROGRESS-Plus inequality characteristics individually (e.g. if there is differential intervention uptake, adherence, or effectiveness by ethnicity or by occupation). I did not consider the effects of intersectionality – where two or more characteristics in which inequalities may occur interact

and produce inequality that is distinct and specific from the inequalities arising from individual characteristics.⁴⁷⁴ This was partly due to a limitation of the PROGRESS-Plus framework, which underpinned my consideration of inequalities, which is it encourages focusing on single characteristics in which inequalities occur rather than where these characteristics may interact with each other. I also did not have a strong pre-hoc rationale in deciding which of the PROGRESS-Plus characteristics to explore intersectionality in. Further, given my analyses in Chapters 6 and 7 were unlikely sufficiently powered a differential effect by a single characteristic, it is highly unlikely that three-way interactions would have provided meaningful insight. Therefore, other research methods – such as qualitative interview studies – may provide more useful insight into if factors around intersectionality affect weight management.

In addition to the effects of disadvantage that occur in each of the PROGRESS-Plus characteristics, there is additional disadvantage people living with obesity face as a result of their weight status. As highlighted in the Discussion section of Chapter 2, higher weight status is associated with increased weight stigma, which is linked to worsened mental and physical health, and healthcare avoidance.^{80,320–324} Whilst beyond the scope of this thesis, the cited literature suggests that increased weight stigma also interacts with sociodemographic characteristics and future research may wish to consider if this interaction is present in interventions for obesity.

8.6 Reflexivity

8.6.1 Personal reflexivity

Reflexivity, when applied to doing research, is a process where a researcher reflects upon their own existing biases, opinions and experiences and considers how these interact with the research process.^{475–478} It involves reflection of how my own perceptions of the world influences my research and how my research influences my perceptions of the world.⁴⁷⁶ Reflexivity is a concept often associated with qualitative research, but it was suggested by Finlay that this process should be completed as part of every research investigation and that it is an important part of ensuring the validity of research.⁴⁷⁷ Therefore, in this section I consider how my own experiences and perspectives may have impacted upon my research

which has been evidence synthesis and quantitatively based. I describe how these relate to the formation of my research question and in the interpretation of the results. In this thesis, I contemplated three core domains when developing the overall research question: inequalities, obesity, and public health interventions. At different points in my pre-PhD career, I have considered or worked across each of the three domains, and I consider this to have had a bearing on how I have approached and interpreted my research.

My background in the inequalities domain is informed by more personal rather than professional experiences. I originally come from a relatively deprived town near to Stoke-on-Trent in the West Midlands and I am the first in my family to go to university. Going to university outside of my home region, first in Southampton for my bachelor's and then Cambridge for master's then PhD studies, made me aware of the regional and class-based inequalities that exist in the UK. It is always relative, but these formative experiences in early adulthood gave me some exposure to socioeconomic inequality and how those from low income or deprived backgrounds do not have the same opportunities in education, work, or socially as those from more 'middle class' backgrounds.⁴⁷⁹ However, this made it particularly important for me to read about inequality across other characteristics – such as ethnicity and gender – in which I am in a more advantaged group. Ultimately, it may have been further beneficial if I had conducted further engagement work to learn from those from minority ethnic groups about the inequality they face and how this may impact upon their health, weight, and weight management. Similarly, during my PhD I volunteered at a food bank centre. This allowed me to place my research findings into perspective by first-hand witnessing what the situation is actually like for those with socioeconomic deprivation. Taking the time to understand about inequalities by ethnicity and gender, and how these impact socioeconomic inequalities further, was important to ensure I discuss my research on these with sensitivity and appropriate language to these groups.

I first worked in the obesity domain when completing a placement year during my undergraduate degree. In this year, I worked at Cancer Research UK conducting obesity policy research on the consumption of foods high in fat, sugar and salt and on the implementation of the soft drink industry levy. This is where I first began to understand the complexity of obesity as a public health challenge and how policy development would need to be multi-faceted and include interventions at both the population and individual level. However, the

research I conducted whilst at Cancer Research UK was conducted with the aim of raising the profile of the organisation's work and to be appealing to both policymakers and the media. Some of their more recent campaigns to raise awareness of the link between obesity and cancer have attracted divisive coverage, and have been considered stigmatising towards people living with obesity.⁴⁸⁰ As a result, I have reflected upon my own internal biases and language and met with several patient advocates over the course of completing this thesis, which is reflected in how I discuss the implications of my findings.

The third domain of my PhD is public health interventions; more specifically, behavioural weight management interventions. From my time working at Cancer Research UK, I was aware of the need for intervention approaches at both the population and individual levels. As I decided I wanted to pursue a PhD researching interventions for obesity, I became aware that behavioural weight management interventions are one of the most widely available and accessible interventions for people to manage their weight. After further literature scoping, I realised there were several high-quality trials of such interventions that have been conducted in the UK – but a relative paucity of research to consider how well these interventions work in different groups in the population. Therefore, I was able to put my interests from across the three core domains of PhD and formulate the central research aim and consequential research projects that make up this thesis.

8.6.2 Reflection on key methodological decisions

The PROGRESS-Plus characteristics shaped my consideration of inequalities in this thesis. I used the literature that outlined the PROGRESS-Plus characteristics, in addition to other published examples, to define groups I considered to be 'advantaged' or 'disadvantaged' in terms of health, and benefit from public health or healthcare interventions. I did find the framework particularly useful for considering if inequalities were generated by behavioural weight management interventions beyond the characteristics that are more typically considered. Whilst this was useful, upon reflection – and through discussions in the viva examination of this thesis – I would have used the PROGRESS-Plus characteristics differently. Rather than being a framework of characteristics that should be directly taken to data to consider if there are subgroup differences in trial or intervention uptake, adherence, effectiveness, and maintenance, I believe more thought should be taken into how the PROGRESS-Plus characteristics apply to the question of interest. In the context of this PhD, I

would have used the characteristics to consider where there was evidence of inequalities in the prevalence of obesity and in behavioural interventions for obesity. Given this PhD responds to the paucity of previous data of if there are inequalities in the effectiveness of behavioural weight management interventions, I would have used the characteristics to look at if there were intervention-generated inequalities in similar behavioural interventions, such as those for diet and physical activity. I would have then used this evidence to hone further which characteristics, and what constitutes advantage or disadvantage in these groups, I would consider intervention-generated inequalities to occur in in this PhD. As a result, I would have been more specific about the characteristics of interest and further hypothesised about how inequalities in behavioural weight management interventions could occur in these prior to conducting the analyses included in this thesis.

The other methodological decision I will discuss here is that I only used data from RCTs in my studies in this thesis. This is opposed to using data from other sources, such as routinely collected data from 'real world' weight management interventions, or by collecting further primary data of my own. As discussed in 8.3.1, RCTs tend to have high internal validity and be robust sources of data (although this is not always the case; reporting of the components of behavioural weight management interventions in RCTs is often poor quality).^{481,482} Further advantages of using data from RCTs is that the data are often more complete, higher quality, include detailed protocols and contain sufficiently broad consent for further analyses that is often the case with service-collected data.⁴⁸³ The decision to use RCTs rather than other sources to examine if there are inequalities in behavioural weight management interventions was also somewhat pragmatic; as most of the UK-based trials were funded by national funding bodies, they were amenable in providing free and timely access to data that may have not been possible with the time and funding available during my PhD.

