Life course socioeconomic adversity and its implications for musculoskeletal ageing

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Qoraalkan waxaan u hibeeyey hooyaday macaan.

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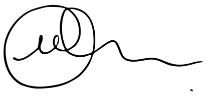
Declaration

I, Mohamed A. Yusuf, confirm that this thesis comprises only my original work, and where information has been derived from other sources, due acknowledgement has been made in the text.

Signed 

Abstract

Developing good musculoskeletal health and function into mid-adulthood, and maintaining it into later adulthood, can help people live independent and healthy lives, with grip strength and standing balance performance serving as important markers. However, associations between life course socioeconomic position (SEP) and these markers remain unclear. The literature on the associations between life course SEP, grip strength, and standing balance performance has gaps and limitations, such as inconsistent patterns of associations at younger ages, insufficient evidence on underlying pathways, a scarcity of studies using prospectively ascertained SEP indicators, and a lack of examination of ethnic differences where feasible. To address these limitations, the body of work set out in this thesis took a life course epidemiological perspective to examine the associations of SEP across life with grip strength and standing balance performance, utilising data from the 1970 British Cohort Study (BCS70) and the UK Biobank (UKB).

In women, lower SEP in childhood and adulthood were robustly associated with weaker grip strength at age 46 years in the BCS70, and lower adulthood SEP was associated with weaker grip strength between ages 37 and 69 in UKB. In men, there were no associations between indicators of childhood SEP and grip strength at age 46 years in the BCS70, but lower adulthood SEP was linked to stronger grip strength in both BCS70 and UKB, possibly due to higher levels of occupational activity related to manual occupations among middle-aged men. Associations between adulthood SEP and grip strength varied by age and ethnicity in men, with men of South Asian heritage not experiencing the same occupational activity advantage as men of other ethnic groups. Additionally, in the UKB, South Asian men were generally weaker than White men, while Black men and women were stronger than their White counterparts, independent of height, adiposity, and health and behavioural factors. Lower childhood SEP was associated with poorer balance performance at age 46 years in the BCS70, primarily explained by adulthood SEP. The association of lower adulthood SEP with poorer standing balance performance was largely unexplained by the potential mediators examined.

These findings have relevance for interventions aimed at improving strength and balance outcomes and promoting healthy ageing. Such interventions should encompass policy measures to address socioeconomic inequalities across the lifespan and ethnic differences in adulthood, along with targeted messaging for strength and balance training.

Outputs from thesis

1. **Peer-reviewed publication in *BMC Public Health*, July 2022:** *Yusuf, M.*, Montgomery, G., Hamer, M., McPhee, J. and Cooper, R., 2022. Associations between childhood and adulthood socioeconomic position and grip strength at age 46 years: findings from the 1970 British Cohort Study. *BMC Public Health*, 22(1), pp.1-12. [See Appendix B.1]

2. **Oral presentation at the *Society for Social Medicine and Population Health* conference, September 2022**: *Yusuf, M.*, McPhee J, Montgomery G, Cooper R. OP66 Pathways between childhood socioeconomic position and standing balance performance at age 46: mediation analysis using the 1970 British Birth Cohort study *J Epidemiol Community Health* 2022;76:A32.

3. **Oral presentation at the *Society for Social Medicine and Population Health* conference, September 2021**: *Yusuf, M.*, McPhee J., Montgomery G., and Cooper R. OP54 Associations between socioeconomic position across life and grip strength at age 46 years: findings from the 1970 British cohort study *J Epidemiol Community Health* 2021;75:A25-A26.

4. **Poster presentation at the *International Sarcopenia Translation Research* conference, July 2021**: *Yusuf, M.*, McPhee J., Montgomery G., and Cooper R. OP54 Associations between socioeconomic position across life and grip strength at age 46 years: findings from the 1970 British cohort study.

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Abbreviations

ALSPAC	Avon Longitudinal Study of Parents and Children
BCS70	1970 British Cohort Study
BMI	Body Mass Index
COVID-19	Coronavirus Disease of 2019
CFA	Confirmatory Factor Analysis
IMD	Index of Multiple Deprivation
KG	Kilograms
MRC	Medical Research Council
NCDS	National Child Development Study
NSHD	National Survey of Health and Development
NS-SEC	National Statistics Socio-economic Classification
RGSC	Registrar General's Social Classification
RMSEA	Root Mean Square Error of Approximation
RRR	Relative Risk Ratios
SEP	Socioeconomic Position
SOC	Standard Occupational Classification
SRMR	Standardized Root Mean Square Residual
SHARE	Survey of Health Ageing and Retirement in Europe
SEM	Structural Equation Modelling
TILDA	The Irish Longitudinal Study of Ageing
UK	United Kingdom
UKB	UK Biobank
UKHLS	UK Household Longitudinal
USA	United States of America

CHAPTER 1

Introduction

Using a life course epidemiological perspective, this thesis examines the associations between socioeconomic adversity at different life stages and grip strength and standing balance performance in adulthood which are important markers of musculoskeletal health and function. It also investigates the potential pathways through which these associations may operate. While the impact of life course socioeconomic adversity on morbidity and mortality indicators such as cardiovascular diseases and all-cause mortality has been well-established for many years (Galobardes et al., 2004; Galobardes et al., 2008), the relationship between socioeconomic adversity at different life stages and objectively assessed indicators of musculoskeletal health and function is not fully understood. Studying these relationships has the potential to help determine the most suitable, timely and effective opportunities to improve people's chances of living healthier lives for longer.

This introductory chapter provides context and background to the thesis and the key conceptual framework used. The first section (1.1) sets the scene and introduces population ageing and the concept of healthy ageing. The second section (1.2) presents the United Kingdom's (UK) Government policy agenda on healthy ageing and explores the context of this agenda by examining the history of inequalities within the UK. Section 1.3 discusses the importance of socioeconomic adversity and its impact on health. The fourth section (1.4) details the factors that influence healthy life expectancy, namely long-term conditions, including musculoskeletal disorders. This section introduces the term musculoskeletal health and function and its use to contextualise physical capability. It also discusses the impact socioeconomic adversity may have on musculoskeletal health and function. The section then introduces the life course perspective to understand this relationship better. Section 1.5 introduces how physical capability is measured. Finally, Sections 1.6 and 1.7 conclude the chapter and outline the structure of this thesis.

1.1 Our ageing population

Due to reductions in mortality rates resulting in improvements in life expectancy and marked falls in fertility rates, the global population is ageing — a trend observed over the course of the 20th century in high-income countries and, more recently, in low-middle income countries (Lutz et al., 2008). For example, between 1950 and 2015, the proportion of the world's population above the age of 65 years increased from 5.1% to 8.3%, and by 2050 this is projected to reach 16.5% (United Nations, 2022). This dramatic change in the age structure is having profound implications for society.

Too often, population ageing is viewed negatively. Indeed, an ageing population does have potentially adverse social and economic implications. However, the fact that older populations offer potential solutions to the many challenges facing our society should be acknowledged, as done by the *World Health Organisation* through their *Decade of Healthy Ageing* initiative (Levy and Macdonald, 2016; World Health Organization, 2020a). An ageing population has the potential to have a positive impact on economic productivity through an increase in the labour force and provides society with an older population that is an invaluable resource for individuals, families, and communities — a population who can live with vitality and contribute to society through various means such as caregiving and family support to community and local participation after retirement (World Health Organization, 2020a).

1.1.1 Healthy ageing

As the population ages, unique health challenges and needs are emerging. Healthy ageing, defined by the *World Health Organisation* as *'the process of developing and maintaining the functional ability that enables well-being in older age'* (World Health Organization, 2015, p. 150), has become central to fostering the positive aspects of population ageing whilst minimising the associated burden. Without improvements in healthy life expectancy — the number of years lived in a healthy state — population ageing will result in an increase in the number of individuals living with ill health and disability and extend the length of time people live in poor health before death; this is likely to have far-reaching impacts on individuals, families, and wider society (Beard et al., 2016). There are also moral implications, as healthy ageing should be a fundamental human right that is central to maintaining dignity and having the freedom to enjoy life (World Health Organization, 2020a). Therefore, to cater to the health needs of an ageing population, increasing the proportion of adults living longer with good health and independence is a moral, political and scientific priority.

1.2 Policy and health inequalities in the UK

In 2018, as part of the UK Government's *Industrial Strategy* to help tackle some of the major challenges facing the modern world and to improve individuals' lives and the country's productivity, ageing was identified as one of four Grand Challenges. The Government set out an ambitious objective of *'ensuring that people can enjoy at least five extra healthy, independent years of life by 2035, while narrowing the gap between the experience of the richest and poorest'* (Department for Business, Energy and Industrial Strategy, 2023:online). This initiative came at a time when life expectancy in the UK had started to stall, with an increased disparity in life expectancy and healthy life expectancy between those of different socioeconomic circumstances, with the less fortunate living not only much shorter lives but also spending more of their shorter lives in poor health (Office for National Statistics, 2018). It is important to note that on March 1st, 2023, the UK Government announced its decision to shift away from its healthy ageing agenda and focus exclusively on economic development and growth (Department for Business, Energy and Industrial Strategy, 2023:online). The urgency of addressing health inequalities in ageing populations remains despite the Government's change in policy direction. The implications of this policy change in relation to the work presented in this thesis are discussed in Chapter 7.

To contextualise the challenge of health inequalities in ageing populations, a brief examination of the UK's historical context of health inequalities is necessary.

The following subsections analyse three influential reports on health inequalities and their policy impact.

1.2.1 Black report

As Davey Smith et al. (2001) described, health inequalities have been recognised for centuries within Britain. One of the most influential reports on socioeconomic inequalities in health was the *Black* report (Black et al., 1980). This report kickstarted a substantial body of research documenting the widening gap in health inequalities in the UK over four decades. The *Black* report was commissioned in 1977 by the Labour Secretary of State, Lord Ennals. It was conducted by the *Research Working Group on Inequalities in Health,* led by Sir Donald Black. The report was the first of its kind; it revealed the nature, scale and causes of health inequalities in the UK. It highlighted that despite the general decline in death rates and ill health, death rates were distributed unequally across different socioeconomic groups. The gap between those at the top and bottom of the socioeconomic scale widened from 1949 to 1972. Following these findings, the working group made 37 ambitious social and welfare policy recommendations to reduce the widening gap in health inequality. However, it was reported that the Government at the time did not welcome these recommendations because of their *costly nature* (Bambra et al., 2011; Exworthy et al., 2003; Marmot, 2001).

1.2.2 Acheson report

In 1998, nearly two decades after the *Black* report, with the first Labour majority Government since the 1970s, the *Independent Inquiry into Inequalities in Health* report was commissioned (Acheson, 1998). This work, led by Sir Donald Acheson, confirmed the findings previously described in the *Black* report and concluded that measures of mortality, life expectancy and health status were all socioeconomically graded, with the gap between those at the top and bottom widening between 1971 and 1996. The report then went on to make 39 policy recommendations to reduce these inequalities and improve living standards in the UK. These recommendations included considering inequalities when evaluating health policies and taking steps to reduce income inequalities and improve the living standards of poorer households. As the report was released in a more favourable political climate than the *Black* report, the Government welcomed these recommendations at the time (Bambra et al., 2011; Marmot, 2001). The Government initiated several schemes that considered the recommendations of the *Acheson* report. For example, more support was provided for deprived areas in the UK. A *Sure Start* scheme was established to *'give children the best possible start in life'* by providing families with childcare, early education, health, and support (Marmot, 1999). A *Healthy Schools* program, designed to target deprived schools to improve health, raise pupil achievement and improve social inclusion, was also established.

1.2.3 Fair Society, Healthy Lives report

In 2008, a decade after the *Acheson* report, the *Fair Society, Healthy Lives* report was commissioned by the UK Government (Marmot and Bell, 2012). The review led by Sir Michael Marmot, which focused on England, found that health inequalities persisted and the gap in health between socioeconomic groups was still increasing. The report emphasised psychosocial-related issues such as equality and stress, and like the previous two reports, it made policy suggestions to reduce these inequalities. Like the Black report, policy recommendations from Sir Michael Marmot's report were not well-received at the time — this has been attributed to the political context in which these reports were published (Bambra et al., 2011).

1.2.4 Policy response to health inequalities

The mismatch between research and policy to tackle health inequalities has been previously reported (Kriznik et al., 2018; Popay, 2012). In a qualitative study involving 112 key figures, including senior researchers, funders, politicians, and journalists who were involved in health inequalities research and policy in Britain between 1997 and 2012, Katherine Smith et al. (2014) found that none of these key figures believed that policies aimed at reducing health inequalities were based on research evidence. It is unclear if such a response is exclusive to health inequalities, or if this is how Government policies are generally formulated. Besides, instead of the research-informed ideas on the socioeconomic risk factors of health, along with other theories, such as the role of external factors, it was evident that individualism dominated many of these policies, especially in Governments led by right-leaning politics. This notion holds that health is governed by human behaviour, and since behaviour is determined by choice, individuals are responsible for their own health (Weber, 1922). Instead of focusing on the upstream social determinants of health (Braveman et al., 2011), such as access to quality education, stable housing, healthy foods, and health care, individualism focuses on the micro-level, making individuals and their behaviours the reason for the observed inequalities. Consequently, the importance of structural and social factors in driving socioeconomic inequalities is ignored or underestimated (Viens, 2016).

While there was no immediate response to the policy recommendations for some of the reports discussed in this section, they all did bring health inequalities to the forefront of public health priorities, making it an important agenda for policymakers (Acheson, 1998; Black et al., 1980; Marmot and Bell, 2012). These reports also played a substantial role in setting the background for research and action into health inequalities within the UK and the rest of the world. The earlier reports made it easier for the subsequent ones to be accepted. The *Black* report differed from the *Acheson*, and *Fair Society, Healthy Lives* reports as it dedicated a section discussing the four possible explanations for health inequalities: measurement artefact, natural or social selection, materialist, and behavioural differences (Bambra et al., 2011; Blane, 1985). This unique feature of the *Black* report gives an insight into the debate happening at the time of publication; it has set the precedent and tone for subsequent research into health inequalities. The *Black* report influenced the initiation of similar reports in countries such as the Netherlands, Sweden and Spain (Bambra et al., 2011). It also played a significant role in developing the *World Health Organisation* international policies around health inequalities and the social determinants of health (Marmot et al., 2012).

1.2.5 Widening inequalities

Now that the historical background of health inequalities research in the UK has been presented, it is crucial to examine the latest report on health inequalities. This will provide a more recent context for the thesis.

Building on previous reviews and research, Sir Michael Marmot and his colleagues updated the *Fair Society, Healthy Lives Report* in 2020. The updated report, titled *Health Equity in England: The Marmot Review 10 Years On,* was commissioned by the *Health Foundation* (Marmot et al., 2020). Using census data and data from the *Office for National Statistics* and *Public Health England*, the *Marmot Review 10 Years On* (Marmot et al., 2020) highlights that health inequalities have continued to grow dramatically between 2010 and 2018 in England. The review reports a fall in life expectancy and healthy life expectancy in those from the country's most deprived areas between 2010 and 2018, with those in the least deprived areas seeing a continued increase in life expectancy and healthy life expectancy. As a result, the gap between the richest and poorest in life expectancy and healthy life expectancy further widened in this period. The differences in life expectancy between those from most deprived and least deprived areas were 9.5 years for males and 7.7 years for females in 2016-2018, whereas, in 2010-2012, the difference in life expectancy was 9.1 for males and 6.8 years for females. In addition, those from the most deprived areas in England lived 19 more years in good health than those from the least deprived areas (Marmot et al., 2020). This highlights that those from deprived areas live shorter lives and spend a greater proportion of their shorter lives in poor health.

1.2.6 Factors behind stalling of life expectancy

There is an ongoing debate on the reasons behind the general stalling of life expectancy in England. With trends also declining in many countries, some researchers believe that society has reached peak life expectancy; therefore, a decline in life expectancy is inevitable (Dong et al., 2016). Though this does not tell the whole story, as highlighted in the *Marmot Review 10 Years On*, other European nations have seen improvements in life expectancy despite the worldwide stall (Marmot et al., 2020). Another explanation is that stalling of life expectancy could be due to increased mortality rates because of bad influenza outbreaks in recent winters or perhaps due to the slowing down of improvements in mortality rates related to cardiovascular diseases, which contributes to a large proportion of deaths (Marshall et al., 2019).

Since the start of this work in early 2020, the *Coronavirus Disease 2019* (COVID-19) pandemic has had an impact on long-term mortality trends in the UK and worldwide, with certain groups experiencing a greater impact, thereby exacerbating existing inequalities (Office for National Statistics, 2020). The excess deaths linked to the virus were high, with COVID-19 deaths being five times higher than deaths related to the 2015 seasonal influenza epidemic (Islam et al., 2021).

Another common hypothesis is that faltering trends in life expectancy could be due to austerity measures. This has been suggested because the declining trends in life expectancy appear to coincide with the introduction of wide-ranging austerity measures in 2010, partly in response to the financial crash of 2008, restricting Government spending policies in welfare payments, housing subsidies and health and social services (Carmona, 2014; Marshall et al., 2019; Stuckler et al., 2017). Often the impact of austerity measures is indirect, whereby financial cuts to local Government and fundamental shifts in benefits systems have led to the poorest regions becoming even poorer (Local Government Association, 2019). Several epidemiological studies have attributed the stalling of improvements in mortality rates to austerity measures in the UK (Martin et al., 2021; McCartney et al., 2022; Rajmil and Fernandez de Sanmamed, 2019; Stuckler et al., 2017; Walsh et al., 2022; Watkins et al., 2017). In 2022, a time-trend analysis examining the period of austerity in the UK between 2012 and 2019, based on a comparison of observed deaths from 1981 to 2011 (the period before austerity), suggests that there were over 330,000 excess deaths in the most socioeconomically deprived areas in Great Britain that have seen the greatest levels of austerity measures (Walsh et al., 2022).

Researchers have suggested that austerity is not the only explanation for the stalling trends in life expectancy (Marshall et al., 2019). Other countries that have seen similar (or worse) austerity measures have not seen the same decline in life expectancy as England. Though austerity measures are varied and may not all be equally detrimental, this argument does not rule out the possibility of England having unique and specific austerity measures that could be linked to the stalling of life expectancy. As there needs to be more causal evidence on either side of the argument, linking austerity and the stalling of life expectancy in England is not clear-cut. Indeed, when comparing different countries, one needs to be mindful of the limitations of the ecological analysis (countries as the unit of analysis) and correlating temporal trends in one factor with temporal trends in another. Just because both factors are correlated does not mean that one causes the other. Hence, one cannot be sure that austerity causes the stalling of life expectancy for these reasons.

In their review, *Public Health England* (2018) acknowledges the complexity of explaining the stalling life expectancy in England. They highlight that there is no single explanation for this and that *‘the overall slowdown in improvement is due to factors operating across a wide range of age groups, geographies and causes of death’* (Public Health England, 2018, p. 73). Nevertheless, overall life expectancy figures may hide the complexity observed at the regional level and in different socioeconomic groups (Murphy et al., 2019). This complexity, which is reported in the *Marmot Review 10 Years On* but not in the *Public Health England* review, highlights that explanations of the varying life expectancy trends across different regions and socioeconomic groups remain to be understood. Perhaps, as reported by Murphy et al. (2019), which adds to the review of *Public Health England* (2018), these trends could be due to a combination of the various explanations given, including seasonal influenza, changes in cardiovascular disease mortality, temporal effects, and Government austerity measures, such as cuts to a range of welfare, social care, public and health services.

1.3 Socioeconomic adversity

This section focuses on the impact of socioeconomic adversity on individual health outcomes and argues the importance of studying socioeconomic inequalities in health in order to better understand health outcomes and their associated risk factors.

1.3.1 Socioeconomic position and health

Socioeconomic position (SEP) is a complex construct with several dimensions at various points of life in different settings. As no single measure of SEP can capture all the required dimensions that may drive inequalities, various indicators of SEP are used within epidemiological studies (Galobardes et al., 2006b; Galobardes et al., 2006c). The most appropriate indicator of SEP depends on the specific research question, the proposed mechanisms linking SEP to the study outcomes, and the available measures in the study period (Galobardes et al., 2006b; Galobardes et al., 2006c). Different indicators of SEP have different theoretical bases, strengths and weaknesses and interpretations of how they could be related to health outcomes. A commonly used indicator of SEP at the individual level is educational attainment.

Education, which captures the knowledge-related assets of a person, is a predictor of an individual's future SEP, as higher education can lead to higher income through higher-paying occupations, access to work-related resources, outcomes and better working conditions (Braveman et al., 2011; Galobardes et al., 2006b). Education may also lead to greater perceived self-control and a higher relative social standing, as well as impart knowledge and wisdom that make an individual receptive to healthy behaviours and enable them with the skills to communicate and seek appropriate healthcare (Berkman et al., 2004; Stormacq et al., 2019). Low educational level has been linked with many poor health outcomes, including obesity (Cohen et al., 2013), type-2 diabetes (Agardh et al., 2011), coronary heart disease (Manrique-Garcia et al., 2011), and mortality (Galobardes et al., 2008; Mackenbach et al., 2008).

Another widely used measure of SEP in the UK is occupational class. As occupation is related to income, the relationship between health and occupation could be mediated through income, with those in higher-paid jobs more likely to be able to afford a healthier lifestyle. In addition, occupational class indicates an individual's standing within a stratified society, as some jobs are considered more prestigious than others. This privilege may indirectly determine access to specific societal resources, thus, contributing to better health outcomes (Bartley, 2016). An individual's occupation may also reflect employment relations and conditions, which could indirectly affect health outcomes; an example could be the health effects of exposure to toxic particles in miners. Like education level, lower occupational class is associated with a number of poor health outcomes, including type-2 diabetes (Agardh et al., 2011), coronary heart disease (Manrique-Garcia et al., 2011), and premature Mortality (Galobardes et al., 2008; Stringhini et al., 2010).