8.7 Covid-19 impact

I began this PhD in October 2019 and spent October – December of that year formulating my overall thesis topic and developing the research projects that make up this thesis. The Covid-19 pandemic did impact on work I planned to conduct for this thesis. For example, I originally planned to conduct a qualitative research study to interview participants from

socioeconomically deprived areas about their experiences of behavioural weight management interventions. Due to the lockdown restrictions introduced in March 2020, I was unable to undertake appropriate training to conduct and analyse qualitative interviews and as a result I decided to not conduct this project. Instead, I analysed data from the SWiM-C trial which forms Chapter 7 of this thesis. Other than this, the main impact Covid-19 had on my work was to cause delays in the conducting of my systematic review and individual participant data meta-analysis as I, and others, adjusted to remote working. I fortunately received a funding extension in response to this, which has enabled me to complete the research included in this thesis.

8.8 Conclusion

In this thesis, I aimed to examine the nature and extent of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions in adults. I investigated this through four research projects that used systematic review, individual participant data meta-analysis, and secondary analysis methods.

Overall, this thesis makes several important contributions to the field. First, I identified characteristics in which there are inequalities in the effectiveness of behavioural weight management interventions. I found that these interventions have a greater effect in men (versus women) and that this effect was produced by men gaining weight overall in the control group. I also found that these interventions were more effective in participants from White, versus minority, ethnic groups, meaning they likely exacerbate existing health inequalities by ethnicity. There was also evidence to suggest that older participants regain less weight following weight loss intervention, and that a digitally-delivered intervention has a greater effect in single people than people who are married, co-habiting, or in a civil partnership. Second, there were several of the PROGRESS-Plus characteristics I did not find evidence of inequalities in behavioural weight management interventions by, such as occupation, education, and socioeconomic status (annual household income). Similarly, I did not find evidence of inequalities in attendance to behavioural weight management interventions. Third, I assessed the representativeness of trial participants and reporting of inequality related data in trials of behavioural weight management interventions. I found that, beyond gender or sex and age, the PROGRESS-Plus characteristics were inconsistently reported and that trials of behavioural weight management interventions were not representative of the population living with overweight and obesity. The fourth contribution of my thesis is that it adds data to the field where there was a previous paucity of data.

Future research should further explore the inequalities by ethnicity to ensure the effects of behavioural weight management interventions do not widen existing health inequalities, and how to better engage men into generic behavioural weight management interventions given their effectiveness.

Chapter 9 References

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Chapter 10 Appendices and supplementary material

Appendix 1: Publications achieved during PhD

Birch JM, Griffin SJ, Kelly MP, Ahern AL (2020). Inequalities in the uptake of, adherence to and effectiveness of behavioural weight management interventions. *BMJ Open* 10(11), e039518. DOI:10.1136/bmjopen-2020-039518

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Appendix 2: Conferences presented at during PhD

2021

UK Society for Behavioural Medicine (poster, online): A systematic review of inequalities in the uptake of, adherence to and effectiveness of behavioural weight management interventions

2022

UK Society for Behavioural Medicine (oral, online): A systematic review of inequalities in the uptake of, adherence to, and effectiveness of behavioural weight management interventions in adults

European Congress on Obesity (poster, in-person): A systematic review of inequalities in behavioural weight management interventions

Society for Social Medicine & Population Health Annual Scientific Meeting (oral, in-person): Association between indicators of inequality and weight regain following a behavioural weight loss intervention

European Association for the Study of Obesity [EASO] Early Career Network Winter School (poster, in-person): Are there inequalities in the attendance and effectiveness of behavioural weight management interventions for adults in the UK? An individual participant data (IPD) meta-analysis

2023

Society for Academic Primary Care South East (oral, online): Inequalities in the attendance and effectiveness of behavioural weight management interventions for adults in the UK: An individual participant data (IPD) meta-analysis

European Congress on Obesity (poster, in-person): Are there inequalities in the attendance and effectiveness of behavioural weight management interventions for adults in the UK? An individual participant data (IPD) meta-analysis

Society for Social Medicine & Population Health Annual Scientific Meeting (oral, in-person): Are there inequalities in the attendance and effectiveness of behavioural weight

management interventions for adults in the UK? An individual participant data (IPD) meta-analysis

Appendix 3: Supplementary Material

Supplementary Table 1 (Chapter 2): PROGRESS-Plus characteristics reported in each trial

Key: *P* – Place of residence, *R* – Race/ethnicity, *O* – Occupation, *G* – Gender/sex, *Re* – Religion, *E* – Education, *SES* – Socioeconomic status, *SC* – Social capital, + – plus other factors where discrimination may occur. *WL* – Weight loss; *WLM* – Weight loss maintenance

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Ackermann 2008 (36)	USA	92	WL	Fair	-	R,G,+	-	-	R,G,+	R,G
Ackermann 2015 (37)	USA	509	WL	Fair	Low-income	R,G,SES, +	R,G,SES, +	R,G,SES, +	-	R
Ahern 2017 (38)	UK	1267	WL	Fair	-	R,G,E,SES, +	R,G,E,SES, +	R,G,E,SES,+	R,G,E,SES, +	G,E,SES
Anderson 2014 (39)	UK	329	WL	Good	Aged 50 to 74 through colorectal screening programme	R,O,G,E, SES,SC, +	-	-	-	O,G,SES, SC,+
Appel 2011 (123)	USA	415	WL	Good	-	R,O,G,E, SES,+	-	-	-	-
Aveyard 2016 (40)	UK	1882	WL	Fair	-	R,G,E,SES, +	R,SES	SES	-	SES

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisa l score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Beeken 2017 (41)	UK	537	WL	Fair	-	R,G,E, SES,+	-	-	G,SES, +	-
Bennett 2012 (42)	USA	365	WL	Good	Socio- economically disadvantaged	R,O,G,E, SES,+	G,+	R,O,G,E, SES, + (age, health literacy)	R,O,G,E, SES,+ (age, language)	R,O,G,E, SES,+ (language)
Bhopal 2014 (124)	UK	171	WL	Good	Individuals of South Asian descent	R,G,Re,E, +	-	-	-	-
Burke 2005 (125)	Australia	241	WL	Fair	-	G,+	-	-	-	-
Cadmus- Bertram 2016 (80)	USA	105	WL	Fair	Women with elevated breast cancer risk	R,G,E,SC, +	-	-	-	-
Chirinos 2016 (81)	USA	230	WL	Fair	Low-income	R,G,E,SES, +	-	-	-	-
Christian 2011 (43)	USA	279	WL	Fair	Health centres with largely Hispanic patients	R,G,+	-	-	-	R,G,+