Income, a vital SEP indicator, directly delineates an individual's financial capabilities. Its role on health is dual-pronged: directly, income facilitates access to high-quality nutrition, accommodation, and healthcare; indirectly, it allows for residence in healthier neighbourhoods, augments educational prospects, and engenders a life with reduced stress (Berkman et al., 2004; Galobardes et al., 2006b; Mackenbach et al., 2008). Like other SEP indicators, lower income is linked to health risks including cardiovascular diseases (Mackenbach et al., 2008), mental disorders (Reiss, 2013), and increased mortality (Stringhini et al., 2017).

The relationship between income and health is gradient rather than linear, indicating progressive health improvements with each income rise (Wilkinson and Pickett, 2008). Importantly, income's impact isn't limited to its magnitude, but also its stability. Unstable income can foster financial stress, triggering adverse health outcomes and harmful coping strategies (Berkman et al., 2004; Miething, 2013).

The associations between lower SEP and adverse health outcomes, including some of the non-communicable diseases mentioned above, and a number of mediators, including smoking, alcohol, obesity, and physical activity, are strengthened by low SEP (Steel et al., 2018). In understanding the associations between SEP and health outcomes, disentangling the pathways these relationships operate through is vital for understanding the best way to intervene so that inequalities in these health outcomes are prevented or mitigated. Nonetheless, to improve health and reduce inequalities, there is also a need for policies and interventions that reduce socioeconomic adversity alongside the other major risk factors which act as intermediaries between SEP and health outcomes. In support of this idea, findings from a multi-cohort international study and meta-analysis of 1.7 million men and women from 48 independent prospective cohort studies (Stringhini et al., 2017) demonstrate that lower SEP has a comparable health effect to major risk factors of health outcomes. For instance, in mutually adjusted models, those of low SEP live 2.1 years shorter than those of high SEP, an effect similar to being physically inactive (2.4 years) and worse than alcohol (0.5 years) and obesity (0.7 years).

It is not only the differential distribution of risk factors, access to knowledge, social standing, and perceived self-control between those of different socioeconomic groups that are behind some of the observed inequalities in health outcomes. Socioeconomic inequalities may also interact with social identities, including age, sex, ethnicity, and gender. The effects of socioeconomic adversity may be amplified or dampened based on the combined membership of these social identities. For example, it is well-documented that women generally experience greater socioeconomic inequalities in health outcomes, such as coronary heart disease, than men (Backholer et al., 2017; L. Young and Cho, 2019). At the same time, those people from minoritised ethnic groups also experience socioeconomic adversity far greater than non-minoritised ethnic groups (Davey Smith et al., 2000; Ren et al., 1999; Ward et al., 2004; D. Williams et al., 1997). Besides, it is reported that the combination of these varying identities may amplify the effects of socioeconomic adversity even more. For instance, during the COVID-19 pandemic in the UK, a disproportionately large number of people from minoritised ethnic groups of lower SEP were more likely to be infected and to die from COVID-19 (Mathur et al., 2021; Nafilyan et al., 2021; Office for National Statistics, 2020). When examining these findings in detail, women of lower SEP from minoritised ethnic groups were affected the most (Mathur et al., 2021; Nafilyan et al., 2021; Office for National Statistics, 2020). One explanation for the increased risk of COVID-19 infection and death rates in minoritised ethnic groups is that some minoritised ethnic groups live in large multigenerational households, which increases the likelihood of infection spread and exposure to high-risk older populations. It is also hypothesised that minoritised ethnic groups may be over-represented in public-facing occupations such as bus drivers and hospital staff, which increases their chances of COVID-19 infection. Studies have also shown that minoritised ethnic groups are more likely to have comorbidities that are associated with worse outcomes in COVID-19 (Mathur et al., 2021; Nafilyan et al., 2021; Office for National Statistics, 2020).

This idea that multiple social identities combine at the individual level to co-produce the multiple systems of power and oppression at the macro level is called intersectionality (Crenshaw, 1989; Crenshaw, 1994). Taking an intersectional lens to examine inequalities in health is important as this captures the complex and multidimensional ways different social identities and economic factors interact, which is reflective of the *real world*. The concept of intersectionality, in relation to the quantitative intersectional analyses presented in this thesis, is discussed in detail in Chapter 6 (Section 6.1.2).

1.4 Disability and musculoskeletal health and function

This section examines the factors that impact healthy life expectancy, specifically disability caused by long-term conditions such as musculoskeletal disorders. It presents the concept of musculoskeletal health and function and the importance of studying the effects of socioeconomic adversity on these aspects of health. To fully understand these relationships, the life course framework is introduced.

1.4.1 *Healthy life expectancy and musculoskeletal disorders*

To achieve healthy ageing, improvements in life expectancy need to be matched with improvements in health (R. Cooper, 2018). Alongside increases in life expectancy, the expansion of morbidity – or the increase in the number of years people live with chronic conditions – is also expected due to the rise in long-term health conditions (Gruenberg, 1977). With advances in medicine, individuals with conditions such as diabetes and cancer that were once fatal now live longer (Rechel et al., 2020).

A systematic review of data from primary and secondary care databases and population-based surveys in the UK found that the prevalence of chronic conditions, including diabetes, lung cancer, stroke, asthma, and chronic obstructive pulmonary disease, increased between 1946 and 2017 (Gondek et al., 2019; Jivraj et al., 2020). These trends occurred alongside general stalling of life expectancy, meaning that individuals are likely to live with chronic conditions for longer periods of time (Gondek et al., 2019). A multi-cohort study using data from three British birth cohort studies also found that healthy life expectancy increased more slowly than total life expectancy between 1993 and 2013 for the working-age population in England (Jivraj et al., 2020). During this period, the prevalence of self-reported long-term conditions, including diabetes, circulatory illnesses, and clinical hypertension, also increased, offsetting much of the improvements in life expectancy (Jivraj et al., 2020). These findings suggest that the UK is currently in an expansion of morbidity phase (Gondek et al., 2019; Jivraj et al., 2020). It has also been projected that the percentage of the population living with four or more long-term conditions in the UK will double from 9.8% in 2015 to 17% in 2035 (Kingston et al., 2018).

Musculoskeletal disorders, which include conditions that affect the muscles, bones, and joints, are a major cause of disability worldwide, with over 1.7 billion people affected globally, according to the 2019 Global Burden of Disease report (Vos et al., 2020). In the UK, 32% of the population suffers from at least one musculoskeletal condition (Vos et al., 2020). These disorders are more common in older age groups, with 49% of those aged 50 to 69 years in the UK suffering from a musculoskeletal condition (Vos et al., 2020). Musculoskeletal disorders can cause pain, reduced physical function, fatigue, anxiety, depression, and social isolation, and they can greatly impact an individual’s quality of life, physical independence, and overall well-being (Crins et al., 2019; Heikkinen et al., 2019; Oh et al., 2018). In addition to the personal impact of these conditions, they also have significant financial consequences, being the second leading cause of lost working days in the last decade and costing the *National Health Service* approximately £5 billion in 2013-14 (National Health Service, 2014; Office for National Statistics, 2021). A systematic review of 13 cohort studies following 3 million people found that musculoskeletal disorders may also increase the risk of developing chronic diseases such as cardiovascular disease (Wilson et al., 2018). These findings underscore the importance of understanding the progression of musculoskeletal disorders for the prevention of their development.

1.4.2 Musculoskeletal health and function

Good musculoskeletal health and function is essential for preventing musculoskeletal disorders and for overall well-being and vitality. It encompasses the maintenance of healthy bones, joints, ligaments, muscles, and tendons, as well as the absence of impairment from normal activities due to injury, pain, or disease in any of these structures. Physical capability, sometimes referred to as physical function and/or physical performance, is an important marker of musculoskeletal health and function (Kuh et al., 2014). It is defined as the intrinsic capacity an individual can draw on to undertake the physical tasks of everyday living (Kuh et al., 2014; World Health Organization, 2015). In this thesis, the focus is on specific indicators of physical capability, and the term musculoskeletal health and function is used in a general sense to contextualise physical capability.

Maintaining good musculoskeletal health and function is essential for leading a healthy life. It allows individuals to live independently, preserve their well-being, meet their basic needs, and participate in society (World Health Organization, 2015). In addition, poor musculoskeletal health and function in specific indicators, particularly physical capability, have been linked to premature mortality and a range of health outcomes, including hospitalisations, fractures, cognitive decline, cardiovascular disease, and cancer (Celis-Morales et al., 2018; R. Cooper et al., 2011b; R. Cooper et al., 2010; Parra-Soto et al., 2022; J. Rijk et al., 2016). Therefore, it is important to understand the risk factors that contribute to variations in musculoskeletal health and function, as this can help identify those at increased risk of poor musculoskeletal health and function and guide the development of interventions to prevent and/or manage any subsequent disability.

1.4.3 *SEP and musculoskeletal health and function*

Many studies have found that lower socioeconomic adversity is associated with poorer musculoskeletal health and function (Birnie et al., 2011a; Gjesdal et al., 2011; Hagen et al., 2005; Rantanen et al., 1999; L. Rijk et al., 2020; Urwin et al., 1998). With a growing socioeconomic gap between the rich and poor in the UK (Marmot et al., 2020) and the risk of developing poor musculoskeletal health and function increasing with old age, the influence of socioeconomic adversity on musculoskeletal health and function will only increase with time as the population ages. In addition, the burden of inequalities in musculoskeletal health and function could be compounded by the shift towards an ageing population, which could have consequences on economic growth and the size and productivity of the labour force (Bevan, 2015; Harper, 2014). Therefore, it is imperative to understand the role of socioeconomic adversity on key healthy ageing phenotypes, including musculoskeletal health and function within the UK, at an earlier point before the onset of age-related conditions. This is a necessary first step, as understanding the role of socioeconomic adversity on these phenotypes is essential for informing policies and interventions that can extend healthy life expectancy and reduce the gap between the richest and poorest in society (Harper, 2014).

1.4.4 *Using the life course perspective*

As health and disease reflect the ability of an organism to adequately adapt to its environmental challenges (Dubos, 1980), examining the health status of individuals at one point in time does not acknowledge the dynamic nature of the body's processes. Further, assessing disability as an endpoint, once fully manifest, does not offer the opportunity to detect and mitigate the early triggers of disability and loss of independence in later life (Ben-Shlomo and Kuh, 2002). Ageing is a lifelong process, with processes from the cellular level to the population level at every life stage (Kuh and New Dynamics of Ageing (NDA) Preparatory Network, 2007). Understanding the role of socioeconomic adversity in musculoskeletal health and function and the pathways it operates through benefits from a life course perspective. The life course perspective is *'the study of long-term effects on later health or disease risk of physical or social exposures during gestation, childhood, adolescence, adulthood and later life'* (Ben-Shlomo and Kuh, 2002, p. 285).

The life course perspective leverages models including sensitive periods, accumulation, and social mobility to evaluate long-term health outcomes. The sensitive period model emphasizes that certain life stages, such as prenatal development or adolescence, may have lasting or irreversible impacts on health due to heightened sensitivity to environmental influences (Ben-Shlomo and Kuh, 2002; Mishra et al., 2009). In contrast, the accumulation model suggests that socioeconomic adversity's impacts on health intensify with prolonged exposure, capturing the additive effect of disadvantage over time (Mishra et al., 2009). The social mobility model focuses on the health implications of changes in SEP throughout the life course. It recognizes that upward mobility generally enhances health outcomes, whereas downward mobility may deteriorate health (Hallqvist et al., 2004). Collectively, these models offer a dynamic framework to investigate how diverse life-stage exposures impact long-term health. They aid in informing strategies to enhance health and longevity, focusing particularly on the interplay between socioeconomic adversity and musculoskeletal health.

In an era marked by increasing socioeconomic inequalities and complex multimorbidity, the use of the life course model framework is indispensable. It helps address the pressing goal of not just extending life, but improving the quality of these additional years, by acknowledging the temporal aspects of ageing and evaluating the impact of varied exposures on musculoskeletal health throughout the life course (Institute for Health Metrics and Evaluation, 2019; Kingston et al., 2018).

1.5 Physical capability

As previously discussed in Section 1.4.2, the term musculoskeletal health and function is used in a general sense to contextualise physical capability. However, it is important to note that when appropriate, such as when referencing literature that specifically uses the term physical capability, the term is employed, as in this section and Chapter 2.

1.5.1 Measurements of physical capability

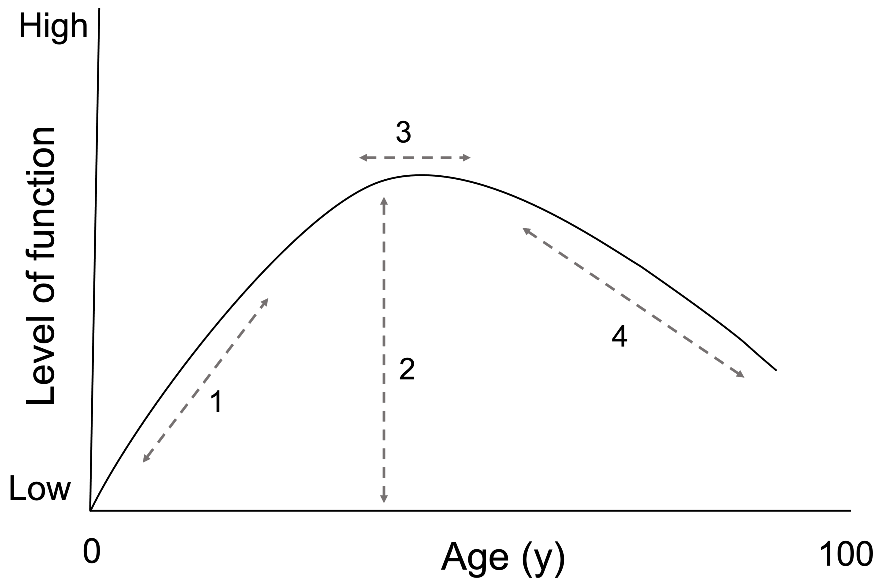
Physical capability can be measured through subjective assessments of functional performance. These are self-reported indicators that capture limitations and the functional ability to perform active daily living tasks. Another way to measure physical capability is through objective assessments, which involve performing specific tasks per a standardised protocol (Guralnik et al., 1989; Kuh and New Dynamics of Ageing (NDA) Preparatory Network, 2007; Kuh et al., 2014; Myers et al., 1993).

One of the most commonly used objective indicators of upper body muscle function is grip strength. This easy-to-use measurement is widely utilised in population-based studies (Roberts et al., 2011). It is operationalised using a handheld dynamometer, recording the peak muscle force generated (Roberts et al., 2011). To test lower-body physical function, walking speed is a commonly used test. Components of balance, strength, speed and coordination are assessed by measuring the time taken to walk a set distance. Variants of this assessment involve getting up from a chair and walking a set distance (usually 3 meters) or walking back and sitting down on the chair (timed up and go test) (Kuh et al., 2014; Roberts et al., 2011). Two more widely used lower-body function test are the chair rise test, which measures how long it takes to stand up and sit back at a chair for a set number of times, and standing balance, which tests the length of time an individual can stand on one leg with eyes open or closed (Kuh et al., 2014; Lara et al., 2015).

The objective measures of physical capability have been shown to be good predictors of future disability and mortality (Celis-Morales et al., 2018; R. Cooper et al., 2011b; R. Cooper et al., 2010; Guralnik et al., 2000). Findings from the *Healthy Ageing across the Life Course* research collaboration systematic reviews have shown that poorer performance in specific objective measures of physical capability are linked with subsequent risks in health outcomes and lower survival rates across life in older community-dwelling populations (Celis-Morales et al., 2018; R. Cooper et al., 2011b; R. Cooper et al., 2010). As they allow for a better understanding of the various processes across the life course, physical capability measures are good indicators of healthy ageing (the locomotor component of healthy ageing in particular) (Kuh et al., 2014; World Health Organization, 2015).

Physical capability levels are influenced by biological, social, and behavioural factors across the life course. Factors in early life, including SEP, may be associated with physical capability in later life through their influence on different parts of the lifetime functional trajectory, i.e., 1) the rate of development, 2) peak level attained, 3) duration of time peak is sustained and, 4) the rate of age-related decline (Kuh and New Dynamics of Ageing (NDA) Preparatory Network, 2007) — see Figure 1.5.1 for an illustration of these.

Figure 1.5.1: Life course trajectory of physical capability.



As adapted from Kuh (2007), the four aspects of the functional trajectory are: 1) the rate of physical capability development, 2) peak levels of physical capability attained, 3) duration of time peak physical capability is sustained and, 4) the rate of physical capability decline. This is a theoretical plot, however, there is empirical evidence that this is the observed trajectory of mean levels of objective measures of physical capability such as grip strength (Dodds et al., 2014; Dodds et al., 2016).

Intra-individual variation in physical capability could be due to various body systems, including musculoskeletal, cardiovascular, respiratory, and nervous systems, as well as the ability to follow instructions and the motivation to complete the task (Bohannon, 2008; Kuh et al., 2014; Lara et al., 2015; Manini and Clark, 2012). Each measure tests a combination of physical functions attributed to these different body systems. For example, grip strength measures contractual strength and coordination dependent on the musculoskeletal and nervous systems (Bohannon, 2008; Kuh et al., 2014; Lara et al., 2015; Manini and Clark, 2012). The *time* *up and go* test requires good balance, strength, power, and endurance, tasking the nervous, musculoskeletal, and cardiovascular systems. The fact that physical capability measures demand these different body systems helps piece together the various pathways of associations and factors across life (Kuh et al., 2014). An understanding facilitates the detection of early impairment and those who may be vulnerable to accelerated ageing, thus allowing for the opportunity for a timely intervention (Kuh and New Dynamics of Ageing (NDA) Preparatory Network, 2007).

1.5.2 Measures used in this thesis

This thesis focuses specifically on grip strength and standing balance performance, despite there being numerous measures of physical capability. Limiting the scope to only these two measures allows for a detailed analysis of the relationship between SEP and these indicators of physical capability, as well as the underlying mechanisms of these associations.

The decision to focus on grip strength and standing balance performance was partly for pragmatic reasons, as these are the only available objective measures of physical capability in the two datasets of interest: the 1970 British Cohort Study (BCS70), assessed both of these measures for the first time at age 46 years, and the UK Biobank study (UKB), included grip strength measurement in the baseline assessment when participants were aged from 37 to 69 years. Other measures, such as walking speed and chair rise speed, have been shown to capture meaningful variation at older ages but are not available at earlier ages in BCS70 or UKB (Kuh et al., 2014; Lara et al., 2015). However, measures of grip strength and standing balance performance have been shown to capture meaningful variation at different life stages (Lara et al., 2015; Reuben et al., 2013), making them suitable for investigating socioeconomic inequalities in strength and balance before the onset of age-related conditions. Another strength of using these measures is that they are included as key outcomes in many national and international physical activity and fall prevention guidelines, highlighting their importance (Bull et al., 2011; C. Foster et al., 2019; Frieden et al., 2015; Montero-Odasso et al., 2022; Olson et al., 2018; UK National Institute for Health and Care Excellence, 2013; World Health Organization, 2020b). Finally, in light of the literature reviewed in Chapter 2, the significant gaps and limitations regarding the understanding of socioeconomic inequalities in grip strength and standing balance performance make it crucial to focus on these two measures in this thesis to address these gaps and limitations.

1.6 Chapter summary

To address the needs of an ageing population, increasing the proportion of adults living longer with good health and independence has become a priority. Maintaining good musculoskeletal health and function is essential to achieving healthy, independent years of life. Early life factors, including childhood SEP (a distal factor of many health risk factors), may be associated with musculoskeletal health and function. Therefore, to determine the most suitable, timely and effective opportunities to improve people's chances of living healthier lives for longer with independence, there needs to be a better understanding of the relationship between life course SEP and specific indicators of musculoskeletal health and function, particularly physical capability. This thesis examines the associations between SEP across life and two objective measures of musculoskeletal health and function in adulthood (grip strength and standing balance performance), which are sometimes referred to as measures of physical capability.

1.7 Thesis outline

Chapter 2 presents a comprehensive review of the literature on previous studies that have examined the relationship between childhood SEP and physical capability in adulthood. Chapter 3 summarises the two population-based studies from which data are drawn for empirical analyses in subsequent chapters: the BCS70 and the UKB. The chapter covers the origins of these studies, their strengths and limitations in addressing the key research questions, and participation rates. Details of the study outcomes, indicators of SEP, and covariates used in the analyses are also presented. The chapter concludes with a description of the study participants based on the key variables of interest. Chapter 4 interrogates the associations between adolescent, childhood and adulthood SEP and grip strength in midlife in the BCS70. Chapter 5 investigates the associations between childhood and adulthood SEP and standing balance performance in midlife using data from the

BCS70 and investigates mediators of these associations. Chapter 6 builds on the findings presented in Chapter 4. It examines the age, sex, and ethnic differences in the cross-sectional associations between adult SEP and grip strength using data from UKB. Finally, Chapter 7 offers a comprehensive summary of the novel and insightful findings presented in Chapters 4 to 6, contributing to the wider literature. It also includes a discussion on the strengths and limitations of the research methods used to answer the questions in this thesis. Additionally, the chapter delves into the far-reaching implications of these findings and their potential impact on informing policies and interventions that aim to improve socioeconomic circumstances and outcomes related to musculoskeletal health and function in individuals. The chapter concludes by identifying areas for future research and providing closing remarks.

CHAPTER 2

Evidence of inequalities in musculoskeletal health and function

This chapter presents a comprehensive review of the literature on previous studies that have examined the relationship between childhood SEP and specific indicators of musculoskeletal health and function in adulthood, particularly physical capability measures including grip strength, standing balance performance, walking speed and chair rise speed. The first section of this chapter summarises findings from a systematic review of the topic (Birnie et al., 2011a). The subsequent sections report on studies published since 2011 (Appendix Table A.1.1 details the literature search strategy and results).

2.1 Socioeconomic position and physical capability

2.1.1 Findings from a systematic review

To test the hypothesis that adverse childhood SEP is associated with lower levels of objective measures of physical capability in adulthood, Birnie et al. (2011a) conducted a systematic review and meta-analysis, which aimed to review all published literature on the associations of childhood SEP and objective measures of physical capability up to 2010. They also aimed to identify all studies with relevant data at that time (even if they had not been published on this association) with requests made to study principal investigators for estimates where these had not been published. The indicators of childhood SEP were father's occupational class, parental educational level, and childhood socioeconomic environment. For measures of physical capability, the review examined grip strength, walking speed, chair rise speed and standing balance performance. The review included 19 studies with total sample sizes in meta-analyses ranging from N=17,215 to N=1,061,855. Results from unadjusted models indicated relationships between lower childhood SEP and poorer grip strength, walking speed, chair rise speed and standing balance performance in adults aged between 18 and 79 years. However, in the second model, when associations were adjusted for age and adult SEP, only walking speed and chair rise speed remained associated with childhood SEP. In the third model, which adjusted for age, adult SEP and body size, only chair rise speed remained moderately associated with childhood SEP.

The pooled estimates of effects from this review need to be interpreted with caution, as there was considerable heterogeneity between studies. Potential sources of heterogeneity investigated included the mean age of study participants, the method of ascertaining childhood SEP (prospective vs retrospective) and study location (Europe vs other). Regarding the method of ascertaining childhood SEP, in some studies, this was determined prospectively, but in 10 out of 19 studies, this was done retrospectively. Retrospective ascertainment of childhood SEP can introduce recall bias, as participants may differ in their recollection of their childhood SEP. This can lead to non-differential misclassification of exposure status, which can bias the estimate of the relationship between childhood SEP and physical capability. Additionally, the longer the gap between the time of exposure (childhood) and the time of measurement, the greater the potential for recall bias and non-differential misclassification, which is a possibility in the case of this work.

In addition, measurements of each physical capability test were operationalised in different ways in all studies. For example, walking times were measured across a range of different distances, ranging from 2.4 meters to 20 meters, thus making comparisons challenging; this is despite attempts to standardise by modelling speed. Besides, the studies also varied in their locations, which is important as associations could vary because of differences in social and political environments. Eleven of the 19 reviewed studies were from the UK, while the remaining eight were from other European countries, Central and South America and the Caribbean and Korea, which may explain the differences in the childhood SEP indicators used. In European countries, father's occupational class was used as an indicator of SEP, while those from other parts of the world used childhood economic environment or parental educational level as their childhood SEP indicator (Birnie et al., 2011a).

The Birnie et al. (2011a) review highlighted that non-participation in physical capability tests may be an issue, as those who are unable to complete physical capability tests due to health reasons are often excluded from these analyses, potentially leading to an underestimate of the associations between lower childhood SEP and poorer physical capability. Another potential gap highlighted in this review was that although the mean age of the populations studied ranged between 18 and 79, there was not an even distribution across these ages; most studies were conducted in populations aged 60 years and above. Associations between childhood SEP and physical capability in earlier adulthood, therefore, remain to be fully elucidated. Moreover, the populations studied were born in different periods with different social and political environments, which requires careful consideration when interpreting the results, as observed differences between these studies could be due to age, cohort or period effects. Therefore, disentangling the associations between childhood SEP and physical capability is not easy.

Since the review by Birnie et al. (2011a), several more studies have undertaken further investigations of the relationship between childhood SEP and the same indicators of physical capability. These studies were identified, for the purposes of this PhD, using a comprehensive review of the literature through a specific search strategy, documented in Appendix Table A.2.1. Grouping studies based on their locations, the following subsections examine these studies in detail.

2.1.2 Findings from subsequent studies

2.1.2.1 British studies

Focusing on the relationships between childhood SEP and physical capability, including grip strength, standing balance performance, walking speed and chair rise, are eight British population-based studies. In comparing the design of these eight studies, a few of them investigate the associations of childhood SEP and physical capability at a single point in time (Anderson et al., 2017; Caleyachetty et al., 2018; Carney and Benzeval, 2018; Hurst et al., 2013; Murray et al., 2013; Starr and Deary, 2011; Strand et al., 2011a), while the others have examined the longitudinal change in grip strength and standing balance times (Blodgett et al., 2020; Kuh et al., 2019). In these analyses, the majority of which have been conducted on the NSHD cohort, two examined physical capability measures at ages 53, 60–64 and 69 (Blodgett et al., 2020; Kuh et al., 2019), two studies at ages 60 and 64 (Caleyachetty et al., 2018; Hurst et al., 2013), three focused on ages between 48 and 54 years (Anderson et al., 2017; Murray et al., 2013; Strand et al., 2011a), one at ages 79 and 87 (Starr and Deary, 2011), and another study had a broad age range between 19 and 99 years (Carney and Benzeval, 2018).

Anderson et al. (2017) found a relationship between lower paternal occupational class and poorer physical capability in mothers aged 48 and 54 using data from the *Avon Longitudinal Study of Parents and Children* (ALSPAC) study. The associations were robust and graded, and remained even after adjusting for other factors such as age, ethnicity, and childhood psychosocial adversity. The study used a composite of chair rise speed, grip strength, standing balance performance, and walking speed, which means that associations between childhood SEP and specific physical capability measures could not be compared with other British population-based studies.

Findings from the *UK Household Longitudinal Study* (UKHLS), which used data from 19,292 participants aged 16 to 99 years (born between 1910 and 1995), reported an association between childhood SEP (Carney and Benzeval, 2018), as indicated by lower maternal educational level and weaker grip across all age groups in both men and women. In women, the differences in grip strength between those of lower and higher childhood SEP reduced with age. The opposite was true for men, as the differences increased with age. The study also examined the differences by age in the association between adulthood SEP and grip strength. It was found that lower income was associated with weaker grip strength for both men and women across the age groups. However, lower own educational level was associated with stronger grip in men. This changed direction with older age, as those with lower educational levels had weaker grip at older ages (Carney and Benzeval, 2018). In women, having a lower educational level in adulthood was associated with weaker grip strength. In addition, the differences in mean grip strength levels between women of lower and higher educational levels increased with age. Similarly, there were associations between lower childhood SEP and weaker grip strength in adults aged between 79 and 87 years in the *1921 Lothian birth cohort* (Starr and Deary, 2011). These associations were robust to the adjustment of several covariates, including study wave, vital status (dead or alive), sex, height, weight and participant's adult SEP.

In the 1946 British birth cohort study, also known as the *Medical Research Council's* (MRC) *National Survey of Health and Development* (NSHD), two additional British studies have found a relationship between childhood SEP and individual indicators of physical capability in adults at midlife (53 years) (Murray et al., 2011; Strand et al., 2011a). The first of these two analyses (Strand et al., 2011a) used maternal educational level and paternal occupational class as measures of childhood SEP. In this study, there was a relationship between lower childhood SEP and poorer performance in standing balance and chair rise speed at age 53 years, though no association with grip strength was found. After adjustments, only standing balance was associated with childhood SEP. Similarly, in the second study (Murray et al., 2011), lower childhood area deprivation was associated with poorer standing balance performance but not with chair rise speed or grip strength. Additional investigations in the NSHD, focusing on ages 60 years and above, show evidence of an association between lower childhood SEP and poorer chair rise speed, grip strength, standing balance time and walking speed (Blodgett et al., 2020; Caleyachetty et al., 2018; Hurst et al., 2013; Kuh et al., 2019). It is important to highlight that these life course investigations use several different indicators of childhood SEP, including parental occupational class, maternal educational level, house ownership and numerous childhood material deprivation measures such as overcrowding, being unclean, poorly cleaned housing and poorly repaired housing. The added strength of using these different indicators of SEP is that by comparing associations, one may be able to gain some insights into the most likely pathways of associations, which includes patterns of growth, early life nutrition, childhood infection, exposure to environmental hazards, cognition, healthy behaviours, obesity, and development of chronic diseases (Kuh et al., 2019).

Another study using data from the NSHD found that father's occupational class and mother's educational level were more strongly related to standing balance performance in midlife than in later life (Blodgett et al., 2020). These results suggest that the effects of childhood inequalities in standing balance performance lessen with increasing age, which is also the time when age-related decline and the onset of chronic diseases tend to occur. However, in the same cohort, the opposite was observed for grip strength, as associations between lower childhood

SEP and weaker grip strength emerged and then strengthened with increasing age (Hurst et al., 2013; Kuh et al., 2019; Strand et al., 2011a). This captures the potentially different underlying associations between early life SEP and the different measures of physical capability. It also highlights the variation in the patterns of associations by age and sex, and cohort.

2.1.2.2 European studies

In addition to the above studies, other European studies have also examined relevant associations between childhood SEP and physical capability. In *The Irish Longitudinal Study of Aging* (TILDA), Henretta and McCrory (2018) found an association between lower paternal education and slower walking speed measured at a single point at ages 50-59. Moreover, three additional papers used data from the *Survey of Health Ageing and Retirement in Europe* (SHARE) (Cheval et al., 2018; Cheval et al., 2019; Weinstein, 2016). All three studies found an association between lower childhood SEP and weaker grip strength and slower chair rise speed measured at a single point between ages 50 and 96 years (Cheval et al., 2018; Cheval et al., 2019; Weinstein, 2016). In the findings from TILDA and SHARE, associations remained despite adjustments for various social, biological and behavioural factors, including age, birth cohort, welfare state, living with biological parents, attrition, adulthood SEP, childhood health problems, adulthood health problems, height, weight and unhealthy behaviours (physical inactivity, poor diet, smoking and alcohol). However, unlike the British cohort studies that have used prospectively ascertained childhood SEP, TILDA and SHARE studies have retrospectively measured childhood SEP; this introduces the possibility of recall error which could bias the association between childhood SEP and physical capability measures (McKenzie and Carter, 2009). Additionally, childhood SEP in the SHARE study was indicated using the number of books in the household during childhood (Cheval et al., 2018; Cheval et al., 2019; Weinstein, 2016). The number of books, a retrospectively ascertained childhood indicator of SEP, has been previously reported as unreliable, with a low agreement between parents and their children when reporting this information (Engzell, 2018; Engzell and Jonsson, 2015; Jerrim and Micklewright, 2014).

Another European study (Petersen et al., 2018), using data from the *Copen-*

hagen Aging and Midlife Biobank, found that lower childhood SEP indicated by father's occupational class and parental social class was associated with poorer performance in grip strength, jump height and chair rise at ages 48-58 years. This study comprised two cohorts, the *Metropolit Cohort* and the *Copenhagen Perinatal Cohort*. In the *Metropolit Cohort*, participants were men aged 55-58 whose fathers' occupational class was measured prospectively using birth certificates. In this cohort, fathers' occupational class was associated with poorer performance in jump height and chair rise speed. In the *Copenhagen Perinatal Cohort* group, participants were men and women between 48 and 52 years, and parental social class was retrospectively recalled. In this cohort, there were associations between lower parental social class and poorer performance in jump height, chair rise speed and grip strength.

Interestingly, there were associations between lower childhood SEP and weaker grip strength in the *Copenhagen Perinatal Cohort*, but none were observed in the men-only cohort (*Metropolit Cohort*). Reasons for associations reported in one study but not in another could be due to the different childhood SEP indicators used, as the *Metropolit Cohort* used fathers' occupational class and the *Copenhagen Perinatal Cohort* used parental social class, which was a composite score obtained from breadwinner's education, occupation, income type, and housing quality. Additional differences could also be due to the fact that one cohort consists mainly of men, while the other includes men and women. In addition, both cohorts reported no associations for standing balance time, flexibility range, lower back force, abdominal force and chair rise speed. To explain the null associations, the authors highlight that the majority of these physical capability measures, such as standing balance time and flexibility range, are less strenuous. They add that the more strenuous measures, including jump height and chair rise speed, can better discriminate between the levels of physical capability in this middle-aged population than some of the less strenuous measures. The authors suggest future research into this cohort at older ages, when associations between childhood SEP and the less strenuous measures could appear. Nevertheless, these explanations differ from the findings reported in the NSHD at midlife (Strand et al., 2011a), where there was an association between lower maternal education and paternal occupation and poorer standing balance time and chair rise speed – what Petersen et al. (2018) refer to as less-strenuous measures.

2.1.2.3 Studies from other world regions

Two studies use data from the *International Mobility in Aging Study* (Hwang et al., 2019; Sousa et al., 2014). This is a cohort study with participants aged between 66 and 78 years from Canada, Brazil, Colombia and Albania. The study retrospectively ascertained family economic status, being hungry, and parental unemployment to indicate childhood SEP. They also used the *Short Physical Performance Battery* test, which includes assessments of standing balance, walking speed, and chair stands. In one of the analyses, associations between lower childhood SEP and poorer physical capability were only observed in women (Hwang et al., 2019). In another study, associations have been observed in both men and women (Sousa et al., 2014). In both studies, associations have remained despite adjustment; in the first study, education, age and sex were adjusted for (Hwang et al., 2019), whereas in the second study, adjustments included location, age and sex (Sousa et al., 2014). As *International Mobility in Aging Study* has participants from various locations with different income statuses and social and political climates, samples were stratified by location as there was evidence of effect modification, which resulted in a smaller sample size (n=400), therefore, limiting statistical power.

A study set in the USA, using data from the *Health and Retirement Study*, reported an association between lower childhood SEP and weaker grip strength for men and women aged 52 to 99 (N. Smith et al., 2019). Childhood SEP was a combined variable that was derived from a number of retrospectively ascertained indicators, including parental education, paternal occupation, whether the father moved due to financial hardship and perception of family SEP before the age of 16 years. In the unadjusted model, lower childhood SEP was associated with weaker grip strength in men only. Conversely, when findings were adjusted for adult SEP, adult psychosocial factors, body mass index, morbidity, physical inactivity and smoking status, lower childhood SEP and weaker grip strength were associated in women only. Using repeat grip strength data, lower childhood SEP was associated with a decline in grip strength in women. However, when social and behavioural factors were adjusted, there were no associations in men and women. In the cross-sectional model, during adjustment, associations change for men and women. Here the social and biological factors, adult SEP, adult psychosocial factors, physical activity status, smoking status, body mass index and presence of morbidity, were positively confounding the associations for men and negatively confounding the associations for women. Nevertheless, as all factors were simultaneously adjusted, it is difficult to determine the pathways these associations act through. In the *Health and Retirement Study*, the interaction of ethnicity in the association between childhood SEP and weaker grip strength was also tested. However, the authors did not find evidence that associations varied by ethnicity (N. Smith et al., 2019).

Another American study, which uses data from the *Performance Across the LifeSpan* cohort (Noppert et al., 2018), found an association between lower parental educational level and slower walking speed. These associations were robust to adjustment for age, ethnicity, sex, marital status, and employment status. The study had a wide age range, with adults aged between 30 and 100 years. Therefore, participants were stratified into three age groups (30-59 years, 60-69 years, and 70+ years), with inequalities reported in the two younger groups. With seven different generations stratified into three groups, there may still be age and cohort differences that still need to be accounted for. However, further stratification could be problematic, as the study was not already sufficiently powered (n=856) to stratify individuals based on age or birth year. Another limitation of this study is that it did not explicitly examine or address sex interactions in the associations between childhood SEP and physical capability, despite the fact that there were more men with degrees and higher walking speeds compared to women.

2.2 Summary of literature review

Birnie et al's. (2011a) systematic review, which drew together data from 19 studies, reported modest associations between lower childhood SEP and physical capability, and adulthood SEP partially explained these associations. Though, there are some caveats to interpreting these findings, as there was evidence of unexplained heterogeneity between studies. After the Birnie et al. (2011a) review, 18 studies emerged to address some of the remaining knowledge gaps and to replicate findings in different cohorts. These studies aimed to investigate whether different types of childhood SEP indicators were associated with physical capability measures (Murray et al., 2011), longitudinal changes in physical capability and childhood SEP association (Blodgett et al., 2020; Kuh et al., 2019; Starr and Deary, 2011), whether certain pathways mediate the relationship between childhood SEP indicators and physical capability (Cheval et al., 2018; Cheval et al., 2019; Strand et al., 2011a; Weinstein, 2016), and whether cumulative exposure to a range of childhood social and psychosocial risk factors, including SEP, was associated with physical capability (Anderson et al., 2017; Caleyachetty et al., 2018; Strand et al., 2011a).

2.2.1 Patterns of associations and gaps in the literature

2.2.1.1 Grip strength

In the systematic review and several subsequent studies, when examining the associations between childhood SEP and grip strength, lower childhood SEP was often associated with weaker grip strength at older ages. However, studies examining associations at younger ages are limited. In the few existing studies (Birnie et al., 2011a; Carney and Benzeval, 2018; Cheval et al., 2018; Cheval et al., 2019; Hurst et al., 2013; Kuh et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Starr and Deary, 2011; Strand et al., 2011a; Weinstein, 2016), associations between childhood SEP and grip strength hint that they may change with age. For example, in studies using data from the NSHD, lower maternal education and paternal occupation were not associated with grip strength at age 53 years, but an association had emerged by age 60–64 years (Hurst et al., 2013; Strand et al., 2011a). There was also some evidence of this association getting stronger with increasing age, as lower childhood SEP was associated with a greater age-related decline in grip strength (Kuh et al., 2019). These findings were further supported by evidence from other studies of older age, which reported an association between childhood SEP and weaker grip strength (Cheval et al., 2018; Cheval et al., 2019; N. Smith et al., 2019; Starr and Deary, 2011; Weinstein, 2016). In the UKHLS study, lower maternal education was associated with stronger grip levels from middle to old age (Carney and Benzeval, 2018). However, several important factors, such as height and body composition, were not adjusted for in this study. The pattern of associations between childhood SEP and grip strength at younger ages was sometimes in different directions than those at older ages. For instance, within the Birnie et al. (2011a) review, a study on Swedish men aged 18 reported an association between lower childhood SEP and stronger grip (Silventoinen et al., 2009). These inconsistent findings highlight the need for more studies examining associations between prospective childhood SEP and grip strength at younger ages. This gap in evidence is addressed in detail in Chapters 4 and 6 of this thesis.

2.2.1.2 Standing balance performance

Inconsistent associations between childhood SEP and standing balance were also seen for standing balance performance. In the few studies that examine associations in balance, lower maternal education and paternal occupation and standing balance time were associated with midlife in the NSHD (Strand et al., 2011a), and this association diminished with age (Blodgett et al., 2020). Compared to other cohorts, there are inconsistencies in the patterns of associations in middle and old age. Additional analyses of British adults aged 63 and 86, included in the Birnie et al. (2011a) review, show that lower childhood SEP was associated with poorer standing balance performance in the *Boyd Orr* cohort but not in the *Caerphilly* cohort. Moreover, in the Danish study (Petersen et al., 2018), there was no association between childhood SEP and standing balance performance in middle age. There is also limited evidence on the mediators of these associations. Accordingly, the work presented in Chapter 5 addresses these gaps in the literature.

2.2.1.3 Chair rise speed

Associations between childhood SEP and chair rise tests were generally consistent. In the Birnie et al. (2011a) review, childhood SEP was robustly associated with slower chair rise speed. There was also moderate heterogeneity between studies (Heterogeneity statistic (I^2) = 33.6%). Within the NSHD, while there were no associations between maternal education and childhood area deprivation with chair rise speed, there was an association between lower paternal occupational class and slower chair rise speed in midlife (Murray et al., 2013; Strand et al., 2011a). At ages 60 and 64 years, lower paternal occupation was associated with poorer performance in chair rise speed (Hurst et al., 2013). Associations were also consistent with those from a middle-aged Danish cohort (Petersen et al., 2018) and those of older age from Israel (Weinstein, 2016).

2.2.1.4 Walking speed

Similar to chair rise speed, lower childhood SEP was also associated with slower walking speed in the Birnie et al. (2011a) review, with associations fully explained by body size. There was a considerable amount of heterogeneity between the studies examining this relationship. Lower father's educational level was robustly associated with walking speed in TILDA participants aged between 50 and 59 years (McCrory et al., 2018). Similarly, lower father's occupational class was robustly associated with slower walking speed in the NSHD at 60 and 64 years (Hurst et al., 2013). In American participants of various ages, robust associations were also seen between parental educational level and slower walking speed (Noppert et al., 2018). Three other studies used walking speed as a composite variable combined with other measures of physical capability. Therefore, these studies could not report individual associations between childhood SEP and walking (Anderson et al., 2017; Caleyachetty et al., 2018; Hwang et al., 2019).

2.2.2 Limitations in the literature

2.2.2.1 Retrospectively ascertained SEP

In ten out of the 19 studies included in the review by Birnie et al. (2011a), childhood SEP was indicated retrospectively through self-report. In most of these studies, parental education and occupation were often utilised. These are two theoretically grounded measures that capture the knowledge, material and social resources available to a child, aspects that determine life course circumstances, and adult health (Galobardes et al., 2006b). Nonetheless, some studies have used non-conventional indicators, including the number of books in the house and whether the father moved due to financial hardship. While some of these indicators may measure aspects of childhood socioeconomic adversity, they tend to vary in reliability from the more conventional measures, such as parental occupation. There was consistency between parents and children in the recall of parental occupation, with mixed results for parental education (Engzell, 2018; Engzell and Jonsson, 2015; Jerrim and Micklewright, 2014). It is still unknown whether these indicators were used for convenience or were explicitly collected as an exposure of interest and deemed the most appropriate for capturing aspects of childhood socioeconomic environment.