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisa l score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Cohen 1991 (44)	USA	30	WL	Fair	-	G,+	-	-	-	G,+
de Vos 2014 (82)	Netherla nds	407	WL	Fair	Women	R,G,E,SC, +	-	-	-	-
Demark- Wahnefried (45)	USA	136	WL	Good	Breast cancer survivors + daughters	R,G,E,SES, +	R,+	-	R,E,SES, +	-
Eaton 2016 (83)	USA	211	WL	Fair	-	R,O,G,E,SE S +	-	-	-	-
Fischer 2016 (46)	USA	163	WL	Fair	-	G,+ (age, language)	-	-	-	+ (protocol language)
Fitzgibbon 2010 (47)	USA	213	WL	Fair	Black women	R,O,G,E,SE S,SC,+	-	-	O,G,E,SES,SC ,+	-
Godino 2016 (85)	USA	404	WL	Good	Young adults (18 to 35)	R,G,+	-	-	-	-
Greaves 2015 (48)	UK	108	WL	Fair	-	R,G,E,SES, +	G,+	-	-	-
Haapala 2009 (86)	Finland	125	WL	Fair	-	G,E,SC, +	-	-	-	-
Hunt 2014 (49)	UK	747	WL	Good	Men	R,O,G,SES, SC,+	-	-	-	R,O,E,SES, SC,+

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Huseinovic 2016 (50)	Sweden	110	WL	Fair	Postpartum women	G,E,SC, +	-	-	Education +	-
Jakicic 2011 (87)	USA	269	WL	Fair	-	R,G,+	-	-	-	-
Jansson 2012 (88)	Sweden	133	WL	Fair	-	G,+	-	-	-	-
Jebb 2011 (51)	UK, Germany and Australia	772	WL	Fair	-	G,+	-	-	+	-
Jeffery 1993 (52)	USA	202	WL	Fair	-	R,E,SC, +	-	G	G	G
Jenkins 2017 (89)	Canada	919	WL	Fair	-	R,G,E,SES, +	-	-	-	-
Jolly 2011 (53)	UK	740	WL	Fair	-	R,G,SES, +	-	-	R,G,SES, +	G
Jones 1999 (90)	USA	112	WL	Fair	-	R,G,+	-	-	-	-
Kanke 2015 (91)	Japan	50	WL	Fair	-	G,E,+	-	-	-	-
Katula 2011 (92)	USA	301	WL	Good	-	R,G,E, +	-	-	-	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisa l score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Knowler 2002 (93)	USA	2161	WL	Good	-	R,O,G,SES, SC,+	-	-	-	R,G
Kuller 2012 (94)	USA	508	WL	Good	Women	R,O,G,E,SC , +	-	-	-	-
Kulzer 2009 (54)	Germany	182	WL	Fair	-	G,E,+	-	-	G,E,+	-
Kumanyika 2012 (55)	USA	261	WL	Fair	-	R,O,G,E,SC , +	-	SES	-	-
Little 2016 (95)	UK	818	WL	Fair	-	G,SES, +	-	-	-	-
Logue 2005 (96)	USA	665	WL	Fair	-	R,G,+	-	-	-	-
Luley 2014 (97)	Germany	184	WL	Fair	-	G,+	-	-	-	-
Ma 2013 (56)	USA	241	WL	Good	-	R,G,E,SES, +	-	-	-	G
Marrero 2016 (98)	USA	225	WL	Fair	-	R,G,E,SES, SC,+	-	-	-	-
Martin 2008 (57)	USA	144	WL	Fair	Low income African	R,G,E,SC, +	-	-	E,SC, +	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differential measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
					American women					
Mensink 2003 (58)	Netherla nds	114	WL	Fair	-	G,+	G,+	-	-	-
Mitsui 2008 (99)	Japan	46	WL	Fair	-	G,+	-	-	-	-
Moore 2003 (100)	UK	843	WL	Fair	-	G,SES, +	-	-	-	-
Morgan 2011 (59)	Australia	65	WL	Fair	Men	O,G,SES, +	-	O,+	+	-
Nakade 2012 (60)	Japan	235	WL	Fair	-	G,+	-	-	-	G
Nanchahal 2012 (61)	UK	381	WL	Fair	-	R,O,G,E,SE S,SC,+	-	-	R,O,G,E, SES,SC, +	-
Nicklas 2014 (101)	USA	75	WL	Fair	-	R,G,E,SES, SC,+	-	-	-	-
Nilsen 2011 (62)	Norway	213	WL	Fair	Women with recent gestational diabetes mellitus	O,G,E,SC, +	-	-	-	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differential measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
O'Brien 2017 (102)	USA	63	WL	Good	Hispanic women, majority foreign born and low income	R,G,E,SES, + (age, country of origin)	-	-	-	-
Ockene 2012 (63)	USA	312	WL	Fair	Latino community	R,O,G,E,SC , +	-	-	G	-
Pacanowski 2015 (64)	USA	162	WL	Fair	-	R,G,E, +	-	-	-	O
Parikh 2010 (65)	USA	99	WL	Fair	Low-income, high ethnic minority community	R,O,G,SES, + (age, language, food sufficiency)	-	-	G,+	-
Patrick 2011 (66)	USA	441	WL	Fair	Men	R,G,E,SC, +	R,SC, +	-	R,+	-
Penn 2009 (67)	UK	102	WL	Fair	-	O,G,SES, +	-	-	+	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Phelan 2017 (68)	USA	370	WL	Good	Low-income postpartum women	R,O,G,SES, SC,+	R,+ (language)	R	R,O,SES,SC,+	R,O,SES,SC, +
Puhkala 2015 (103)	Finland	113	WL	Fair	Male truck and bus drivers	G,+	-	-	-	-
Rock 2007 (104)	USA	70	WL	Fair	Women	R,G,E,SC, +	-	-	-	-
Rock 2015 (105)	USA	697	WL	Good	Women who were breast cancer survivors	R,G,+	-	-	-	-
Rodriguez- Cristobal 2017 (106)	Spain	864	WL	Fair	-	G,+	-	-	-	-
Rosas 2015 (69)	USA	207	WL	Good	Low-income Latinos	R,O,G,E,SE S,+ (age, food security, birthplace)	-	-	G	G
Ross 2012 (70)	Canada	490	WL	Fair	-	G,+	-	G	G,+	G

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Shapiro 2012 (71)	USA	170	WL	Fair	-	R,G,E, +	-	G,E, +	G,E,+	-
Silva 2010 (72)	Portugal	239	WL	Fair	Women	G,E,SC, +	-	-	E,SC, +	-
Stevens 1993 (73)	USA	564	WL	Good	-	R,O,G,SC, +	-	G	-	R,G
Stevens 2001 (74)	USA	1191	WL	Good	-	R,G,E, +	R,O,G,E, SC,+	-	-	R,G,+
Svetkey 2015 (75)	USA	365	WL	Good	Young adults (18 to 35)	R,O,G,E,SE S,SC,+	-	-	-	R,G,E,SES, +
Thomas 2017 (77)	USA	271	WL	Good	-	R,G,E, +	-	-	R,G,E, +	-
Tsai 2010 (107)	USA	50	WL	Good	-	R,E,+	-	-	-	-
Tuomilehto 2001 (108)	Finland	522	WL	Good	-	G,+	-	-	-	-
van Wier 2011 (109)	Netherla nds	1386	WL	Fair	"Dutch service- sector employees"	G,E,SC, + (age, birthplace)	-	-	-	-
Venkat Narayan 1998 (76)	USA	95	WL	Fair	Pima Indians	R,O,G, +	G	O	-	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisa l score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
von Gruenigen 2012 (110)	USA	75	WL	Fair	Endometrial cancer survivors (women)	R,O,G,E,SE S,SC,+	-	-	-	-
Wadden 2011 (111)	USA	261	WL	Good	-	R,G,E, +	-	-	-	-
Whelton 1998 (78)	USA	585	WL	Good	Older persons (aged 60 to 80)	R,G,E, +	-	-	-	R,G
Wing 1998 (112)	USA	154	WL	Fair	-	G +	-	-	-	-
Wylie-Rosett 2001 (79)	USA	588	WL	Fair	-	R,G,E, +	R,G,E, +	-	R,G,E,SC, +	R,G
Yeh 2016 (113)	USA	60	WL	Fair	Chinese immigrants	R,G, +	-	-	-	-
Cussler 2008 (129)	USA	135	WLM	Fair	Middle-aged women	G,+	-	-	-	-
Pekkarinen 2015 (126)	Finland	201	WLM	Fair	-	O,G,E,SC, +	-	-	-	O,G,E, +
Perri 1988 (130)	USA	123	WLM	Fair	-	G,+	-	-	-	-