2.2.2.2 Ethnic differences

Despite evidence of ethnic differences in maximum grip strength (Dodds et al., 2016; Duchowny et al., 2017; Haas et al., 2012; McGrath et al., 2019; Ong et al., 2017; Thorpe et al., 2016; Woo et al., 2014), only one study has examined how associations between childhood SEP and specific measures of physical capability vary by ethnicity (N. Smith et al., 2019). Though, it is worth mentioning that many of the studies do not have sufficient diversity in their sample to examine these ethnic differences. As discussed in Chapter 1 (Section 1.3.1), SEP may interact with social identities, including age, sex, and ethnicity. Therefore, where possible, the interaction of age, sex, and ethnicity in the association between SEP and specific indicators of grip strength are examined in this thesis.

2.3 Literature review summary

This chapter examined the literature on the associations between childhood SEP and specific indicators of physical capability. As discussed in Chapter 1 (Section 1.4.2), the specific indicators of musculoskeletal health and function used in this thesis are grip strength and standing balance performance. Moreover, the key research questions surrounding grip strength and standing balance performance are different, given their underlying processes and patterns of association with SEP across life, and they, therefore, justify their own analyses. Hence, the inequalities in grip strength are examined in Chapters 4 and 6, while in Chapter 5, inequalities in standing balance performance are investigated.

In this PhD thesis, addressing the gaps and limitations identified in this chapter, the relationships between life course SEP and grip strength and standing balance performance in adulthood are further investigated. Examining these relationships using indicators that capture different aspects of SEP can help disentangle the underlying mechanisms which explain how and why life course socioeconomic adversity could be associated with specific objective markers of specific indicators of musculoskeletal health and function.

2.4 Overall aim of the thesis

The overall aim of this thesis was to examine the associations between SEP and grip strength and standing balance performance in the BCS70 and the UKB. Associations were examined to see if they varied by age, sex, and ethnicity (where these can be studied). Additionally, using variables chosen based on the literature, there were further investigations on whether body size (height and adiposity) and health and behavioural factors (co-morbidity, physical activity, occupational activity, sedentary behaviour and smoking) mediated these associations. The BCS70 and UKB are two valuable datasets that complement each other. The BCS70 dataset was used to study the relationship between childhood, adolescent, and adulthood SEP with grip strength and standing balance performance measured at age 46 years. The UKB dataset was then utilised to build upon the findings obtained in the BCS70, with a specific focus on adulthood SEP and grip strength. To address the aims of this thesis, the following research questions were asked:

Questions addressed in Chapter 4 using data from the BCS70

1. Are there associations between indicators of childhood, adolescent and adulthood SEP and grip strength at age 46 years in the BCS70, and do they vary by sex?
2. If there are associations in Question 1, is there evidence of social mobility?
3. Do important factors across life, including obesity, smoking, and occupational activity, mediate these associations (Question 1)?

Questions addressed in Chapter 6 using data from the UKB

4. Is there a relationship between SEP and grip strength at baseline in the UKB and does this vary by age and sex?
5. Is there a relationship between ethnicity and grip strength at baseline in the UKB and does this vary by age and sex?
6. Are there interactions between SEP and ethnicity in their relationships with grip strength?

7. If there are relationships in Questions 4 and 5, to what extent do important factors in adulthood, including height, adiposity and health and behavioural factors, explain these relationships?

8. Is there a relationship between occupational class and grip strength in working-age men?

9. If there is a relationship in Question 8, is it observed across different age groups, and is it explained by higher occupational activity levels?

Questions addressed in Chapter 5 using data from the BCS70

11. Are there associations between indicators of childhood and adulthood SEP and standing balance at age 46 years in the BCS70, and do they vary by sex?

12. Does tracking of SEP from childhood to adulthood explain any observed associations?

13. If associations exist, to what extent do specific factors across life mediate these associations?

The next chapter introduces the BCS70 and UKB studies and the analytical strategy used to address all the aims of this thesis.

CHAPTER 3

Introduction to the population-based studies

This chapter introduces the BCS70 and UKB, two large population-based studies from which data have been drawn and analysed to address the main aims of this PhD. The chapter discusses the origins of the studies, their strengths and limitations in addressing the key research questions, participation rates, details of the specific outcomes utilised in analyses, the covariates, and the socioeconomic indicators used as explanatory variables. The chapter concludes with a description of the participants in each study.

BCS70 is the third oldest of four national British birth cohort studies with prospective ascertainment of multiple indicators of SEP across life and assessments of grip strength and standing balance at age 46 years, making it suitable for disentangling the associations between childhood and adulthood SEP and grip strength and standing balance performance in midlife. The UKB is a large study with around 500,000 participants aged between 37 and 73 years. These study data allow for detailed interrogation of whether associations between indicators of SEP and grip strength vary by age, sex, and ethnicity.

3.1 1970 British Cohort Study

3.1.1 History of the cohort

The BCS70 is an ongoing large-scale prospective cohort study of people born in England, Scotland, and Wales after the 24th week of gestation between the

5th of April and the 11th of April 1970. The BCS70, originally named the *British Birth Survey*, was commissioned by the *National Birthday Trust Fund* and the *Royal College of Obstetricians and Gynaecologists* to examine the social and biological characteristics of maternal circumstances and health outcomes, and to compare the results with those of the *1958 National Child Development Study* (NCDS) (Power and Elliott, 2006). Like the two previous British birth cohort studies, the MRC NSHD and NCDS, the BCS70 was originally intended to be a census, but later became a longitudinal study (Power and Elliott, 2006; M. Wadsworth et al., 2006). In subsequent waves, the study was broadened to examine health, education, and social development in early life, family formation, employment, and the development and maintenance of adulthood in later years (J. Elliott and Shepherd, 2006). The BCS70 has a long history of generating evidence to guide various policies aimed at improving people's education, development, health, and well-being. For example, the BCS70 was one of the first studies to shed light on the effects of smoking during pregnancy and parental smoking in general (Taylor and Wadsworth, 1987).

3.1.2 Strengths and limitations of the BCS70

The BCS70 has data on a wide range of prospectively ascertained factors across the life course, including socioeconomic circumstances, health, behavioural and developmental characteristics, which have been assessed multiple times. This rich dataset enables us to investigate the confounding, mediating and moderating role of these different factors.

Another key strength of the BCS70 is its prospective design. Here, the independent variables, such as parental socioeconomic circumstances, have been prospectively ascertained by the study team, unlike in many other studies where childhood SEP indicators are retrospectively ascertained (see Section 2.2.2.1). A prospective study design minimises recall bias, which could impact the scale and direction of estimated associations between childhood SEP and health outcomes, as participants may differ in their recollection of childhood SEP. Additionally, the prospective design allows us to examine the temporal relationship between exposure and outcome (Euser et al., 2009).

A limitation of the BCS70, and in general secondary datasets, is that users of the study rely on the data already collected. In primary research, investigators have full control of the data collected, whereas, for secondary analyses, investigators cannot specify the data they want to collect (Cheng and Phillips, 2014). For example, in the case of this thesis, it would have been beneficial to have had access to physical capability measures in childhood and adolescence. However, during the early waves of the BCS70, questions on the implications of early life factors on physical capability had not emerged. It is only in the last two to three decades that interest in this area grew (Ben-Shlomo et al., 2016) — this is the nature of research, which is ever-evolving; as our knowledge expands, new hypotheses are generated, thus informing the data collected in subsequent waves of ongoing studies. Moreover, low participation and missing data are additional limitations in the BCS70 and cohort studies in general, and these issues are discussed in the next section with consideration of the implications for analyses in discussion Sections 4.5.4 and 5.5.3 and Chapter 7.

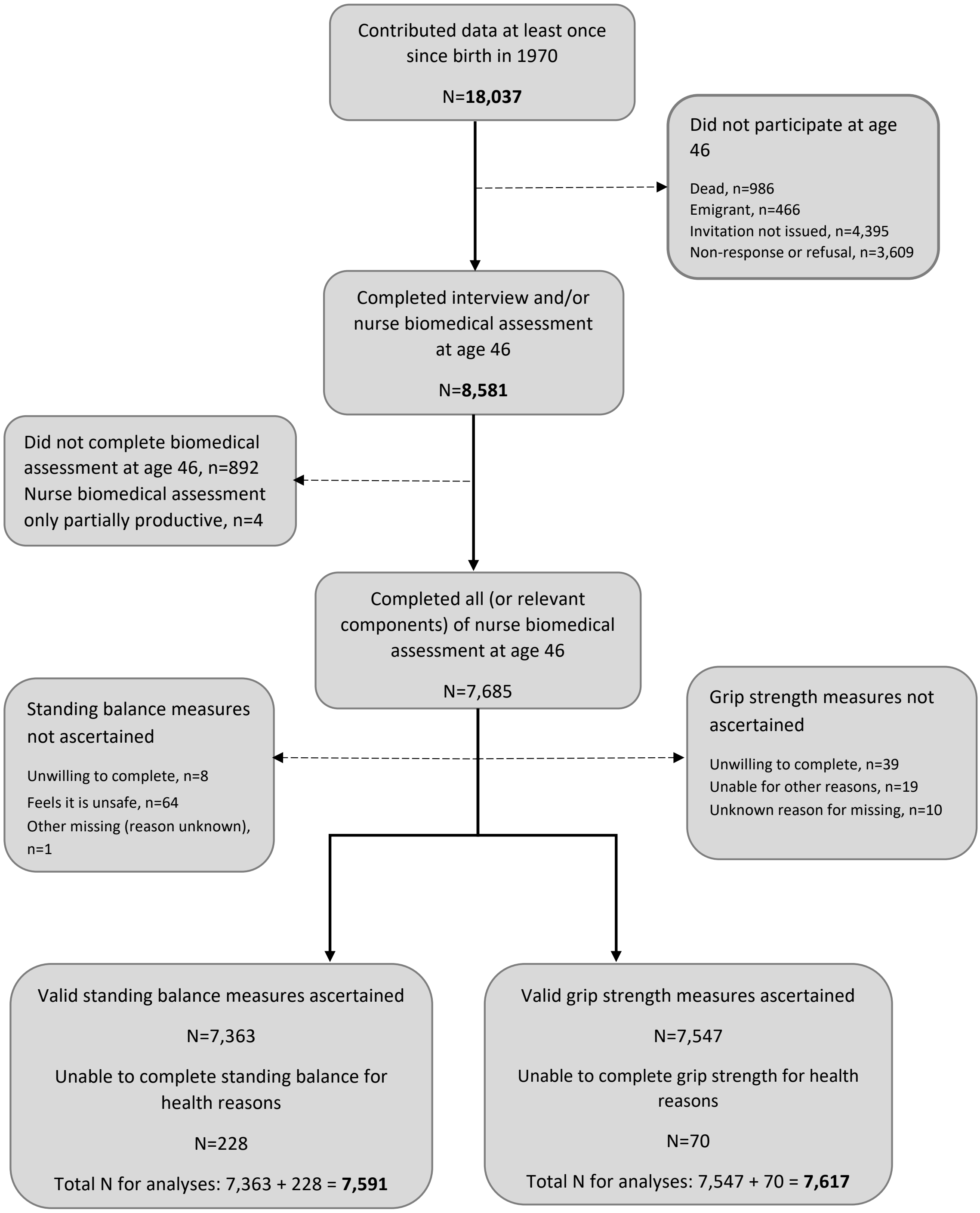
3.1.3 Study participation

In the BCS70, participants recruited at birth have been followed up across life on ten separate occasions since, with regular assessments throughout childhood and adulthood. The target sample was updated at ages 5, 10 and 16 to include people born at the same time who had migrated to Great Britain, which led to the inclusion of 839 extra participants (Plewis et al., 2004). The work presented in this thesis uses data collected at each of the 10 waves, including at birth, ages 5, 10, 16, 26, 30, 42, and 46 years (Centre for Longitudinal Studies, 1970; Centre for Longitudinal Studies, 1975; Centre for Longitudinal Studies, 1980; Centre for Longitudinal Studies, 1986; Centre for Longitudinal Studies, 1996; Centre for Longitudinal Studies, 1999; Centre for Longitudinal Studies, 2012; Centre for Longitudinal Studies, 2016; Centre for Longitudinal Studies, 2021). A total of 18,037 men and women were recruited and assessed on at least one occasion — see Figure 3.1.1 for a flow diagram of participation in the BCS70 up to age 46 years. Over the years, up to age 46 years, the target sample in the BCS70 has gradually decreased due to death (n=986), survey non-response and refusal (n=3,609), and emigration (n=466). Observed samples have also been affected by survey non-contact (n=4,395). In the latest wave, at age 46 years, there was a detailed assessment that included two main components – participants had 50 minutes of interviews followed by a further 50-minute comprehensive biomedical assessment conducted by a trained nurse during a home visit. In the biomedical assessment, grip strength and standing balance outcomes were measured for the first time in the history of BCS70. In the BCS70, the approach to gaining ethical approval changed over the years (Shepherd and Gilbert, 2019). There were only internal ethical reviews for the surveys between 1970 and 1996. However, for follow-ups from 2000 onwards, ethical approval was sought from the *Multicentre Research Ethics Committees* (Shepherd and Gilbert, 2019). For example, at age 46 years, there was full ethical approval from N*RES Committee South East Coast—Brighton & Sussex* (Ref 15/LO/1446). From birth to age 16 years, parental consent was sought, and from age 26 years, informed consent was sought from the study members. See the report from Shepherd and Gilbert (2019) on the ethical review and consent history of the BCS70. Before accessing the BCS70 datasets, ethical approval was granted by the Manchester Metropolitan University's ethics committee following an application, which provided details of the research aims and objectives along with the methodology of analyses (EthOS Reference Number: 24005). Additionally, the BCS70 data used in this thesis are available from the UK Data Service and were accessed via a standard data application (project ID 186390).

As reported by the *Centre for Longitudinal Studies* (Ketende et al., 2010), there have been specific cohort events that could have contributed to the reduction in survey responses within the BCS70. For example: i) there was a significant drop in response rate at age five years, this could be due to the British Birth Survey initially being set up as a survey and not a cohort study, thus making contact tracing at age five years complicated; ii) the teachers' strike in 1986 affected the data collection at age 16 years as many of the instruments were set up for teachers to complete; iii) and at age 26 years, there was a ten-year gap since cohort members were last contacted, and as this ten-year period was an important period of transition into adulthood, many cohort members were likely to have moved away from home (J. Elliott and Shepherd, 2006). Further, age 26 years was the first time the BCS70 data collection was administered by post.

Based on the analyses of attrition and non-response in the BCS70 by Mostafa and Wiggins (2015), males were more likely not to respond, particularly those whose mothers had lower levels of education and whose fathers were manual workers. Additionally, cohort members whose mothers were single or lived in London in 1970, and those with at least three siblings, were more likely to have been lost to follow-up (Mostafa and Wiggins, 2015). The sample sizes in the BCS70 (Figure 3.1.1) align with the cases for which information on the key variables of the BCS70 dataset was available, also known as productive cases. It is worth noting that different figures may be found depending on the source used. This is mainly due to the continuous revision of the BCS70 longitudinal sample over time, which the *Centre for Longitudinal Studies* maintains. As members may leave the survey and come back later, known as a non-monotone pattern, determining loss to follow-up in survey waves is not straightforward.

Figure 3.1.1: Flow diagram of the BCS70 study sample.



3.1.4 Measurement of outcomes

3.1.4.1 Assessment of grip strength

During the nurse assessment (home visit) at age 46 years, grip strength was measured in kilograms using the *Smedley* spring-gauge dynamometer. Participants were instructed to stand with their upper arm against their trunk and their forearm at a 90-degree angle to their trunk, and to squeeze the dynamometer as hard as possible. Those unable to perform the assessment standing were seated, and those unable to hold their arm against their trunk had their arm supported. A single practice run was conducted in the dominant arm before the assessment began. Three measurements were taken in each hand, starting with the non-dominant hand and then alternating between hands. The maximum measurement of the six attempts (3 in each hand) for each participant was used in analyses.

Participants were excluded from taking part in the grip strength assessment if they had undergone surgery on their hands in the past six months or if they had swelling, inflammation, severe pain, or a recent injury to their hands. If participants were unable or unwilling to complete the grip strength tests, the nurse recorded the reason for this. Participants who were unable to complete the grip strength assessment due to health reasons (n=70) (see Table 3.1.1) were allocated a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution, on the assumption that these participants were likely to have had low grip strength and that their exclusion may bias the results (R. Cooper et al., 2014; Hurst et al., 2013). Sensitivity analyses were conducted to test this assumption and check the impact of including these participants on the findings.

3.1.4.2 Assessment of standing balance

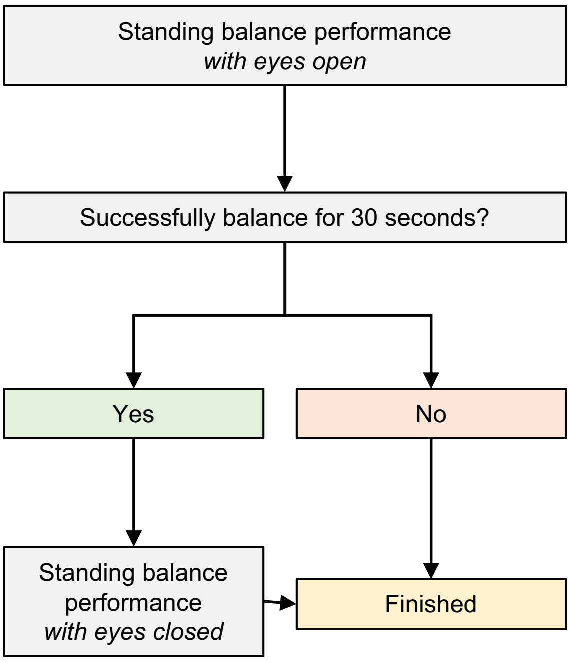
To assess standing balance performance, participants were first asked to remove their shoes and slippers, unless they had flat heels on at the time. Subsequently, participants were asked to stand on one leg (of their preference) whilst raising the other leg a few inches off the ground and to hold this position for as long as possible, up to a maximum of 30 seconds. Participants completed one test with their eyes open, and if they successfully balanced for 30 seconds, they progressed to the next stage, which involved standing on one leg with eyes closed (see Figure

3.1.2). In both tests (eyes open and eyes closed), the nurse started timing when the participant lifted their foot off the ground; timing stopped when participants successfully completed 30 seconds or when participants lost balance (this was indicated by the raised foot touching the floor or the foot on the floor moving out of position); it was acceptable for participants to move their arms to keep themselves balanced.

Participants were excluded from undertaking the standing balance test if they met the following criteria: (a) they were chair/wheelchair-bound; (b) they needed to use an aid for walking or standing; (c) the nurse considered that it was unsafe to conduct the measurement because the participant was too unsteady on their feet; (d) the participant found it too painful to stand or balance on one leg, because of surgery or longstanding or current short-term illness or injury; (e) the participant was pregnant. Similar to grip strength, nurses made a record of the reasons why participants were unable or unwilling to do the standing balance measurement. Participants who were unable to carry out the standing balance test for health reasons (Table 3.1.1) had their missing time imputed with a time of zero. This is based on the assumption that those unable to conduct the standing balance test due to health reasons would have a very low balance time (Blodgett et al., 2020). Sensitivity analyses were conducted to test this assumption and check the impact of including these participants on the findings.

The times for the standing balance with eyes closed test were heavily skewed to the right, as a considerable proportion of participants could achieve a time of 30 seconds (see Figure 3.1.5b). For analytical purposes, standing balance time with eyes open and eyes closed were combined and categorised using 15-second intervals: 1) Eyes Open <15 seconds; 2) Eyes Open 15-29.9s; 3) Eyes closed <15s; 4) Eyes Closed 15-29.9s; 5) Eyes Closed 30s (R. Cooper et al., 2020). When examining the distribution of standing balance time categories, most individuals were in the Eyes closed <15s category. Therefore, standing balance time was also broken down into 5-second intervals for the middle categories. The seven categories were Eyes open <15s, Eyes open 15-29.9s, Eyes closed <5s, Eyes closed 5-9.9s, Eyes closed 10-14.9s, Eyes closed 15-29.9s and Eyes closed 30s. This categorisation will be used for sensitivity analyses in Chapter 5.

Figure 3.1.2: Flow diagram detailing the progression in the standing balance performance test in the BCS70.



3.1.5 Measurement of SEP

Prior to selecting SEP measures in the BCS70, a full assessment of all the different indicators of SEP ascertained at each wave was undertaken (see Appendix Table B.2.1). Decisions as to which indicators to include were based on considerations of what the SEP indicator captured in relation to health, how widely it was used in the UK, the context if the indicator was a time-varying measure, and whether there were repeat measurements. To capture childhood, adolescence, and adulthood SEP, indicators of SEP ascertained at ages five, sixteen, thirty, and forty-six years were chosen as the focus a priori. At age five years, the father's occupational class (or at birth if missing (n=1,181)), the mother's and father's educational levels, and family housing tenure were used. In adolescence, the father's occupational class at age sixteen years (or at age ten years if missing (n=3,302)) was used as an indicator. The justification for using the father's occupational class is that as children are dependent on their parents and carers, the father's occupational class indirectly tells us about the child's place in society, their access to resources, opportunities, as well as social and educational capital, as indicated by their parent's/carer's occupational class (Galobardes et al., 2006b). In addition, occupational class is a repeat measurement that has been collected in all waves, thus making it possible for us to examine associations across the life course. Furthermore, the mother's and father's highest known qualifications at age five years were used, as parental educational levels are important to a child's academic and behavioural outcomes (which are important to health outcomes) (Galobardes et al., 2004; Galobardes et al., 2008). Family housing tenure at age five years was used as an additional indicator of childhood SEP; in industrialised nations, housing tenure is often used to measure material circumstances. The *Registrar General's Social Classification* (RGSC) (Rose and Harrison, 2014) was used to classify occupational class into six categories which were collapsed into four categories for the purposes of most analyses in order to increase statistical power: I Professional/II Intermediate, III Skilled non-manual, III Skilled manual and IV Partly skilled/V Unskilled. Both the mother's and father's educational levels were based on the highest qualification achieved and categorised into four groups: Higher vocational/degree and higher, A-level/equivalent, Vocational/O-level/equivalent, and No qualification. Housing tenure was classified into owned, private renting, council renting, and other (consisting of housing tied to occupation and other non-specified categories).

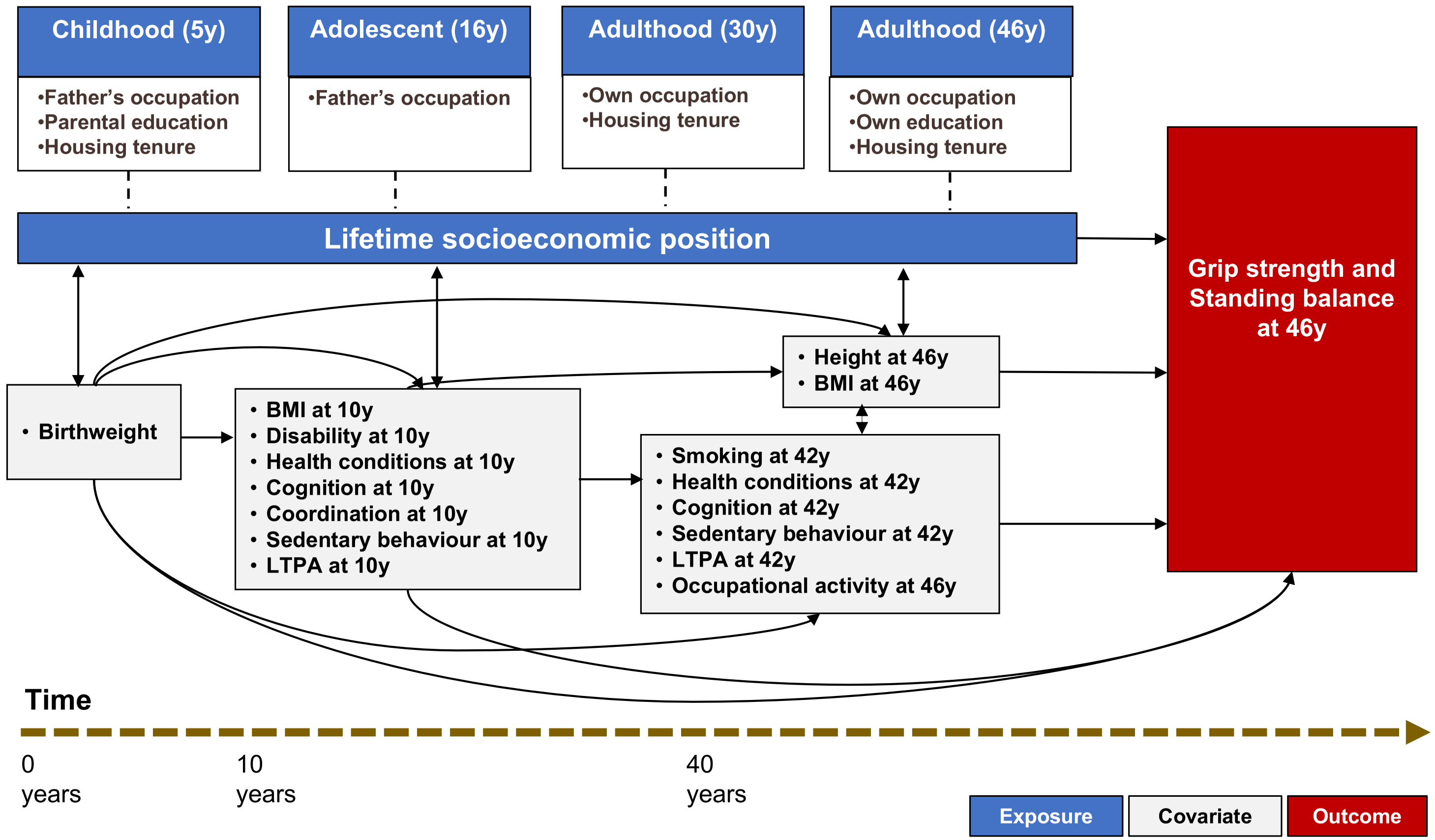
In adulthood, own occupational class at ages 30 (or at age 26 years if missing (n=730)) and 46 was used. As there was a move away from the RGSC to the *National Statistics Socio-economic Classification* (NS-SEC) classification of occupations in 1998, occupational class at age 46 years was classified using NS-SEC coding (Rose and Pevalin, 2005)). However, since RGSC was the coding system applied in all the other waves in the BCS70, and there is a need to have occupational class indicators in the same coding so that results could be compared, NS-SEC occupational class was back-coded to RGSC. The NS-SEC to RGSC back-coding was validated using data from age 42 years where the RGSC and NS-SEC classification were known; Section B.3 in the Appendix details the validation of the method used to back-code NS-SEC to RGSC classification at age 46 years. Own occupational class is used as the main indicator for SEP in adulthood. The justification for this is that occupational class is a widely utilised indicator that has been used to describe the socio-economic gradient of health outcomes and reflects social standing and material reward and resources of an individual (Galobardes et al., 2006b). Similarly, the highest qualification at age 46 years and tenure of current address at ages 30 (age 26 if missing at 30 (n=443)) and 46 are two commonly used SEP indicators. Highest educational qualification measures the knowledge-related assets and captures the SEP transition from childhood to adulthood, and strongly predicts future employment and income, while housing captures an individual's material assets (Galobardes et al., 2006b). Own highest qualification at age 46 years was categorised into the following groups: Degree and higher, A-level and vocational qualification (advanced secondary education), GCSEs (ordinary secondary education) and No qualification. Own housing tenure was categorised as Owned, Renting, and other (including Live rent-free, squatting, etc.). Additionally, own weekly income after tax at age 46 years was used and broken down into eleven categories (see Table 3.1.6 for categorisation).

To examine social mobility, father's occupational class at age five years and own occupational class at age 46 years, were recoded as High, Medium and Low. Here, occupational classes I and II were coded as High, occupational classes III NM and III M were coded as Medium, and occupational classes IV and V were coded as Low. There was also a binary of High-Low categorisation presented for analyses where there was a linear effect in the associations between childhood and adulthood SEP and grip strength or standing balance performance. As such, fathers and own occupational class was categorised into two categories: High category, which includes levels I, II and III NM, and Low category, which includes levels III M, IV and V. The transition between the two occupational classes were categorised as High to High, Low to High, High to Low and Low to Low.

3.1.6 Measurement of covariates

In this section, the covariates hypothesised to contribute to the relationship between SEP across life and grip strength and standing balance at age 46 years are reported. These covariates were selected a priori based on previous literature (Birnie et al., 2011a; Birnie et al., 2011b; Blodgett et al., 2020; A. Cooper et al., 2015; R. Cooper et al., 2011c; R. Cooper et al., 2016; R. Cooper et al., 2020; Dodds et al., 2012; Dodds et al., 2013; Hamer and Stamatakis, 2013; Hardy et al., 2013; Keevil et al., 2016; Kuh et al., 2005; Kuh et al., 2009; Rapuri et al., 2007; Strand et al., 2011b; Walker-Bone et al., 2016). The categorisation of all covariates is presented in the results section (Tables 3.1.8 and 3.1.9). Figure 3.1.3 provides an overview of these covariates and their respective pathways in relation to the explanatory and outcome variables.

Figure 3.1.3: Illustration of the life course framework for the BCS70.



3.1.6.1 Anthropometric factors

Anthropometric measures, including height and body mass index (BMI) and birth weight, have been included to examine the relationship between SEP across life and grip strength and standing balance at age 46 years. Based on previous meta-analyses, low birth weight has been linked with poor grip strength (Dodds et al., 2012), taller individuals have been shown to have better grip strength and standing balance time (Kuh et al., 2005), and individuals with higher BMI have been found to have better grip strength but poorer standing balance performance (Blodgett et al., 2020; R. Cooper et al., 2022; Hardy et al., 2013). Factors used in childhood include birth weight (kg) as ascertained from birth records and BMI at age ten years (calculated as kg/m^2 from height and weight measured by a nurse). Height, which is strongly associated with grip strength (Kuh et al., 2005) and is often used to normalise grip strength in population-based studies (Spruit et al., 2013), and BMI at age 46 years (derived from nurse-measured height and weight) were also used.

3.1.6.2 Behavioural risk factors

Leisure-time and occupational physical activity, sedentariness and smoking were included as behavioural risk factors. In childhood, the following indicators, which were assessed at age ten years, were used: leisure-time physical activity (based on a maternal report of how often the participant played sports in their spare time); sedentary behaviour (based on a maternal report of how often the participant watched television in their spare time). In adulthood, sedentary behaviour at age 42 years (based on a self-report of the length of time spent watching television on a typical weekday) and leisure-time physical activity at age 42 years (based on a self-report of the number of days they spent doing 30 minutes or more of exercise in a typical week) were used. These factors are socioeconomically graded and have been linked with poor musculoskeletal health and function (Birnie et al., 2011a; A. Cooper et al., 2015; R. Cooper et al., 2011c; R. Cooper et al., 2016; R. Cooper et al., 2020; Dodds et al., 2013; Hamer and Stamatakis, 2013; Keevil et al., 2016; Kuh et al., 2005; North et al., 2015).

Occupational activity was also included, as higher occupational activity has previously been linked with better grip strength and standing balance performance (Birnie et al., 2011a; Walker-Bone et al., 2016). Occupational activity was ascertained at age 46 years (based on a self-report of the types and amount of physical activity involved in the participant's work) and was used to account for different occupational activity levels. As smoking has previously been associated with poor grip strength and standing balance performance (Birnie et al., 2011a; Rapuri et al., 2007; Strand et al., 2011b), self-reported smoking status at age 42 years was used.

3.1.6.3 Health and neurodevelopmental outcomes

To account for health and neurodevelopmental risk factors, health status, disability, cognition, and coordination were used. Poor health status has previously been linked with poor grip strength and standing balance performance (Birnie et al., 2011b; Blodgett et al., 2020; R. Cooper et al., 2016). At the age of ten years, health status was determined by creating a composite variable that indicated the total number of conditions each participant had at that age; these conditions were recurrent abdominal pain, pneumonia, migraine, wheezing, seizure, abnormality, and bronchitis.

As disability is related to poor performance in grip strength and standing balance, disability in childhood was included as a covariate. Initially, adulthood disability was considered. However, as age 42 years was the first time disability was measured in adulthood within the BCS70, the possibility of reverse causality was a concern. Moreover, there was a concern for over-adjustment, as adulthood disability could be a mediator between lifetime SEP and grip strength and standing balance performance. Therefore, we used disability at age ten years (based on a parental report of whether they considered the participant to have a physical or mental disability or handicap, or any other disabling condition that interfered with everyday life or might be a problem at school) as a better indicator since it is distal from the outcome.

Neurocognitive factors, including cognition and coordination, are important for standing balance performance; for example, poor cognition and coordination are risk factors for poor standing balance performance (Blodgett et al., 2020; Kuh et al., 2009). For neurodevelopmental factors in childhood, cognition at age ten years was ascertained using the Edinburgh reading test, a test of word recognition (Parsons, 2014), and childhood coordination at age ten years, which was a self-report of parents describing their child's coordination ability, was also used.

Adulthood cognition was determined by *Applied Psychology Unit* vocabulary test at age 42 years — this is a test where participants had to match a list of 20 words with words that have the same meaning. The test gets progressively harder (Closs and Hutchings, 1976). In adulthood, health status at age 42 years was also included. This was derived in the same way as childhood health status, and the health conditions used to create this variable were diabetes, cancer or leukaemia, high blood pressure, seizure, arthritis, asthma, or wheezy bronchitis at age 42 years.

3.1.7 Descriptive analyses of the BCS70

3.1.7.1 Derivation of analytical sample

As shown in Figure 3.1.1, 8,581 participants completed at least one component of the data collection at age 46 years. Of these, 7,685 completed a biomedical assessment conducted by a nurse, of whom 7,547 completed a grip strength assessment, and 7,363 completed standing balance tests.

Table 3.1.1 describes those unable to complete a grip strength assessment for different reasons. There were 39 and 8 individuals who were unwilling to complete grip strength and standing balance measurements, respectively. For standing balance, 64 individuals felt it was unsafe to do the assessment. There were also 70 individuals who were unable to complete the grip strength assessment for health reasons (women, n=50; men, n=20) and 228 who could not complete the standing balance assessment for health reasons (women, n=139; men, n=89). Table 3.1.2 shows a breakdown of the different health reasons recorded, explaining why some participants could not complete the test. For grip strength, the most common health reason was musculoskeletal condition/injury (n=55), and for standing balance, the most common reasons were current medical condition (n=92) and current/recent lower back problems (n=78).

As previously mentioned in Section 3.1.4, a decision to include individuals who were unable to complete grip strength and standing balance measurements for health reasons was made, with imputed values based on evidence from the literature (Blodgett et al., 2020; R. Cooper et al., 2014; Hurst et al., 2013). After this inclusion, there were 7,617 individuals for inclusion in grip strength analyses and 7,591 for inclusion in analyses of standing balance performance. The overall maximum analytic sample used in this thesis was 7,643 individuals (3,944 women and 3,699 men) with complete data on grip strength or standing balance.

Figure 3.1.4: Distribution of grip strength by in men and women in the BCS70 (N=7,617). The dotted line represents the mean.

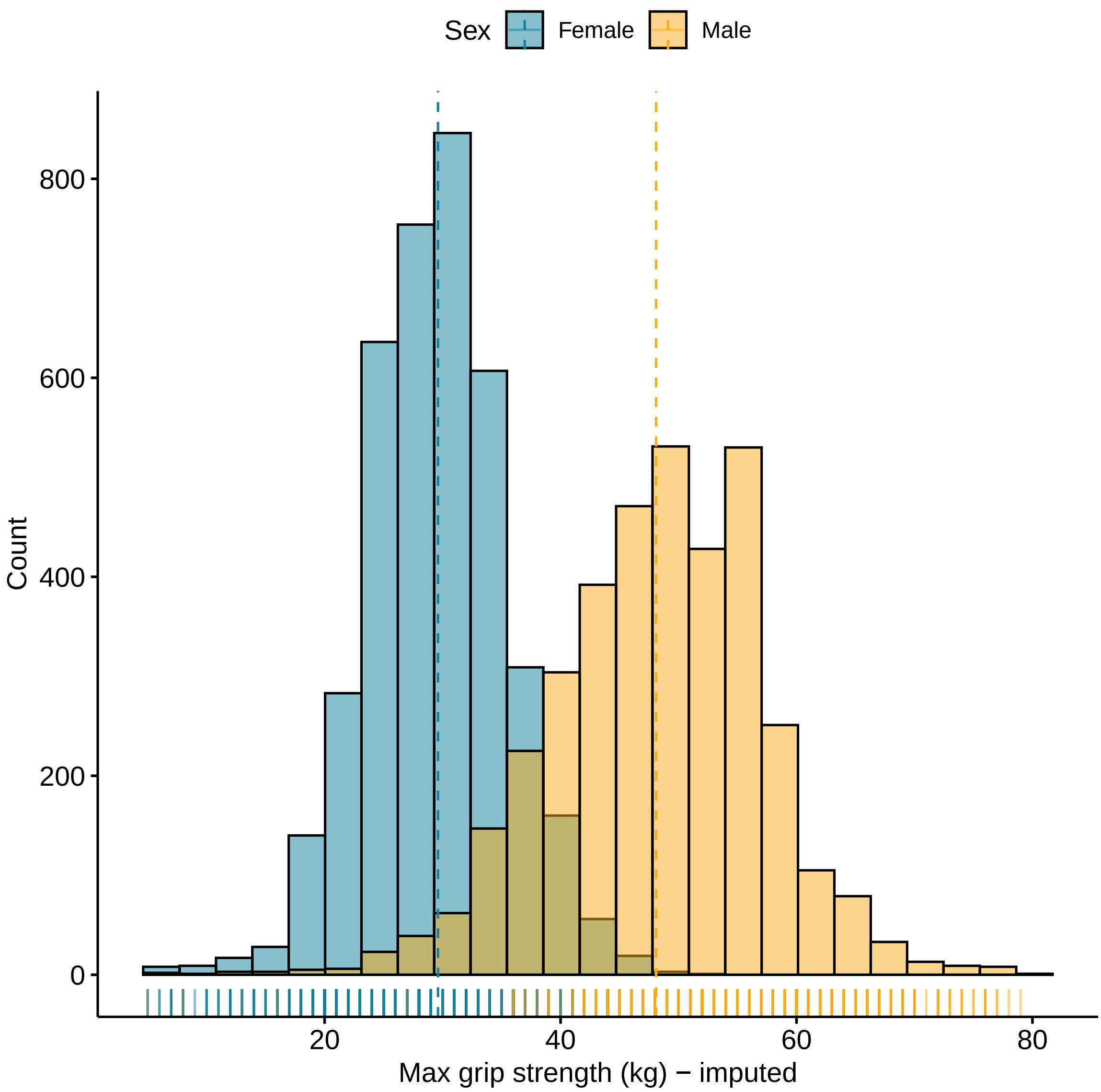


Figure 3.1.5: Distribution of standing balance time in the BCS70 by sex.

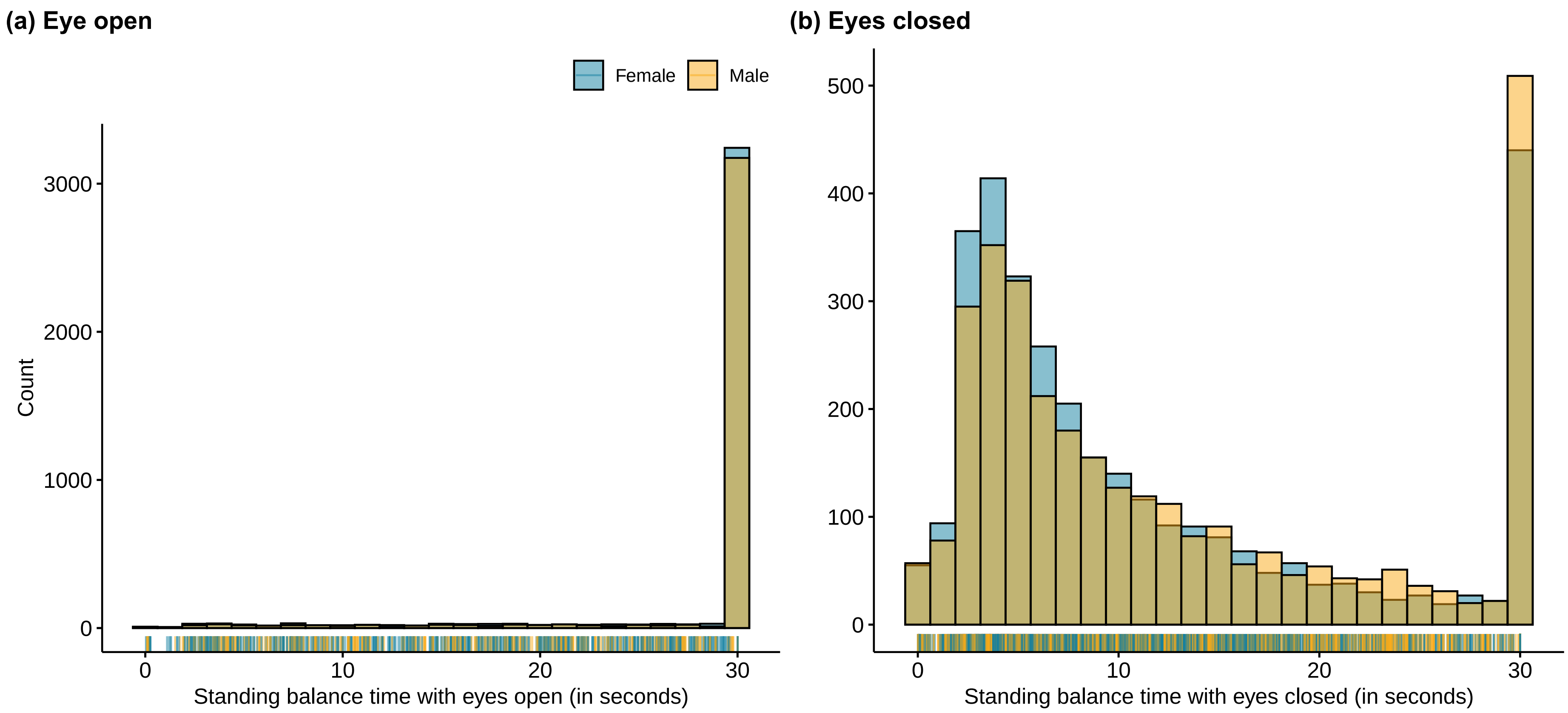


Table 3.1.1: Description of participants in the BCS70 sample who did and did not complete grip strength and standing balance assessments, with reasons for incompletion.

Outcome and reasons	N	% of total (N=8,581)
Grip strength		
Completed	7,547	88.0
Did not complete	128	1.5
Unwilling/refusal	39	0.5
Unable to for health reasons	70	0.8
Lack of time	12	0.1
Equipment problem (no/faulty dynamometer)	6	0.1
Unable to understand instructions	1	0.1
Standing balance		
Completed	7,363	85.8
Did not complete	300	3.5
Unable to for health reasons	228	2.7
Felt it was unsafe to do	64	0.7
Unwilling/refusal	8	0.1

Table 3.1.2: Description of participants unable to complete grip strength and standing balance assessments for health reasons in the BCS70.