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Sherwood 2013 (131)	USA	419	WLM	Good	-	G,+	-	-	-	-
Simpson 2015 (132)	UK	166	WLM	Fair	-	R,G,+	-	-	-	-
Svetkey 2008 (127)	USA	1032	WLM	Good	-	R,G,E,SES, +	-	R,G,E, SES, +	R,G,E,SES, +	R,G,+
Voils 2017 (133)	USA	222	WLM	Fair	-	R,O,G,E,SC , +	-	-	-	-
Wing 2006 (134)	USA	314	WLM	Fair	-	G,+	-	-	-	-
Young 2017 (128)	Australia	92	WLM	Good	-	O,G,E,SES, SC,+ (age, birthplace, language)	-	-	O,G,E,SES,SC ,+ (age, place of birth, language at home)	SES,+
Astbury 2018 (114)	UK	278	WL	Fair	-	R,G,SES, +	G,SES, +	G,SES, +	G,SES, +	G,SES, +
Bennett 2018 (115)	USA	351	WL	Fair	-	R,O,G,E,SE S,SC,+	-	-	-	R,G

Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Daley 2019 (135)	UK	583	WLM	Fair	-	R,O,G,SES, SC,+	-	-	R,G,E,SES, SC	G
Fernandez- Ruiz 2018 (12)	Spain	74	WL	Good	-	O,G,E,SC, +	-	-	-	-
Fjeldsoe 2019 (116)	Australia	228	WL	Fair	-	P,R,O,G,E, SES,+ (age, language)	-	-	P,R,O,G,E, SES,+ (age, language at home)	-
Godino 2019 (84)	USA	298	WL	Good	-	R,O,G,E,SE S,SC,+ (age, language)	-	-	-	R,G,+ (age, language at home)
Haire-Joshu 2018 (117)	USA	230	WL	Fair	Mothers of preschool- aged children	R,G,E,SES, SC,+	-	-	-	R,SES
Mai 2018 (136)	Germany	143	WLM	Fair	-	G,+	-	-	-	G,+
Nakata 2019 (137)	Japan	119	WLM	Fair	-	G,+	-	-	-	-
Sniehotta 2019 (138)	UK	288	WLM	Good	-	O,G,E,SES, +	-	-	-	-

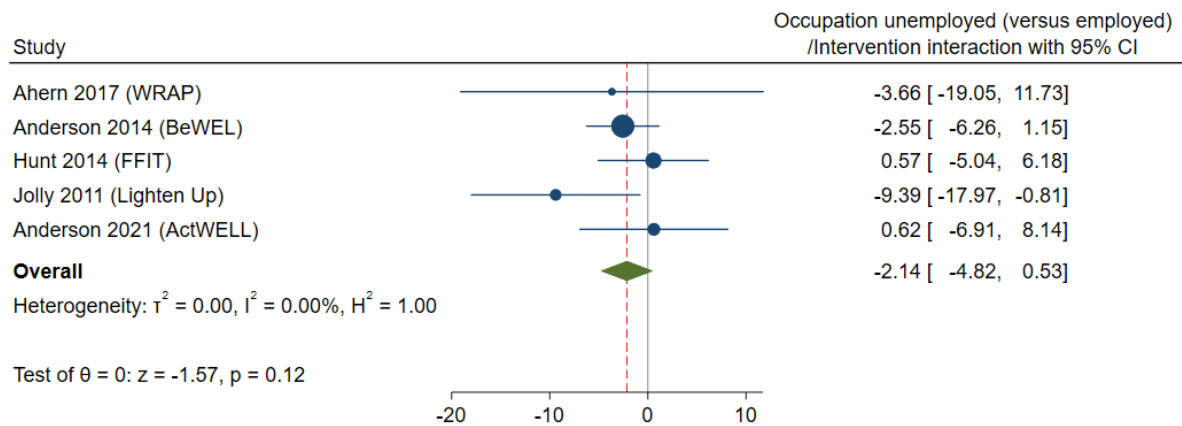
Author, year (Harvest plot reference)	Country	Sample size	Weight loss (WL) or weight loss maintenance (WLM)	Quality appraisal score	Group targeted	Variables reported at baseline	Differentia l measures reported for uptake	Differential measures reported for adherence and attendance	Differential measures reported for attrition variables	Differential measures reported for weight outcome
Tapsell 2017 (118)	Australia	251	WL	Fair	-	R,G,E, + (age, birthplace)	-	-	-	G
Tarraga Marcos 2017 (121)	Spain	180	WL	Fair	-	G,+	-	-	-	-
Teeriniemi 2018 (122)	Finland	532	WL	Fair	-	R,G,+	-	-	-	-
Viglione 2019 (119)	USA	45	WL	Fair	Veterans	R,O,G,SES, + (age, food security)	-	R,G,SES, + (age, food security)	-	-

P – Place of residence, R – Race/ethnicity, O – Occupation, G – Gender/sex, Re – Religion, E – Education, SES – Socioeconomic status, SC – Social capital, + – plus other factors where discrimination may occur. WL – Weight loss; WLM – Weight loss maintenance

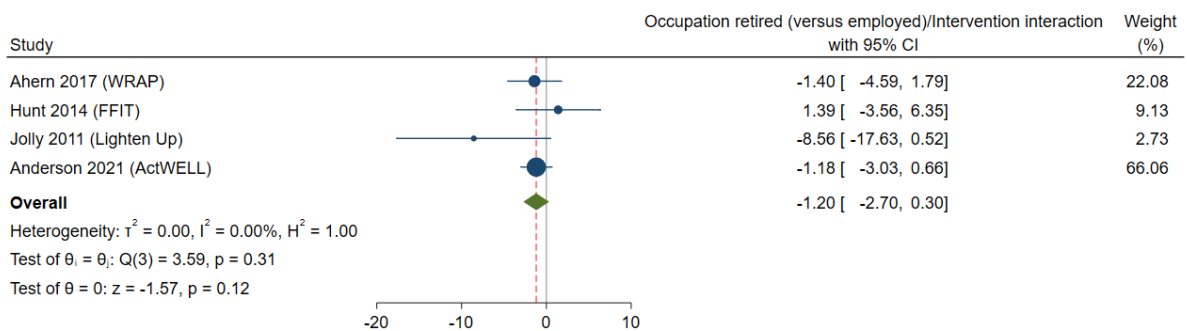
Supplementary Material (Chapter 5): Meta-analysis forest plots of the differential effectiveness of behavioural weight management interventions