Outcome and health reasons	N
Grip strength (N = 70)	
MSK condition/injury	55
Other health condition/injury	15
Standing balance (N = 228)[a]	
Recent injury on preferred leg	31
Current/recent lower back problems	78
Current/recent hip problems	18
Current medical condition affects balance	92
Other specific answer given	25

[a] 206 people reported just 1 problem, 16 reported 2 problems and 2 people reported 3 problems.

3.1.7.2 Description of outcomes

Tables 3.1.3 and 3.1.4 show the distributions of grip strength and standing balance measurements by sex. On average, men had a much stronger grip than women (48.1kg vs 29.6kg) — see Table 3.1.3 and Figure 3.1.4.

Figures 3.1.5a and 3.1.5b show the distribution of eyes open and closed standing balance time by sex. In Figure 3.1.5a, the time to complete standing balance with eyes open was skewed to the left, as many participants could accomplish the 30 seconds of standing balance eyes open. In Figure 3.1.4, there was a bimodal distribution in the eyes closed standing balance test, with most participants achieving under 15 seconds of eyes closed and a sizable proportion of participants achieving 30 seconds of eyes closed. With the 15-second categorisation, nearly 60% of participants were in the Eyes closed for <15s category. On average, men were more likely to achieve standing balance with eyes closed for 30 seconds than women (14% vs 11%) (see Table 3.1.4). In contrast, more women than men recorded standing balance times with eyes open for less than 15 seconds (10% vs 8%) (Table 3.1.4). When using the 5-second categorisation, 26-28% of participants were in the Eyes closed for <5s category; the rest of the distribution for the 5-second categorisation is similar to that of the 15-second categorisation.

Table 3.1.3: Distribution of grip strength by sex in the BCS70 sample with complete grip strength measurements.

Outcomes	N	Women N=3,926	Men N=3,691	*p-value*†
Grip strength (kg)	7,547			<0.001
N		3,876	3,671	
Mean (SD)		29.52 (5.84)	48.03 (9.00)	
Range (min, max)		5, 51	5, 79	
Grip strength (kg) (including imputed values for n=70)‡	7,617			<0.001
N		3,926	3,691	
Mean (SD)		29.61 (5.81)	48.10 (8.98)	
Range (min, max)		5, 51	5, 79	

† Statistical tests of sex difference: t-test; ‡ Includes those unable to do grip strength for health reasons N=70 (50 Women & 20 Men). These individuals were allocated grip strength values equivalent to the mean of the bottom sex-specific fifth.

Table 3.1.4: Distribution of standing balance by sex in the BCS70 sample with complete standing balance measurements.

Outcomes	Observed N	Women N=3,925	Men N=3,666	*p-val*‡
Balance time (secs) (eo)*	7,363			<0.01
N		3,797	3,587	
Median (IQR: 25%, 75%)		30 (30, 30)	30 (30, 30)	
Range (min, max)		0.03, 30.00	0.09, 30.00	
Balance time (secs) (eo)* - imputed§	7,612			<0.001
N		3,936	3,676	
Median (IQR: 25%, 75%)		30 (30, 30)	30 (30, 30)	
Range (min, max)		0.00, 30.00	0.00, 30.00	
Balance time (secs) (ec†)	6,381**			<0.001
N		3,225	3,156	
Median (IQR: 25%, 75%)		7.45 (4.02, 16.13)	8.73 (4.38, 19.92)	
Range (min, max)		0.01, 30.00	0.00, 30.00	
Balance time (eo*, ec†) in 15s categories	7,591			<0.001
Eyes open <15s		397 (10.1%)	289 (7.9%)	
Eyes open 15-29.9s		303 (7.7%)	221 (6.0%)	
Eyes closed <15s [a]		2,340 (59.6%)	2,127 (58.0%)	
Eyes closed 15-29.9s		451 (11.5%)	530 (14.5%)	
Eyes closed 30s		434 (11.1%)	499 (13.6%)	
Balance time (eo*, ec† in 5s categories	7,591			<0.001
Eyes open <15s		397 (10.1%)	289 (7.9%)	
Eyes open 15-29.9s		303 (7.7%)	221 (6.0%)	
Eyes closed <5s		1,080 (27.5%)	945 (25.8%)	
Eyes closed 5-9.9s		848 (21.6%)	763 (20.8%)	
Eyes closed 10-14.9s		412 (10.5%)	419 (11.4%)	
Eyes closed 15-29.9s		451 (11.5%)	530 (14.5%)	
Eyes closed 30s		434 (11.1%)	499 (13.6%)	

* eo = eye opens (in seconds); † ec = eyes closed (in seconds); [s] includes those who have achieved 3 the eyes closed category also includes those who have achieved eyes open for 30sec, i.e., this category is technically Eyes open 30s, eyes closed <15s; ‡ Statistical tests of sex difference: chi-square test of independence; ‡§ Includes those unable to do standing balance for health reasons N=228 (139 Women & 89 Men) ‡** N's drops as those unable to complete eyes open 30s not carried forward to eyes closed.

3.1.7.3 Socioeconomic characteristics

Participants were most often born to a father of occupational class III manual, parents who had no formal qualifications and lived in family-owned housing (see Table 3.1.5). At ages 30 and 46, participants were most likely to belong to occupational class I or II. Women were more likely to be in skilled non-manual occupations than men, whereas men were more likely to be in skilled manual occupations (p<0.001) than women (Table 3.1.6). At age 46 years, women were slightly more likely than men to have a degree (27% vs 25%, respectively), and men were more likely than women to have no formal qualifications (31% vs 25%). In adulthood, most men and women lived in owner-occupied housing. Most SEP indicators, apart from housing tenure, were highly correlated with each other in the expected direction (I-value for chi-squared tests: <0.001).

As shown in Tables 3.1.6 and 3.1.7, there was some mobility in occupational class from childhood to adulthood in the BCS70. For males, 59% whose fathers were in high occupational class in childhood were also in high occupational class in adulthood, and for females, this was 65%. Over 30% of males and females transitioned from low to high occupational class. Similarly, 46-54% of males and females have transitioned from low to medium occupational class. A similar number of males and females have also stayed in the medium class from childhood to adulthood (46-47%). Over 40% of males and females went from medium to high occupational class. More females than males went from medium to low occupational class (13% vs 9%, respectively).

Table 3.1.5: Distribution of childhood and adolescence SEP indicators by sex in the BCS70 sample with complete grip strength and/or balance measurements.

Factors	Observed N	N(%)* Women N=3,944	Men N=3,699	*p-val*†
Father's occupational class (5y)§	7,223			0.06
I Professional/II Intermediate		1,065 (28.4)	1,040 (29.9)	

Factors	Observed N	N(%)* Women N=3,944	Men N=3,699	p-val†
III Skilled Non-manual		399 (10.6)	390 (11.2)	
III Skilled Manual		1,595 (42.5)	1,481 (42.6)	
IV Partly skilled/V Unskilled		691 (18.4)	562 (16.2)	
Missing		194	226	
Mother's highest qualification (5y)	5,952			0.9
Higher voc/degree and higher		289 (9.3)	276 (9.7)	
A-level/equivalent		138 (4.5)	134 (4.7)	
Vocational/O-level/equivalent		1,097 (35.4)	1,011 (35.4)	
No qualification		1,574 (50.8)	1,433 (50.2)	
Missing		846	845	
Father's highest qualification (5y)	5,583			0.7
Higher voc/degree and higher		521 (18.1)	512 (19.0)	
A-level/equivalent		253 (8.8)	221 (8.2)	
Voc/O-level/equivalent		846 (29.3)	789 (29.3)	
No qualification		1,266 (43.9)	1,175 (43.6)	
Missing		1,058	1,002	
Family housing tenure (5y)	6,253			0.2
Owned		1,999 (61.6)	1,897 (63.0)	
Private renting		187 (5.8)	166 (5.5)	
Council renting		907 (28.0)	781 (26.0)	
Other (from occupation etc.,)		151 (4.7)	165 (5.5)	
Missing		700	690	
Father's occupational class (16y)§			6,817	0.9
I Professional/II Intermediate		1,210 (34.2)	1,149 (35.0)	
III Skilled Non-manual		412 (11.7)	366 (11.1)	
III Skilled Manual		1,388 (39.3)	1,290 (39.3)	
IV Partly skilled/V Unskilled		523 (14.8)	479 (14.6)	
Missing		411	415	

* Maximum N, though N varies due to missing data on each SEP indicator; † Statistical tests of sex difference: chi-square test of independence; †‡ Ascertained when the BCS70 participant was age 5/16y; †§ With value from birth if missing at age 5y; with values from age 10 if missing at age 16y.

Table 3.1.6: Distribution of adulthood SEP indicators by sex in the BCS70 sample with complete grip strength and/or balance measurements.

Factors	Observed N	N(%)* Women N=3,944	Men N=3,699	*p-val*†
Own occupational class (30y)‡	6,271			< 0.001
I Professional/II Intermediate		1,339 (42.0)	1,437 (46.6)	
III Skilled Non-manual		1,202 (37.7)	401 (13.0)	
III Skilled Manual		237 (7.4)	907 (29.4)	
IV Partly skilled/V Unskilled		408 (12.8)	340 (11.0)	
Missing		758	614	
Own housing tenure (30y)	7,044			<0.001
Owned		2,509 (67.7)	2,143 (64.2)	
Renting		931 (25.1)	779 (23.4)	
Other (rent-free, squatting, etc.,)		268 (7.2)	414 (12.4)	
Missing		236	363	
Own highest qualification (46y)	7,537			<0.001
Degree and higher		1,059 (27.1)	924 (25.4)	
A-level and vocational		609 (15.6)	467 (12.8)	
GCSEs		1,254 (32.2)	1,120 (30.8)	
No qualification		980 (25.1)	1,126 (31.0)	
Missing		44	62	
Own occupational class (46y)	6,417			<0.001
I Professional/II Intermediate		1,413 (45.4)	1,617 (49.0)	
III Skilled Non-manual		1,001 (32.1)	469 (14.2)	
III Skilled Manual		327 (10.5)	959 (29.0)	
IV Partly skilled/V Unskilled		374 (12.0)	257 (7.8)	
Missing		829	397	
Own weekly income after tax (46y)	7,007			<0.001
£2,000 and above		146 (4.1)	208 (6.1)	
£1,750 to £1,999		67 (1.9)	74 (2.2)	
£1,500 to £1,749		132 (3.7)	151 (4.4)	
£1,250 to £1,499		201 (5.6)	214 (6.2)	

Factors	Observed N	N(%)* Women N=3,944	Men N=3,699	*p-val*†
£1,000 to £1,249		351 (9.8)	394 (11.5)	
£750 to £999		644 (18.0)	638 (18.6)	
£500 to £749		744 (20.8)	702 (20.5)	
£200 to £499		865 (24.2)	645 (18.8)	
£100 to £199		202 (5.6)	173 (5.0)	
£50 to £99		106 (3.0)	97 (2.8)	
Below £50		123 (3.4)	130 (3.8)	
Missing		363	273	
Own housing tenure (46y)	7,044			<0.001
Owned		2,989 (76.3)	2,830 (77.1)	
Renting		802 (20.5)	660 (18.0)	
Other (Rent-free, squatting, etc.,)		127 (3.2)	180 (4.9)	
Missing		603	976	
Occupational class mobility (from age 5 to 46yrs) 3 category[b]	6,064			<0.001
High-High		615 (19.9)	521 (17.5)	
High-Medium		297 (9.6)	298 (10.0)	
High-Low		38 (1.2)	59 (2.0)	
Medium-High		747 (24.2)	641 (21.6)	
Medium-Medium		782 (25.3)	731 (24.6)	
Medium-Low		148 (4.8)	206 (6.9)	
Low-High		153 (4.9)	187 (6.3)	
Low-Medium		253 (8.2)	239 (8.0)	
Low-Low		59 (1.9)	90 (3.0)	
Missing		363	273	
Occupational class mobility (from age 5 to 46yrs) 2 category[c]	6,064			<0.001
High-High		1,006 (32.5)	1,005 (33.8)	
High-Low		292 (9.4)	199 (6.7)	
Low-High		941 (30.4)	1,299 (43.7)	
Low-Low		853 (27.6)	469 (15.8)	

Factors	Observed N	N(%)* Women N=3,944	Men N=3,699	p-val†
Missing		603	976	

* Maximum N, though N varies due to missing data on each SEP indicator; † Statistical tests of sex difference: chi-square test of independence; ‡ With values from age 26 if missing at age 30y; [b] High category includes those in class I or II; Medium category includes those in class III NM and III M; Low category includes those in class IV or V; [c] High category includes those in class I or II and III NM; Low category includes those in class III M and IV or V.

Table 3.1.7: Cross-tabulation of occupational class in childhood and adulthood in the BCS70 sample with complete grip strength and/or balance measurements.

	Own occupational class (46yrs)†			
Factors	Low	Medium	High	Total
Father's occupational class (5yr) †				
Women (N=2,972)				
Low	90 (17.4%)	239 (46.3%)	187 (36.2%)	516 (100%)
Medium	206 (13.1%)	731 (46.3%)	641 (40.6%)	1,578 (100%)
High	59 (6.7%)	298 (33.9%)	521 (59.3%)	878 (100%)
Men (N=3,092)				
Low	59 (12.7%)	253 (54.4%)	153 (32.9%)	465 (100%)
Medium	148 (8.8%)	782 (46.6%)	747 (44.5%)	1,677 (100%)
High	38 (4.0%)	297 (31.3%)	615 (64.7%)	950 (100%)

* Maximum N, though N varies due to missing data on each SEP indicator. There were 6,780 participants who had complete data for father's and own occupational class; †; High category includes those in class I or II; Medium category includes those in class III NM and III M; Low category includes those in class IV or V.

3.1.7.4 Description of covariates

Tables 3.1.8 and 3.1.9 describe the childhood and adulthood factors used for analyses within the BCS70. On average, males had a greater mean birth weight than females, while females had a slightly higher mean BMI at age ten years than males. Males were taller and had a higher BMI at age ten years than females ($p<0.001$) (Table 3.1.9). More than 50% of the BCS70 population had no health conditions at age ten. Additionally, at age ten years, females were more likely to have a better reading score than males ($p<0.001$), while males were more likely than females to have poor coordination ($p<0.017$). Males were also more likely to watch TV and play sports in their spare time at age ten years than females ($p<0.001$) (Table 3.1.8).

In adulthood, most men and women were healthy, with 78% presenting with no morbidity. Men performed better in the vocabulary test at age 42 years than women ($p<0.001$). At age 42 years, men were more likely to spend more than five hours a day watching TV, smoke, and have a higher weekly physical activity level than women ($p<0.001$). Men were also more likely to have higher occupational activity levels at age 46 years; they were also more likely to do occupations that involved heavy manual work than women (9% vs 1%).

Table 3.1.8: Distribution of the childhood and adolescent covariates by sex in the BCS70 sample with complete grip strength and/or balance measurements.

Factors	Observed N	N(%)[†] Women N=3,944	Men N=3,699	*p-val*[‡]
Birth weight, *kg*	7,069			<0.001
Mean (SD)		3.26 (0.50)	3.37 (0.53)	
Missing		262	312	
BMI (*kg/m²*) (10y)	6,037			0.028
Mean (SD)		16.93 (2.20)	16.73 (1.90))	
Missing		803	803	
Leisure-time physical activity (10y)	6,630			<0.001

Factors	Observed N	N(%)† Women N=3,944	Men N=3,699	*p-val*‡
Often		1,401 (40.9)	2,130 (66.4)	
Sometimes		1,658 (48.4)	918 (28.6)	
Never or hardly ever		365 (10.7)	158 (4.9)	
Missing		524	489	
Watching TV in spare time (10y)	6,648			<0.001
Often		2,574 (74.8)	2,671 (83.3)	
Sometimes		818 (23.8)	510 (15.9)	
Never or hardly ever		449 (1.4)	26 (0.8)	
Missing		507	488	
Disability (10y)	6,629			0.060
No		3,226 (93.8)	2,943 (92.3)	
Yes, slight		196 (5.7)	227 (7.1)	
Yes, severe		19 (0.6)	18 (0.6)	
Missing		507	507	
Number of health conditions (10y)	5,839			0.017
No condition		1,723 (56.9)	1,502 (53.4)	
1 conditions		788 (26.0)	750 (26.7)	
2 conditions		372 (12.3)	410 (14.6)	
3+ conditions		144 (4.8)	150 (5.3)	
Missing		917	887	
Standardised Edinburgh Reading Test (10y)	5,654			<0.001
Mean (SD)		0.07 (0.95)	-0.05 (0.99)	
Missing		992	997	
Coordination (10y)	6,392			0.017
Normal limb coordination		3,033 (91.5)	2,561 (83.2)	
Questionably clumsy		192 (5.8)	311 (10.1)	
Mildly clumsy		75 (2.3)	172 (5.6)	
Moderate/markedly clumsy		15 (0.5)	33 (1.1)	
Missing		629	622	

* Participants unable to complete the grip strength and standing balance tests for health reasons were included; † Maximum N, though N varies due to missing data on each factor; ‡ Statistical tests of sex difference; chi-square test of independence.

Table 3.1.9: Distribution of the adulthood covariates by sex in the BCS70 sample with complete grip strength and/or balance measurements.

Factors	Observed N	N(%)† Women N=3,944	N(%)† Men N=3,699	*p-val*‡
Height (*cm*) (46y	7,639			<0.001
Mean (SD)		163.70 (6.33)	176.80 (6.88)	
Missing		1	3	
BMI (*kg*/*m*2) (46y)	7,603			<0.001
Mean (SD)		28.24 (6.19)	28.64 (4.63)	
Missing		27	13	
Number of health conditions (42y)	7,137			0.200
No condition		2,904 (78.0)	2,667 (78.1)	
1 conditions		700 (18.8)	640 (18.7)	
2 conditions		95 (2.6)	98 (2.9)	
3+ conditions		23 (0.6)	10 (0.3)	
Missing		222	284	
Applied Psychology Unit	6,906			<0.001
Vocabulary test (42y) // 0 - 5 words		124 (3.4)	114 (3.5)	
6 - 10 words		736 (20.4)	591 (17.9)	
11 - 15 words		1,852 (51.4)	1,631 (49.4)	
16 - 20 words		890 (24.7)	968 (29.3)	
Missing		342	395	
Smoking status (42y)	7,134			0.005
Never smoker		1,785 (48.0)	1,592 (46.6)	
Ex-smoker		1,114 (29.9)	967 (28.3)	
Current smoker (less than daily)		211 (5.7)	183 (5.4)	
Current smoker (daily)		611 (16.4)	671 (19.7)	
Missing		223	286	
Watching TV in the week (42y)	6,387			<0.001
0 to <1 hour		624 (18.4)	447 (15.0)	
1 to <3 hours		1,988 (58.5)	1,792 (60.0)	
3 to <5 hours		624 (18.4)	555 (18.6)	

Factors	Observed N	N(%)† Women N=3,944	Men N=3,699	*p-val*‡
5+ hours		164 (4.8)	193 (6.5)	
Missing		544	712	
Watching TV in the weekend (42y)	6,252			0.005
0 to <1 hour		243 (7.3)	177 (6.1)	
1 to <3 hours		1,656 (49.7)	1,380 (47.3)	
3 to <5 hours		1,049 (31.5)	959 (32.8)	
5+ hours		384 (11.5)	404 (13.8)	
Missing		612	779	
Physical activity (days/week) (42y)	7,031			<0.001
0 days		1,143 (31.2)	810 (24.1)	
1 day per a week		440 (12.0)	391 (11.6)	
2 days per a week		562 (15.3)	482 (14.3)	
3 days per a week		536 (14.6)	507 (15.1)	
4/5 days per a week		550 (15.0)	661 (19.6)	
6/7 days per a week		433 (11.8)	516 (15.3)	
Missing		280	332	
Occupational activity (46y)	6,304			<0.001
Sitting occupation		1,758 (55.7)	1,684 (53.5)	
Standing occupation		637 (20.2)	339 (10.8)	
Physical work		735 (23.3)	853 (27.1)	
Heavy manual work		28 (0.9)	270 (8.6)	
Missing		786	553	

* Participants unable to complete the grip strength and standing balance tests for health reasons were included; † Maximum N, though N varies due to missing data on each factor; ‡ Statistical tests of sex difference; chi-square test of independence; wilcoxon rank sum test.

3.2 UK Biobank

3.2.1 History of the cohort

Intended to be *'the world's biggest study [examining] the role of nature and nurture in health and disease'* (Wallace, 2005, p. 324), the UKB was established in 2006 in the UK by the *Wellcome Trust*, the MRC, and the *UK's Department of Health and Social Care* (Collins, 2012). The UKB aimed to capitalise on the knowledge gained from the *Human Genome Project*, which was also funded by the *Wellcome Trust* (Schuler et al., 1996), by investigating the role played by genes and lifestyle factors in the distribution and development of disease (Wallace, 2005). The UKB has data on approximately 500,000 participants aged between 37 and 69 at recruitment in 2006-2010, and has rich phenotypic and health-related data, including blood, urine, and saliva samples, imaging, and information on health, lifestyle, and environmental factors. After the initial wave, there were three subsequent waves of varying objectives and sample sizes. For example, in 2012, there was a first repeat assessment visit of around 20,000 participants; there was an imaging visit with 100,000 participants in 2014, and this was followed up with a repeat imaging visit of 10,000 participants in 2019 (UK Biobank, 2022). Additionally, data from the UKB datasets have also been linked with study member's *General Practice* and hospital records. These features of the UKB provide the opportunity to research the relationships and mechanisms between phenotypic, environmental, and lifestyle factors and health outcomes (Sudlow et al., 2015).

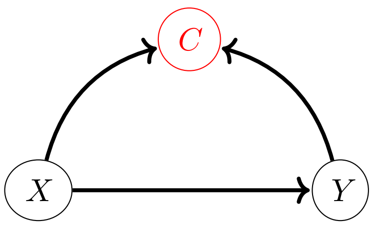
3.2.2 Strengths and limitations of the UKB

The UKB has a number of strengths that make it well-suited to address some of the key questions raised in this thesis. One of the key strengths of the UKB is its large sample size, which makes it sufficiently powered to detect the interactions between different drivers of inequalities in the associations between SEP and grip strength. This large sample size was initially based on statistical power calculations for nested case-control studies of any condition, with an odds ratio ranging between 1.3 and 1.5 for an association between any exposure in a 20-year follow-up period (Burton et al., 2009). The age range of 37 to 73 years for participants recruited is also a key strength of the work presented in this chapter. This age range allows for a detailed examination of how indicators of SEP are associated with grip strength across different age groups. With the youngest cohort members in their late 30s and the oldest in their late 60s, associations between SEP and grip strength can be examined across various age groups. An additional strength of the UKB is that it is slightly more ethnically diverse than the BCS70, making it possible to test whether associations vary by ethnicity.

Despite the UKB's strengths, there are some weaknesses. One of these is potential sampling issues. Initially, over 9 million individuals registered with the NHS received postal invites to join UKB. However, only 5% (approximately 500,000) of these invited participants joined (Allen et al., 2012). Analyses comparing population characteristics of responders and non-responders have shown that participants in UKB are more likely to be female, older, and live in socioeconomically affluent parts of the UK (Allen et al., 2012), suggesting potential selection bias. A study in 2020 shows that associations between several common risk factors and mortality related to cardiovascular disease, selected malignancies, and suicide in the UKB are similar to those from the *Health Survey for England and Scotland* (Batty et al., 2020); thus, the authors conclude that risk factor associations in the UKB are generalizable. However, a previous discussion on the topic suggests that the conclusion presented by Batty et al. (2020) does not reflect their results, as participation in the *Health Survey for England and Scotland* may also suffer from selection bias (Huang, 2021). Huang (2021) highlights that there was an association between obesity and a low risk of mortality related to cardiovascular disease in the *Health Survey for England and Scotland* (Batty et al., 2020), which is indicative of a collider bias, as those who are sicker and overweight are less likely to be part of the survey.

Visually depicted in Figure 3.2.1, collider bias is a type of selection bias that occurs when an exposure and an outcome independently contribute to causing a third variable (Munafo et al., 2018). It has been argued that the UKB may suffer from collider bias due to differential selection (Griffith et al., 2020). Participation in the study could be determined by various factors such as health, healthy behaviours, beliefs, psychology, income, education, etc., often considered as exposure and/or outcome. Associations may be biased, as men, individuals with lower SEP, poorer health outcomes, and minoritised ethnic groups are less likely to be represented (Richiardi et al., 2019). To minimise the impact of collider bias by design, given that it is common in most population-based studies, one should examine the plausibility of their findings, be mindful of assumptions and bias when interpreting these findings, and if data (i.e. population weights), resources and expertise exist, methodological approaches such as inverse-probability weighting could be used (Biele et al., 2019; Griffith et al., 2020; Munafo et al., 2018; Richiardi et al., 2019).

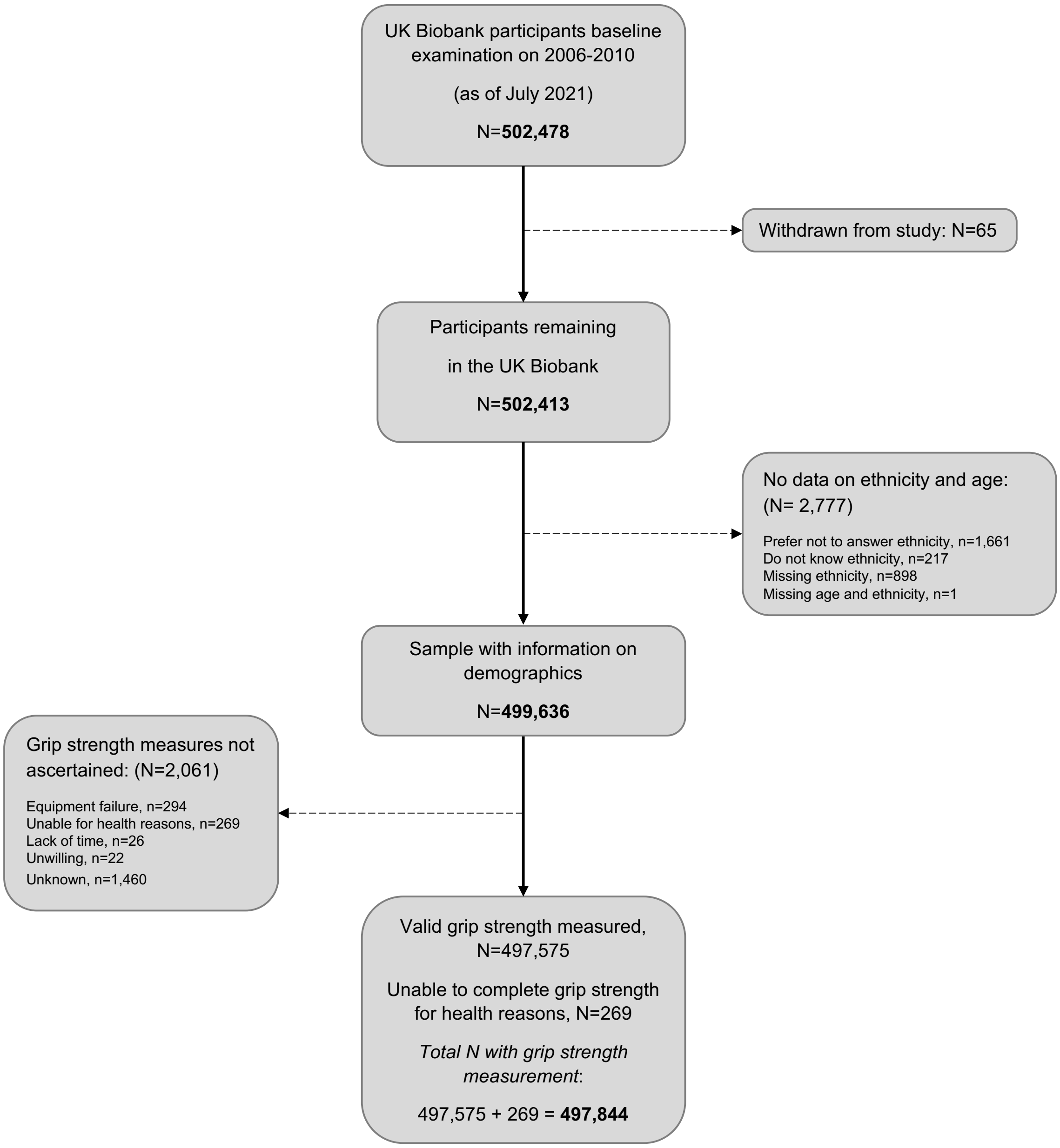
Figure 3.2.1: Graphic of a collider bias, with exposure X, collider C, and outcome Y



3.2.3 *Study participants*

Recruitment and baseline measurements for the UKB were carried out between 2006 and 2010. After responding to invitations sent through the NHS, participants attended one of the 22 assessment centres located across the UK (UK Biobank, 2006). Participants completed electronically signed consent forms and were asked a range of questions on socio-demographics, current health, and lifestyle through self-completed touchscreen questionnaires and a computer-assisted face-to-face interview with a study nurse (Sudlow et al., 2015; UK Biobank, 2006). Participants also completed a number of physical measures, such as grip strength, blood pressure, weight, lung function, and bone density, and had their blood, urine, and saliva collected (P. Elliott et al., 2008; Sudlow et al., 2015). Ethics approval for the UKB study was obtained from the *North-West Centre for Research Ethics* Committee (11/NW/0382), and all participants provided written informed consent to participate in the study. The Manchester Metropolitan University's ethics committee granted ethical approval for the use of the UKB data after we submitted an application detailing our research aims, objectives, and methodology of analyses (EthOS Reference Number: 32338). Furthermore, the UKB data used in this thesis were obtained through a formal application with a detailed protocol (application number 71242). In this thesis, data from the baseline assessment of the UKB is used. As of July 2021, there were 502,478 participants who completed the baseline assessment, and since then, 65 participants have withdrawn from the study, resulting in an overall sample of 502,413 participants (see Figure 3.2.2).

Figure 3.2.2: Flow diagram of the UKB study sample



3.2.4 Measurement of grip strength

Under the guidance and supervision of healthcare technicians and nurses, grip strength was assessed during the baseline measurement at the assessment centres. Grip strength was measured using the *Jamar J00105* hydraulic handheld dynamometer (UK Biobank, 2006). Staff members calibrated the dynamometer at the start of the day by measuring their own grip strength and ensuring that the needles moved in the correct direction based on the movement. Participants were seated in a chair with their resting arm placed on an armrest, and held the dynamometer in the testing hand with their elbow bent at a 90-degree angle, their forearm pointing forwards and their thumb upwards. Starting with their right arm, participants squeezed the dynamometer as hard as possible for three seconds. Once complete, measurements were recorded in kilograms. The grip strength measurement was then repeated on the left hand.

If participants were unable to complete the test for any given reason, such as being unwilling to do the measurement or due to health-related or equipment failure, these reasons were recorded. When collapsed, out of those who had grip strength measured either on their left or right, there were 269 participants who were unable to do grip strength for health reasons and 295 who were unable to do the measurement due to equipment failure. Similar to the approach used for grip strength in the BCS70 (Section 3.1.4), participants in the UKB unable to complete the grip strength assessment due to health reasons (n=269) were allocated a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution on the assumption that these participants were likely to have had low grip strength, and their exclusion may bias results (R. Cooper et al., 2014; Hurst et al., 2013) — see Figure 3.2.2. Sensitivity analyses were conducted to test this assumption and check the impact of including these participants on the findings.

3.2.5 Measurement of SEP

The selection of SEP indicators in the UKB was based on the types of SEP variables available and was guided by a scoping exercise conducted for the BCS70 cohort (Section 3.1.5). The indicators chosen for analysis were own education, own occupational class, and Index of Multiple Deprivation (IMD) at baseline. Participants determined their level of education through self-completing touchscreen questionnaires by answering the question, *'Which of the following qualifications do you have?'*. Education was then categorised into four categories, as previously done in literature (Guggenheim et al., 2015): Degree [College or University degree], A-levels, professional, or equivalent [A levels/AS levels; Other professional qualifications; NVQ, HND, HNC or equivalent], O-levels, CSEs, or equivalent [O levels/GCSEs; CSEs or equivalent], and No qualification.

Similarly, occupational status was recorded during the baseline assessment recruitment through self-completed touchscreen questionnaires. Individuals in employment were interviewed, and further details about their job, such as the name of their job industry and the tasks involved, were gathered. Based on this information, the interviewers manually coded the four-digit *Standard Occupational Classification* (SOC) code for each occupation, which includes over 350 commonly occurring jobs in the UK. The NS-SEC coding was derived using the SOC 2000 coding (Rose and Pevalin, 2005). The five-category version of NS-SEC coding was used to increase power within the occupational categories. These categories included Managerial and professional occupations, Intermediate occupations, Small employers and owner account workers, Lower supervisory and technical occupations, and Semi-routine and routine occupations (Rose and Pevalin, 2005).

To measure material deprivation, the IMD index was utilised. This index is widely used and is composed of four indicators that assess area-level deprivation, including income, health, education, and crime (L. Jones, 2014; Office for National Statistics, 2012; Payne and Abel, 2012; UK Ministry of Housing, Communities and Local Government, 2015). Participants were assigned values based on their postcode at the time of recruitment, with higher values indicating a higher level of deprivation. These values were categorised into five quantiles. As the IMD is calculated differently in England, Scotland, and Wales, participants were given nation-specific quantiles. For example, participants from Wales were categorised based on their position within the IMD distribution relative to all other participants from Wales (L. Jones, 2014). This was performed for all three nations, resulting in the combination of their quantiles into a single variable.

3.2.6 Measurement of covariates

3.2.6.1 Demographic

Sex, age, and ethnicity were the key demographic variables. To examine associations at earlier ages, six categories were used for age: below 45, 45 to below 50, 50 to below 55, 55 to below 60, 60 to below 65, and 65 and above. For ethnicity, the main categorisation was based on existing groupings from the literature, in which sample sizes were sufficiently large enough (Mathur et al., 2021). These categorisations were: White [White, British, Irish, or any other white background], South Asian [Asian or Asian British, Indian, Pakistani, Bangladeshi, or any other Asian background], Black [African, Caribbean, Black or Black British, or any other Black background], Mixed [Mixed, White and Black Caribbean, White and Black African, White and Asian, or any other mixed background], and Other [Chinese, or any other ethnic group].

3.2.6.2 Anthropometric factors

The anthropometric factors selected were height, waist-to-hip ratio, and body fat percentage. As discussed in Section 3.1.6.1, height is important for grip strength, as taller participants have stronger grips (Dodds et al., 2012). Additionally, body fat percentage is a good measure of obesity, and waist-to-hip ratio is a useful indicator of body fat distribution — whether fat is subcutaneous (under the skin) or visceral or abdominal (around the internal organs) (Egger, 1992; Ibrahim, 2010; Pouliot et al., 1994). While BMI is easy to measure, it does not account for body weight related to muscle mass (Willett et al., 1999), and body fat percentage has been suggested as a better measure of obesity (Prentice and Jebb, 2001).

Standing height was measured using a *Seca 202* device, while hip and waist circumference were measured using a tape measure (UK Biobank, 2006). Staff read the measurements and manually entered them into the computer, which automatically flagged up impossible or implausible values. One participant with a recorded height of 70cm, which was 9.28 SD from the mean, had their height coded as missing. Waist-to-hip ratio was calculated by dividing the waist measurement by the hip measurement. Body fat percentage was measured using a bio-impedance device (*Tanita BC-418MA* body composition analyser (Jebb et al., 2000; UK

Biobank, 2006)). These devices are easy to use and are widely adopted in clinical and population health research (Ellis, 2000); they send a weak electrical signal through the body, and the voltage is measured so that the resistance of the signal by the tissue is calculated, this is possible given that the body is mostly made from water.

3.2.6.3 Health and behavioural factors

Co-morbidities, smoking status, sedentary behaviour, leisure-time physical activity, and occupational activity were all included as additional factors. Co-morbidity was determined by a composite variable that indicated the total number of conditions each participant presented with during baseline. Through self-completed touch-screen questions, participants were asked if a doctor had ever told them that they had any number of the following conditions: heart attack, angina, stroke, high blood pressure, blood clot in the leg, blood clot in the lung, emphysema/chronic bronchitis, asthma, diabetes, cancer or any other serious medical conditions. This variable was categorised as no condition, one condition, two conditions, and three or more conditions. Participants also declared their smoking status through self-report and were classed as never-smokers, former smokers, and current smokers.

To determine sedentary behaviour, participants were asked to report the hours spent using a computer or watching TV on a typical day. If they were unsure, as their time varied considerably, they were asked to report the average time using a computer or watching TV for a 24-hour day in the last four weeks. For physical activity, participants were asked how many days in a typical week they did 10 minutes or more of vigorous activities that made them sweat or breathe hard, such as fast cycling, aerobics, and heavy lifting. Additionally, information on occupational activity was captured as participants were asked if their job *'involves heavy manual or physical work'* or *'involves mainly walking or standing'*. This was categorised as always, usually, sometimes, and rarely. As previously done by (Pearce et al., 2021)., both the manual work and standing/walking variables were collapsed into a single variable with six mutually exclusive categories: a) no manual, no standing/walking; b) no manual, some standing/walking; b) no manual, mostly standing/walking; c) some manual, some standing/walking; d) some manual, mostly standing/walking; e) mostly manual, mostly standing/walking (Pearce et al., 2021).

3.2.7 *Descriptive analyses of the UKB*

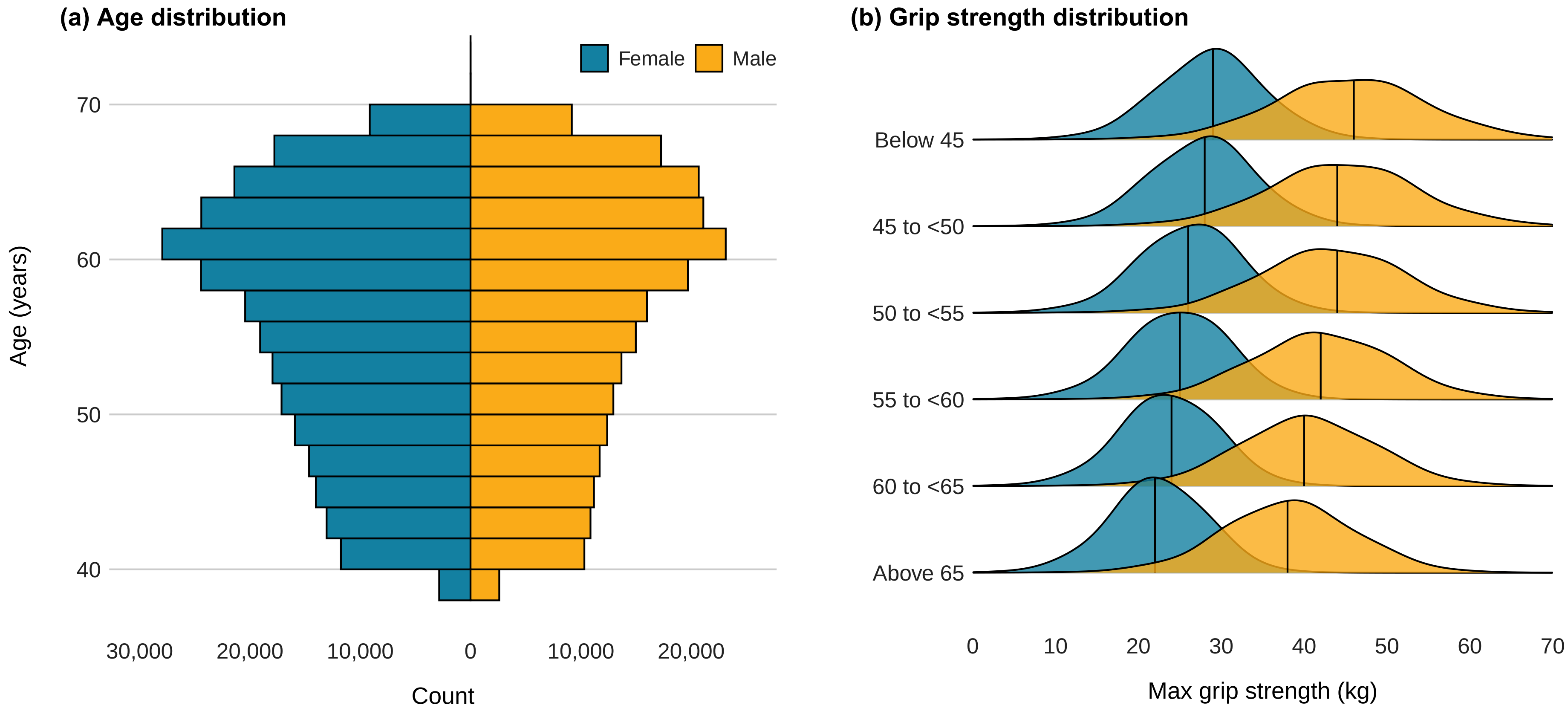
3.2.7.1 Derivation of analytical sample

As shown in Figure 3.2.2, after removing the 65 participants who withdrew from the study, there were 502,413 remaining participants. Furthermore, 2,777 participants without information on demographics (2,776 without information on ethnicity and one without information on age and ethnicity) were unable to be included in analyses, resulting in a sample of 499,636 participants with information on demographics. Of these participants, 2,061 did not have grip strength measurements. While the reason for not having grip strength was missing for 1,460 participants, 294 participants were unable to complete the grip strength measurement due to equipment failure, and 269 participants were unable to do so for health reasons; the most common reason being arthritis (N=111) (Table 3.2.1). After assigning a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution for the 269 participants who were unable to complete the grip strength assessment due to health reasons (as discussed in Section 3.2.4), the analytic sample that could be included in analyses of grip strength and had information on demographics was 497,844.

3.2.7.2 Description of demographics

Within the UKB analytic sample, there were more women than men, with 271,122 women (54%) and 226,722 men (46%). A total of 43% of the cohort was over 60 years of age. Figure 3.2.3a shows the age distribution of men and women in UKB at baseline. Participants were predominantly white (95%), with a small percentage of individuals from other ethnic groups, such as South Asian (2.0%) and Black (1.7%) — as can be seen in Table 3.2.3.

Figure 3.2.3: Age and grip strength distribution of men and women in the UKB at baseline(N=497,844). In the age distribution, each band represents a two-year interval, while the black line in the grip strength distribution represents the mean.



3.2.7.3 Description of outcomes

As can be seen in Table 3.2.2, the mean grip strength for women in the UKB was 25.1kg (SD: 6.41), and for men, it was 41.7kg (SD: 9.03). Illustrated in Figure 3.2.3b, the distribution of grip strength varied by age and sex. Men were stronger than women in all age groups, and grip strength decreased with age in both sexes. For example, men under 45 years of age had a mean grip strength of 45.5kg (SD: 9.46). For women, this was 28.7kg (SD: 6.37). However, for those aged 65 and above, men had a mean grip strength of 38.1kg (SD: 8.05), and women had a mean grip strength of 22.3kg (SD: 5.79).