Occupation

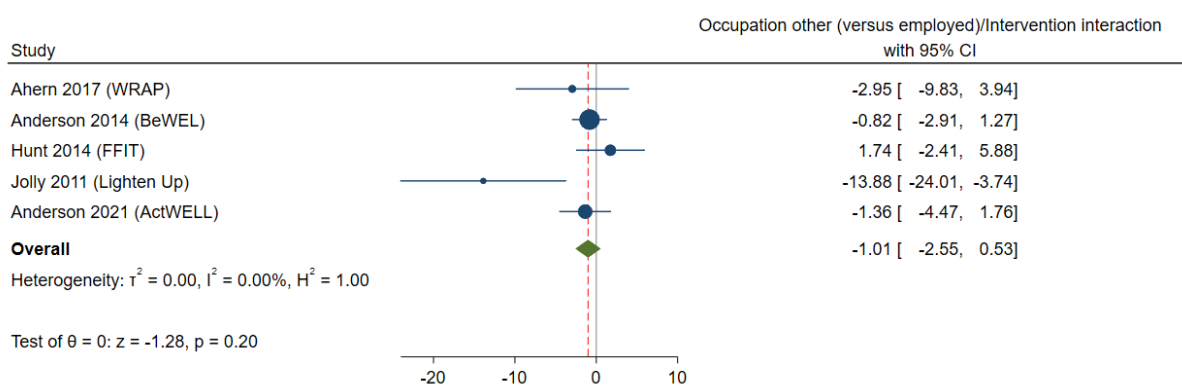
Unemployed vs employed



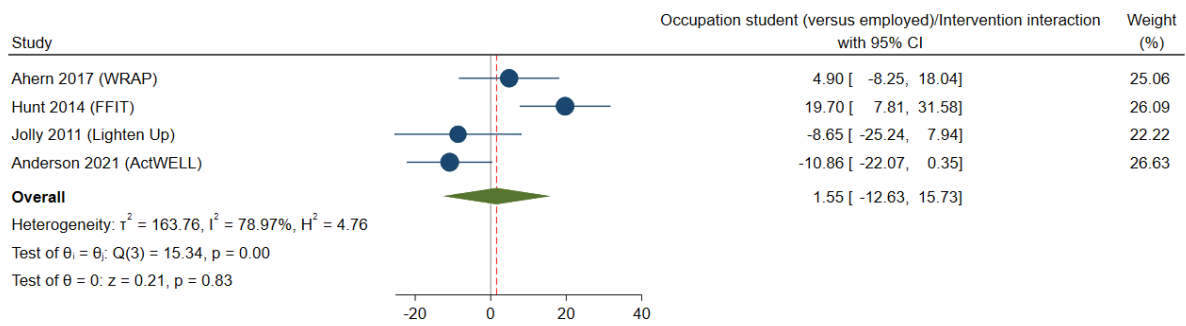
Retired vs employed



Other versus employed

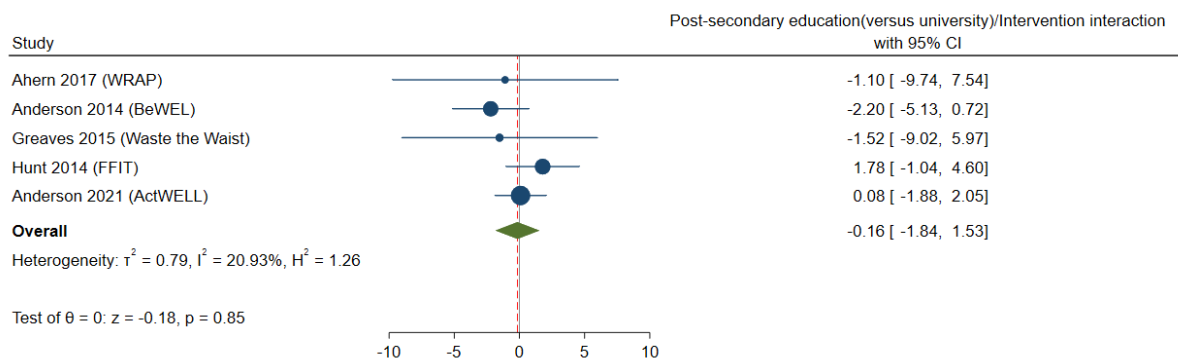


Student versus employed

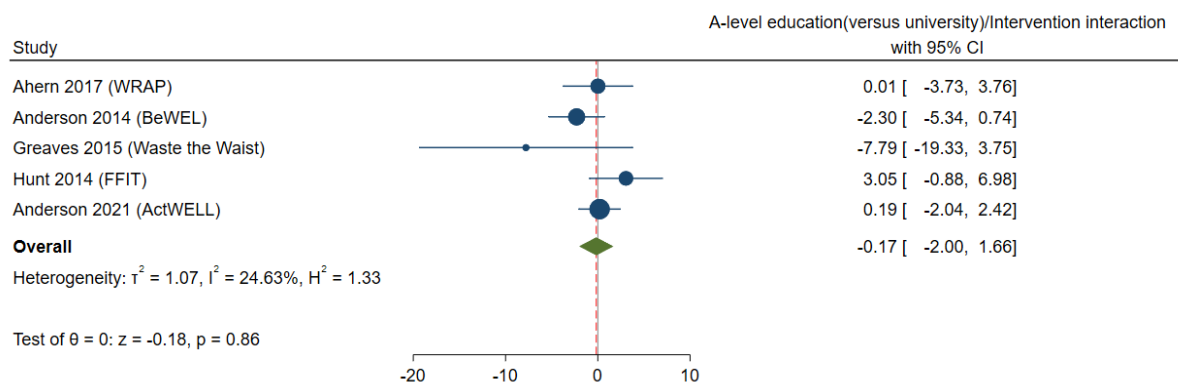


Education

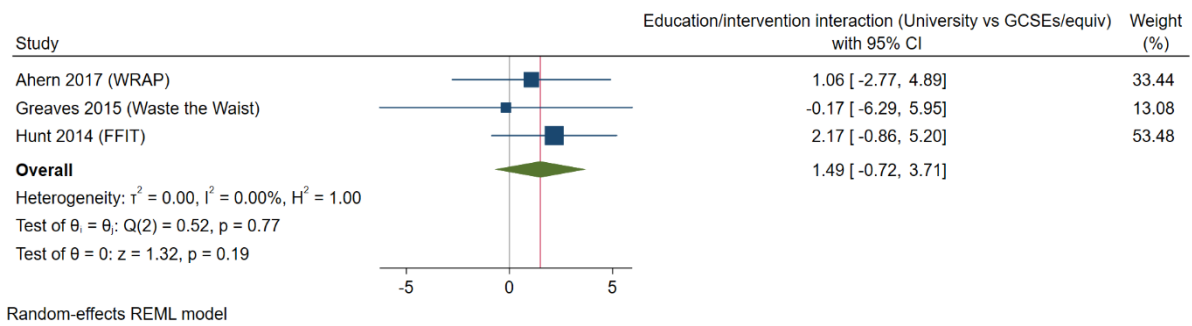
University versus Post-secondary



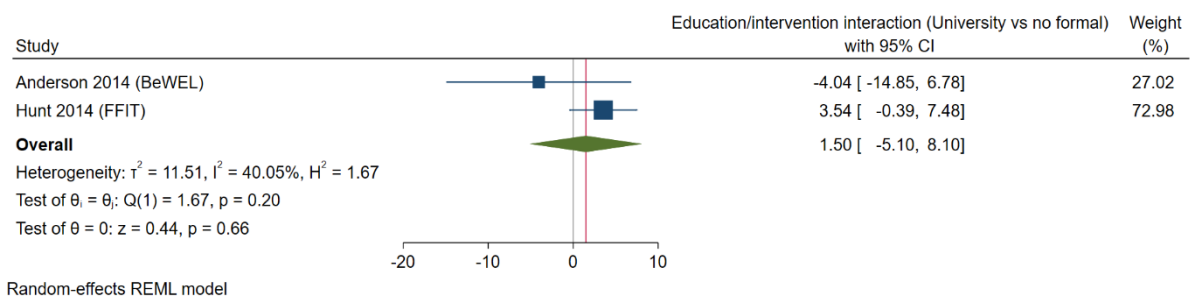
University versus A-levels or equivalent



University versus GCSEs or equivalent

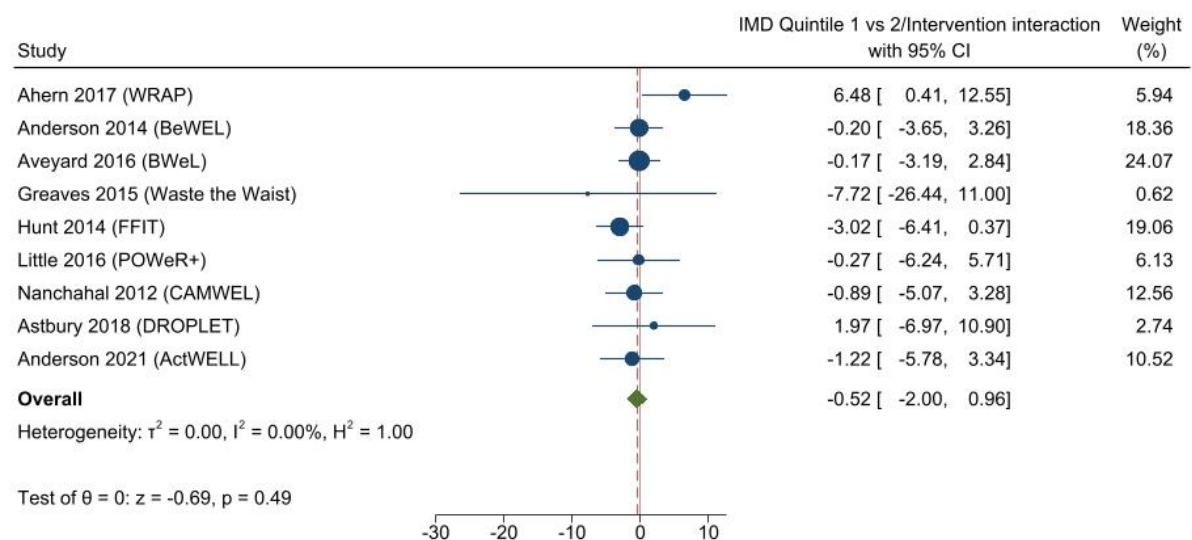


University versus no formal qualifications

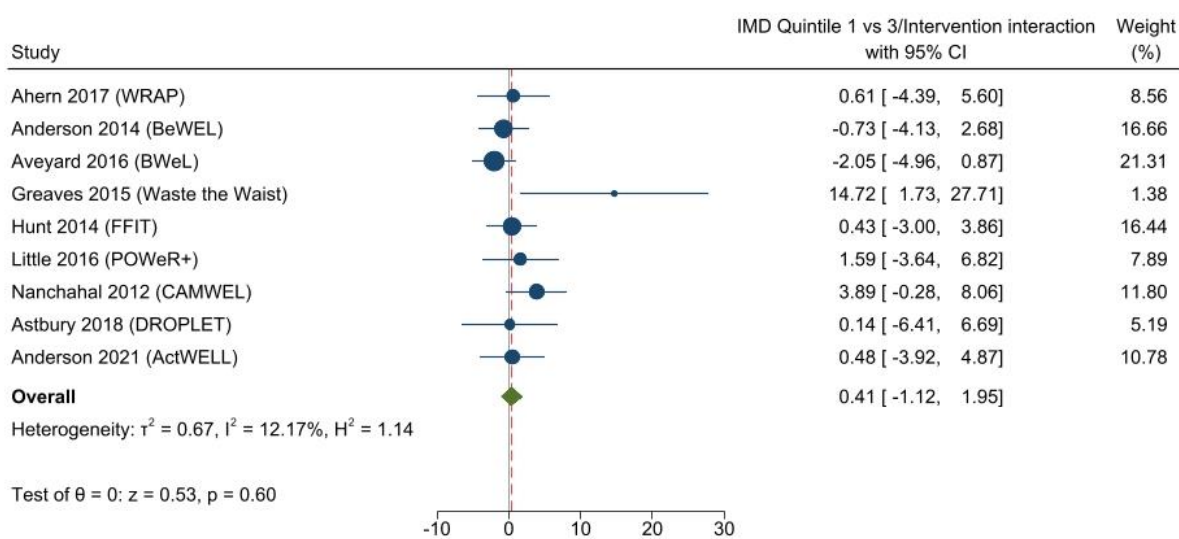


Socioeconomic status (IMD)

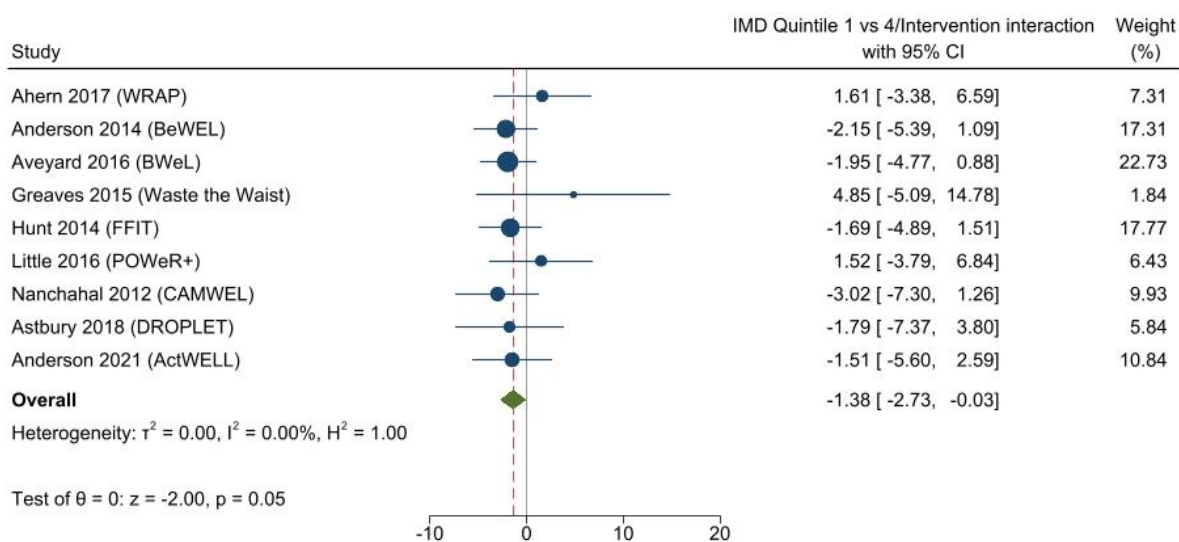
IMD quintile 1 (most deprived) versus 2



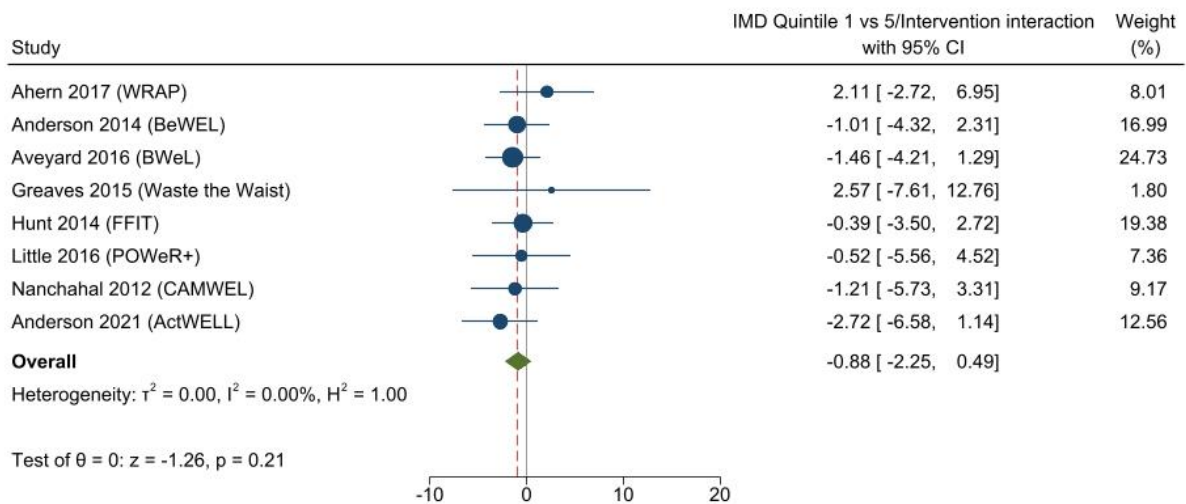
IMD quintile 1 (most deprived) versus 3



IMD quintile 1 (most deprived) versus 4

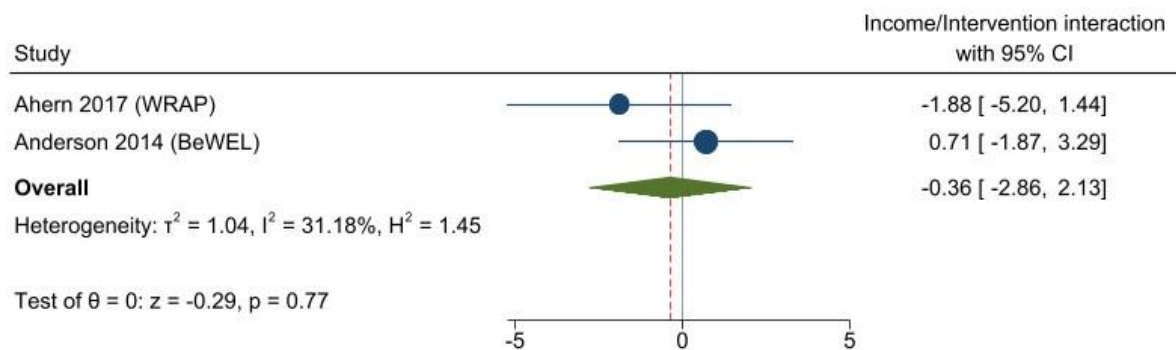


IMD quintile 1 (most deprived) versus 5 (least deprived)



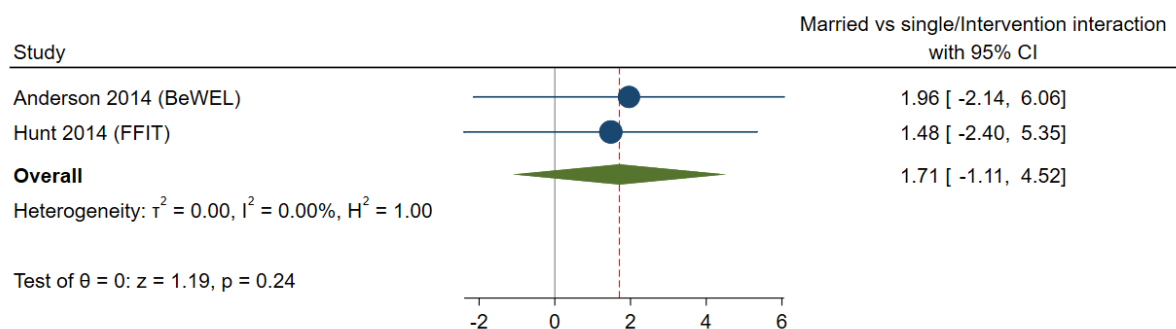
Socioeconomic status (annual household income)

\geq £40,000 versus $<$ £40,000

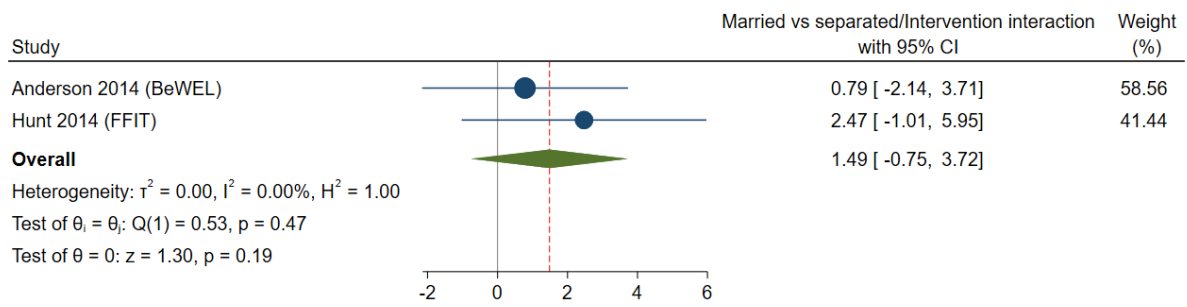


Social capital (marital status)

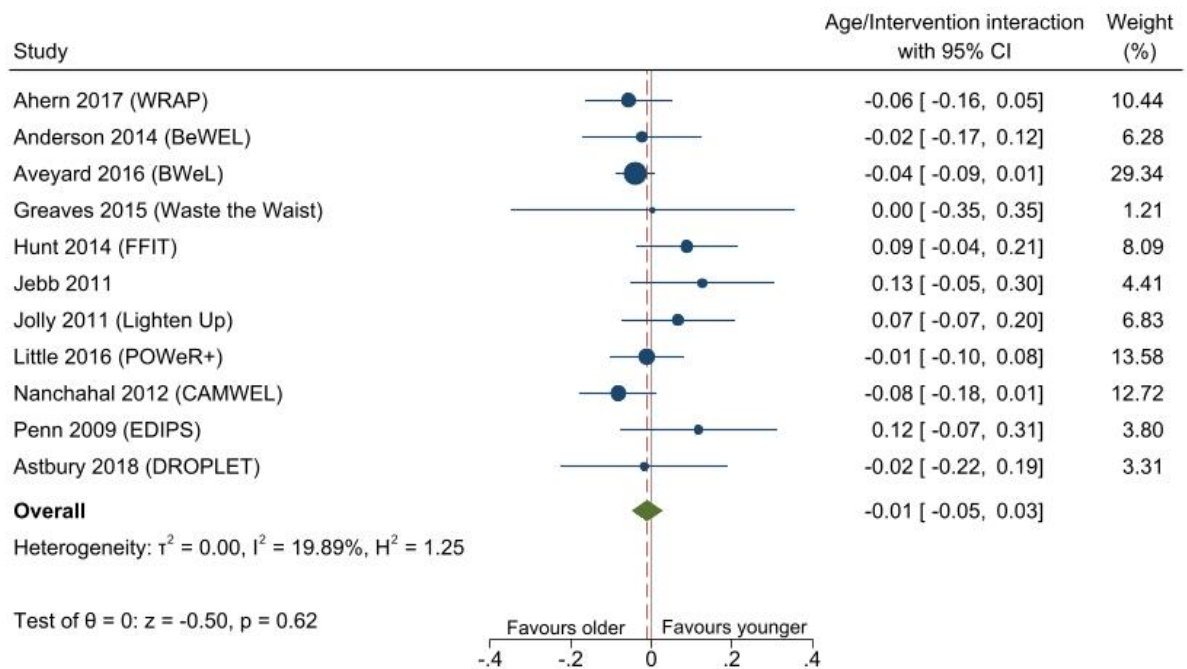
Married or cohabiting versus single



Married or cohabiting versus separated, widowed, or divorced



Plus (age)



Supplementary Material (Chapter 7): baseline demographics survey

SWiM COVID Demographics Questionnaire

We would like to ask you some questions about your background, so that we can understand whether this intervention meets the needs of different groups of people.

What is your age in years? _____

What is your sex?

- Male
- Female
- None of these (please specify) _____
- Prefer not to say

What is your ethnicity?

- White (including British, English, Welsh, Scottish, Northern Irish, Irish, Gypsy or any other White background)
- Mixed (including White and Black Caribbean or any other Mixed background)
- Black/African/Caribbean/Black British
- Asian or Asian British (including Indian, Pakistani, Bangladeshi, Chinese or any other Asian background)
- None of these (please specify) _____
- Prefer not to say

What is your highest educational qualification?

- No formal qualification
- GCSE or equivalent (e.g. CSE, O Levels, level 2 awards)
- A-Level or equivalent (e.g. Level 3 awards, Applied General, Advanced apprenticeship)
- Post-secondary education (e.g. CertHE DipHE HNC, HND, Foundation Degree, Level 4 or Level 5 Awards)
- University Degree or equivalent (e.g. BA, BSc, degree apprenticeship, Level 6 award)
- Higher Degree or equivalent (e.g. MA, PhD, PGCE, Level 7 or Level 8 award)
- Other (please specify) _____
- Prefer not to say

Which category best describes your **usual** occupation?

- Employee in full-time job (30 hours or more a week)
- Employee in part-time job (under 30 hours a week)
- Self-employed, full or part-time
- On a Government supported training programme (e.g. Modern Apprenticeship/ Training for Work)

- Full-time education at school, college or university
- Voluntary work, full or part-time
- Unemployed and available for work
- Permanently sick/disabled
- Wholly retired from work
- Looking after the home, children or other dependents
- Other (please specify)
- Prefer not to say

What is your **current** situation?

- Travelling to a place of work or study (e.g. to a hospital, office, factory or supermarket)
- Usual occupation working from home
- Furloughed
- Unable to carry out usual occupation
- Voluntary work, full or part-time
- Unemployed and available for work
- Permanently sick/disabled
- Wholly retired from work
- Looking after the home, children or other dependents
- Other (please specify)
- Prefer not to say

Are you...?

- Single
- Married/Civil partnership
- Co-habiting
- Widowed
- Separated/Divorced
- Prefer not to say

How many adults (aged 18 and over) are living in your household? _____

How many children (aged 17 and under) are living in your household? _____

Do you have any caring responsibilities?

- None
- Primary carer of a child (or children) aged under 18 years?
- Primary carer of a child (or children) with a disability?
- Primary carer of an adult with a disability?
- Primary carer of an older person or people (age 65+)?
- Secondary carer

- Prefer not to say

Thinking about the cost of living as it affects you and your household, which of these best describes your situation **at present**?

- Find it a strain to get by from week to week
- Have to be careful about money
- Able to manage without much difficulty
- Quite comfortably off
- Prefer not to say

About how long would it take to get from your home to the nearest accessible open recreation area such as a park or other open space if you walked to it?

- 1-5 min
- 6-10 min
- 11-20 min
- 21-30 min
- More than 30 min
- Don't know

Which of these best applies to your home?

- I have access to my own garden
- I have access to a communal garden
- I have access to a private outdoor space but not a garden (e.g. balcony, yard, patio area)
- I don't have access to a garden
- Don't know

We would like to ask you some questions about your food consumption since **lockdown**. Since lockdown, has there been a time when:

- You were worried you would run out of food because of a lack of money, access or other resources?
 - Yes
 - No
- You were unable to eat healthy and nutritious food because of a lack of money, access or other resources?
 - Yes
 - No
- You ate only a few kinds of foods because of a lack of money, access or other resources?
 - Yes
 - No
- You had to skip a meal because there was not enough money, access or other resources to get food?
 - Yes

- No
- You ate less than you thought you should because of a lack of money, access or other resources?
 - Yes
 - No
- Your household ran out of food because of a lack of money, access or other resources?
 - Yes
 - No
- You were hungry but did not eat because there was not enough money, access or other resources for food?
 - Yes
 - No
- You went without eating for a whole day because of a lack of money, access or other resources?
 - Yes
 - No

We would like to understand more about your support during social distancing. Please rate how much you agree with the following statements on a scale of 1 to 5, where 1=strongly disagree and 5=strongly agree.

	Strongly Disagree				Strongly Agree
	1	2	3	4	5
I receive a lot of understanding and security from others	1	2	3	4	5
There is someone very close to me whose help I can always count on	1	2	3	4	5
If I need to, I can borrow something from friends or neighbours without any problems.	1	2	3	4	5
I know several people with whom I like to do things	1	2	3	4	5
When I am sick, I can ask friends/relatives to handle important things for me without hesitation	1	2	3	4	5
If I'm very depressed, I know who I can turn to.	1	2	3	4	5