Table 3.2.1: Description of participants unable to complete grip strength in the UKB.

Reasons unable to complete grip strength	N (%)
Reason not recorded	1,450
Equipment failure	294
Unable for health reasons[a]	269
Due to arthritis	111 (41.2)
Due to other health reason	81(30.7)
Due to stroke/weakness/paralysis	26 (9.7)
Due to limb injury	25 (9.3)
Due to recent surgery	17 (6.3)
Due to being amputee	5 (1.9)
Feeling unwell	4 (1.5)
Lack of time	26
Unwilling	22

[a] Specific health reasons presented as the proportion out of the total sample unable to grip strength measurement for health reason (N=269)

3.2.7.4 Socioeconomic characteristics

As shown in Table 3.2.3, a third of UKB participants had a degree (33%), with slightly more men than women having one (34.2% vs 31.5%). There was generally an even distribution of participants across different IMD quantiles. A large proportion

Table 3.2.2: Distribution of grip strength by sex in the UKB sample with complete grip strength measurement.

Outcomes	N	Women	Men	*p-val*†
Grip strength (kg)	497,575			<0.001
N		270,935	226,640	
Mean (SD)		25.1 (6.41)	41.7 (9.03)	
Range (min, max)		1, 89	1, 90	
Grip strength (kg)‡ (including imputed values for n=269)‡	497,844			<0.001
N		271,122	226,722	
Mean (SD)		25.1 (6.41)	41.7 (9.03)	
Range (min, max)		1, 89	1, 90	

† Statistical tests of sex difference: t-test; ‡ Includes those unable to do grip strength for health reasons, N=269 (187 women & 82 men). These individuals were allocated grip strength values equivalent to the mean of the bottom sex-specific fifth.

of the UKB participants were either not working or had never worked (35%); this was higher for women (37%) than for men (32.4%). Among those who were working, a third of the employed participants were in Managerial/professional occupations (35%). In these roles, there were more men than women (39.2% vs 32.0%). Intermediate occupations were the second most common (12%), with more women than men in these roles (15.8% vs 7.2%).

Table 3.2.3: Distribution of demographic and socioeconomic factors by sex in the UKB sample with complete grip strength measurement.

Factors	N ‡	N(%)† Women N=271,122	Men N=226,722
Age group at baseline (years)	497,844		
Below 45		27,553 (10.2)	23,693 (10.5)
45 to <50		36,500 (13.5)	28,898 (12.7)
50 to <55		42,908 (15.8)	32,714 (14.4)
55 to <60		50,361 (18.6)	39,684 (17.5)
60 to <65		65,605 (24.2)	54,835 (24.2)
Above 65		48,195 (17.8)	46,898 (20.7)
Ethnicity	497,844		
White		256,636 (94.7)	214,541 (94.6)
South Asian		4,527 (1.7)	5,221 (2.3)
Black		4,582 (1.7)	3,355 (1.5)
Mixed		1,841 (0.7)	1,099 (0.5)
Other		3,536 (1.3)	2,506 (1.1)
Highest educational qualification	489,969		
Degree		84,204 (31.5)	76,217 (34.2)
A-levels, professional, or equivalent		59,551 (22.3)	53,747 (24.1)
O-levels, CSEs, or equivalent		77,444 (29.0)	54,099 (24.3)
No qualification		45,704 (17.1)	39,003 (17.5)
Missing		4,219	3,656
IMD (quantiles)	485,244		
1 (most affluent)		53,539 (20.2)	44,018 (19.9)
2		53,632 (20.3)	43,661 (19.8)
3		53,443 (20.2)	43,607 (19.8)
4		53,126 (20.1)	43,779 (19.8)
5 (least affluent)		50,756 (19.2)	45,683 (20.7)
Missing		6,626	5,974
Occupational class (NS-SEC)	497,844		
Managerial/professional occupations		86,643 (32.0)	88,778 (39.2)
Intermediate occupations		42,928 (15.8)	16,355 (7.2)

Factors	N ‡	N(%)† Women N=271,122	Men N=226,722
Small employers & owner account workers		5,924 (2.2)	10,948 (4.8)
Lower supervisory & technical occupations		1,210 (0.4)	12,354 (5.4)
Semi-routine/routine occupations		32,637 (12.0)	24,889 (11.0)
Never worked/unemployed		101,780 (37.5)	73,398 (32.4)

† Maximum N, though N varies due to missing data on some covariates; ‡ Includes those unable to do grip strength for health reasons N=269 (187 women & 82 men). These individuals were allocated grip strength values equivalent to the mean of the bottom sex-specific fifth.

3.2.7.5 Description of covariates

Table 3.2.4presents the covariates used in the UKB. On average, men were taller, had a larger waist and hip circumference, a bigger waist-to-hip ratio, and a lower body fat percentage than women (t-test: $p<0.001$). Half of the UKB cohort had no co-morbidity, while 31% presented with one condition. More men than women had two or more conditions (24% vs 17%). More than half of the UKB participants had never smoked (55%), while more men than women were previous smokers (31.5% vs 38.5%) and current smokers (8.9% vs 12.5%). For sedentary behaviour, the most represented category was two hours a day watching TV or on a computer (23%). On average, men were more likely than women to be sedentary for six or more hours a day (20.3% vs 14.5%).

Additionally, over a third of the UKB participants were more likely to have done no vigorous physical activity for ten or more minutes a day in a typical week (38%). Women were more likely than men to not do vigorous physical activity for at least 10 minutes (40.4% vs 34.1%), and men were more likely than women to do vigorous physical activity more than four times a week for at least 10 minutes (22.9% vs 15.4%). Among those who worked, participants were more likely to never or rarely do work that involved no manual, no standing/walking. On average, men were more likely than women to do jobs that were mostly manual, mostly standing/walking (11.0% vs 5.9%).

Table 3.2.4: Distribution of covariates by sex in the UKB sample with complete grip strength measurement.

Factors	N ‡	N(%)† Women N=271,122	Men N=226,722
Height (cm)	497,100		
Mean (SD)		162 (6.3)	176 (6.8)
Missing		281	463
Waist circumference (cm)	497,466		
Mean (SD)		85 (12.6)	97 (11.4)
Missing		216	162
Hip circumference (cm)	497,411		
Mean (SD)		103 (10.4)	103 (7.6)
Missing		235	198
Waist-to-Hip Ratio	497,365		
Mean (SD)		0.82 (0.07)	0.94 (0.07)
Missing		259	220
Body fat percentage (%)	489,329		
Mean (SD)		37 (6.9)	25 (5.8)
Missing		4,205	4,310
Co-morbidity§	481,935		
No condition		132,832 (50.7)	99,800 (45.3)
1 condition		81,920 (31.3)	67,025 (30.4)
2 conditions		35,082 (13.4)	37,741 (17.1)
3+ conditions		11,985 (4.6)	15,550 (7.1)
Missing		9,303	6,606
Smoking status	495,949		
Never		161,022 (59.6)	110,626 (49.0)
Previous		84,969 (31.5)	86,931 (38.5)
Current		24,137 (8.9)	28,264 (12.5)
Missing		994	901
Sedentariness	486,595		
1hr or less a day		29,795 (11.3)	18,263 (8.2)

Factors	N ‡	N(%)† Women N=271,122	Men N=226,722
2hrs a day		52,403 (19.9)	36,462 (16.4)
3hrs a day		60,576 (23.0)	47,590 (21.4)
4hrs a day		51,187 (19.4)	44,592 (20.0)
5hrs a day		31,462 (11.9)	30,637 (13.7)
6hrs or more a day		38,329 (14.5)	45,299 (20.3)
Missing		7,370	3,879
Vigorous physical activity (10min+)	471,688		
None		103,099 (40.4)	73,825 (34.1)
1 day a week		36,825 (14.4)	29,619 (13.7)
2 days a week		40,793 (16.0)	33,771 (15.6)
3 days a week		35,256 (13.8)	29,631 (13.7)
4+ days a week		39,297 (15.4)	49,572 (22.9)
Missing		15,852	10,304
Occupational activity	459,599		
No manual, No standing/walking		54,723 (22%)	45,490 (22%)
No manual, Some standing/walking		33,044 (13%)	29,429 (14%)
No manual, Mostly standing/walking		17,467 (7.0%)	9,524 (4.5%)
Some manual, Some standing/walking		9,671 (3.9%)	12,158 (5.8%)
Some manual, Mostly standing/walking		18,365 (7.4%)	16,650 (7.9%)
Mostly manual, Mostly standing/walking		14,609 (5.9%)	23,291 (11%)
Never worked/unemployed		101,780 (41%)	73,398 (35%)
Missing		21,463	16,782

† Maximum N, though N varies due to missing data on some covariates; ‡ Includes those unable to do grip strength for health reasons N=269 (187 women & 82 men). These individuals were allocated grip strength values equivalent to the mean of the bottom sex-specific fifth; § *Conditions include heart attack, angina, stroke, high blood pressure, blood clot in leg, blood clot in lung, emphysema/chronic bronchitis, asthma, diabetes, cancer or any other serious medical conditions.

3.3 Summary

In this chapter, the origins, strengths, and limitations of the BCS70 and UKB were discussed, and the study outcomes, indicators of SEP, and covariates used in the analyses were presented. The subsequent three chapters will use the data described in this chapter. In Chapter 4, findings from analyses of the associations between childhood, adolescent, and adulthood SEP and grip strength in midlife using data from the BCS70 will be presented. Chapter 5 presents findings from analyses of the associations between childhood and adulthood SEP and standing balance performance in midlife using data from the BCS70. Chapter 6 presents findings from analyses that investigate age, sex, and ethnic differences in the associations between adult socio-economic position and grip strength using data from UKB.

CHAPTER 4

Socioeconomic position across life and grip strength at age 46

The aim of this chapter was to investigate the associations between childhood, adolescent and adulthood SEP and grip strength in midlife. The analyses presented in this chapter use the BCS70 dataset. This work builds on the literature review presented in Chapter 2, describing associations between childhood SEP and musculoskeletal health and function indicators, particularly grip strength.

4.1 Introduction

Maintaining good musculoskeletal health is a key component of healthy ageing, and muscle strength is fundamental to this. Muscle weakness, commonly indicated by low grip strength (Roberts et al., 2011), is associated with mobility disability, loss of independence, premature mortality and many other adverse health outcomes (Celis-Morales et al., 2018; R. Cooper et al., 2011b; R. Cooper et al., 2010; McLean et al., 2014; Ouden et al., 2011; Parra-Soto et al., 2022). Muscle weakness is also a key criterion for important age-related conditions, including sarcopenia and frailty (Cruz-Jentoft et al., 2019; Fried et al., 2001). These age-related conditions, which are highly prevalent (Collard et al., 2012; Mayhew et al., 2019), have profound implications for individuals, their families and society. In addition, estimates of the annual healthcare costs associated with muscle weakness and sarcopenia are substantial and likely to increase as populations age globally (Norman and Otten, 2019; Pinedo-Villanueva et al., 2019). To address the public health challenge that muscle weakness represents, there is a need to identify strategies that improve people's chances of developing optimal strength in early life, maintaining strength through midlife and minimising future declines in later life. This requires a better understanding of the risk factors across life that are associated with grip strength at different life stages.

4.1.1 *Existing studies*

Over the last two decades, a growing body of evidence has shown that differences in levels of grip strength in later life may originate in early life (Sayer et al., 2004; Shaw et al., 2017). This has resulted in many investigations into the associations of various childhood factors with grip strength in adulthood, including indicators of SEP (Birnie et al., 2011a; Strand et al., 2011a). However, despite a systematic review published in 2011 that synthesised data from 12 studies that had examined the association between childhood SEP and adult grip strength (Birnie et al., 2011a) (described in detail in Chapter 2, Section 2.1.1), and several subsequent investigations (Cheval et al., 2018; Cheval et al., 2019; Hurst et al., 2013; Kuh et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Starr and Deary, 2011; Strand et al., 2011a; Weinstein, 2016) (Chapter 2, Section 2.2), evidence of an association between lower childhood SEP and weaker grip strength in adulthood remains equivocal. The authors of the systematic review reported considerable heterogeneity between studies (Birnie et al., 2011a). This may be due to variations in the scale and direction of associations between childhood SEP and grip strength by age, sex, birth cohort, and/or place.

4.1.2 *Studies of older populations*

To identify differences in association by age, ideally, studies that have assessed grip strength at different life stages are required. However, as highlighted with reference to the Birnie et al. (2011a) systematic review, most existing studies of childhood SEP and grip strength have focused on adults aged 60 years and over (Birnie et al., 2011a; Cheval et al., 2018; Cheval et al., 2019; Hurst et al., 2013; Kuh et al., 2019; N. Smith et al., 2019; Starr and Deary, 2011; Weinstein, 2016).

Therefore, it remains difficult to establish how associations vary across adulthood. For example, participants examined by Hurst et al. (2013) were aged 60–64 years, while participants studied by N. Smith et al. (2019) and Cheval et al. (2018) were aged between 52–99 years and aged 50–96 years, respectively (see Appendix Table A.2.1 for a complete summary of the reviewed studies). In addition, even where existing studies have examined populations spanning a wider age range, including younger adults (Cheval et al., 2018; Cheval et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Weinstein, 2016), interactions between age and SEP have rarely been formally tested, apart from one study which assessed the interactions between SEP and age (Carney and Benzeval, 2018). This study used data from the UKHLS with participants aged 16 to 99 years and found an association between lower maternal education, lower income, and weaker grip, except for own education for men, where lower own education was associated with stronger grip strength; this relationship changes direction at older age (Carney and Benzeval, 2018).

4.1.3 Direction of associations

Where associations were found between lower childhood SEP and weaker grip strength in older adults, it was not possible to establish whether these were explained by the influences of SEP in early life on the attainment of peak grip strength or its subsequent decline. More studies of younger adults closer to peak grip strength are required to establish this. The only study on younger adults included in the systematic review (Birnie et al., 2011a) found lower childhood SEP was associated with a stronger grip in Swedish males at age 18 years (Silventoinen et al., 2009). This is in the opposite direction to the association reported in some studies of older adults. Similarly, as discussed above, findings from Carney and Benzeval (2018) show associations between lower maternal education and weaker grip strength in men reduced with age, while lower own education was associated with stronger grip strength in earlier adulthood, but associations were in the opposite direction at older ages. These findings highlight that childhood SEP may have different patterns of association with grip strength at different life stages. This is particularly important as knowing when on the life course functional trajectory early life SEP is primarily acting could help inform strategies to promote the development and maintenance of high levels of grip strength in mid-adulthood before the onset of major age-related declines in later adulthood.

4.1.4 *Cohort effect*

As most existing studies of the association between childhood SEP and grip strength focused on older adults, they included adults born before 1950 (Birnie et al., 2011a; Cheval et al., 2018; Cheval et al., 2019; Hurst et al., 2013; Kuh et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Starr and Deary, 2011; Strand et al., 2011a; Weinstein, 2016). Examples of these cohorts include the NSHD (born in 1946), Lothian Birth Cohorts (born in 1921 and 1936), Health and Retirement Study (born in 1931–41) and Aberdeen Birth Cohort (born in 1921 and 1936) (Birnie et al., 2011a). Whether similar associations exist in more recently born generations exposed to different social, political and economic environments across life remains to be established (Strand et al., 2019).

4.1.5 *Sex-differences*

Although evidence suggests that some health impacts of SEP may vary by sex (Backholer et al., 2017; Russell et al., 2018), and Birnie et al. (2011a), and sex differences may be a potential source of variation between studies, few existing studies have interrogated possible sex differences in this association. This warrants further investigation, especially as women live longer than men but with poorer musculoskeletal health and health in general (R. Cooper et al., 2011a; E. Gordon et al., 2017).

4.2 Chapter aims and research questions

The analyses presented in this chapter address the need for studies of the association between SEP and grip strength in younger adults. Below are the chapter's aims and questions. The literature examined in this chapter focuses on childhood and adolescent SEP, considered the most distal indicator of SEP but the analyses also include the associations between adulthood SEP and standing balance performance. Studying the role of SEP across life on grip strength is vital given that SEP, such as material resources, opportunities and education capital, track across the life course and that the continuity of SEP from childhood to adulthood has previously been shown to explain the association between childhood SEP and grip strength in adulthood (Birnie et al., 2011a).

It was hypothesised that lower SEP in childhood, adolescence and adulthood would be associated with weaker grip strength at age 46 years in the BCS70 for women. However, as lower adulthood SEP was associated with stronger grip strength in the UKHLS at middle age (Carney and Benzeval, 2018), it was hypothesised that in the BCS70, men of lower SEP in childhood, adolescence and adulthood would have a stronger grip than men of higher SEP. These associations were also hypothesised to be explained by several important covariates, particularly weight and height in adulthood (Strand et al., 2011a). It was also hypothesised that social mobility would play an important role in the associations observed. To investigate these hypotheses, the following research questions were asked:

1. Are there associations between indicators of childhood, adolescent and adulthood SEP and grip strength at age 46 years in the BCS70, and do they vary by sex?
2. If there are associations in Question 1, is there evidence of a cumulative association?
3. Do important factors across life, including obesity, smoking, and occupational activity, mediate these associations (Question 1)?

4.3 Methods

4.3.1 Variables used in analyses

This chapter uses data from the BCS70, described in Chapter 3. The analytical sample included the 7,617 men and women with complete grip strength measurements at age 46 years. The main outcome was maximum grip strength at age 46 years. The childhood and adolescent explanatory variables used in this chapter were, father's occupational class and parental highest qualification at age five and father's occupational class at age sixteen years. The adulthood explanatory variables used were the highest qualification at age 46 years and own occupational class at ages 30 and 46 years. Covariates included: birth weight (kg) and the following variables assessed at age ten years: BMI; leisure-time physical activity;

sedentary behaviour; disability. Additionally, BMI at age 46 years; self-reported smoking status at age 42; sedentary behaviour at age 42; leisure-time physical activity at age 42; occupational activity at age 46 years. The measurement, categorisation and description of the outcome, explanatory variables and covariates were presented in Chapter 3 (Section 3.1.4 to 3.1.6).

4.3.2 Statistical analyses

4.3.2.1 Main associations

The associations between each SEP indicator and maximum grip strength at 46 years were tested using linear regression models. Initially, formal tests of interaction between sex and each SEP indicator were conducted. Where there was evidence of sex interaction (based on the cut-point $p<0.1$), subsequent models were stratified by sex. Linear trends were assessed using likelihood ratio tests. Covariates were added to the models sequentially. Initially, adult height was included. This is because height is strongly associated with grip strength (Kuh et al., 2005) and is often used to normalise grip strength in population-based studies (Spruit et al., 2013). Subsequently, included covariates were childhood factors and then adulthood factors. As well as running models with factors grouped, models with adjustment for each adulthood covariate separately were also performed. To take account of the continuity of SEP from childhood to adulthood, associations between childhood SEP indicators and grip strength were also adjusted for adulthood SEP at age 46.

4.3.2.2 Social mobility

To test the potential influence of social mobility from childhood to adulthood in explaining the associations between childhood, adolescent and adulthood SEP and grip strength, a secondary analysis was conducted. In this analysis, two variables, father's occupational class at age five years and own occupational class at age 46 years, were recoded as High, Medium and Low. Here, occupational classes I and II were coded as High, occupational classes III NM and III M were coded as Medium, and occupational classes IV and V were coded as Low. Subsequently, a variable which cross-tabulated these three categories in the two occupational variables (father's occupational class at age five and own occupational class at age 46) was created. The pairs were High-High, High-Medium, High-Low, Medium-High, Medium-Medium, Medium-Low, Low-High, Low-Medium and Low-Low.

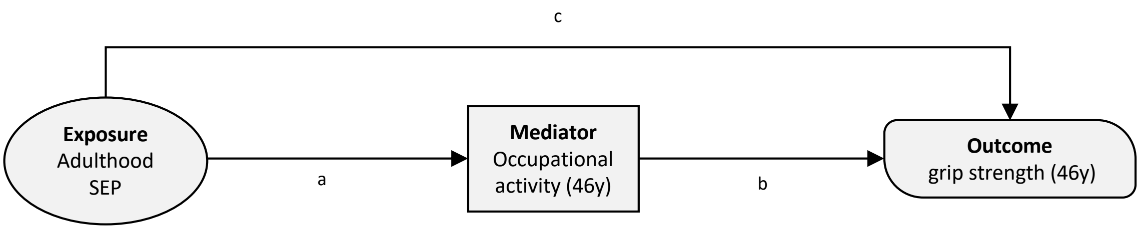
Further, where associations were linear, an additional categorisation for social mobility in women was included, and results using both categorisations were presented. For this, there was a binary recoding of father's occupational class at age five years, and own occupational class at age 46 years; the High category included those in class I or II and III NM, and the Low category included those in class III M and IV or V. The pairings for these two binary variables were High-High, High-Low, Low-High and Low-Low. A linear regression model, which examined the associations between change and stability in occupational class from childhood and adulthood with grip strength, was conducted. Here, the High-High category was used as the reference group.

4.3.2.3 Mediation analysis

To interrogate the extent to which factors appear to play an important role in explaining the main associations in regression analyses, mediation analysis was conducted. This was done using *Structural Equation Modelling* (SEM), which is a powerful modelling framework that has a number of multivariate techniques from various disciplines integrated into it, such as measurement theory, regression, path analysis and latent variable analysis (Hayes, 2013). Like traditional regression methods, SEMs are based on linear statistical models (Hayes, 2013; Hoyle, 1995). Structural Equation Models are more flexible than traditional regression methods, as users can formally specify models that match closely to their hypothesis of interest (Bagozzi and Yi, 2012; Hoyle, 1995). They are also more advantageous than the traditional regression methods as they enable researchers to create unobserved latent constructs based on observed variables (i.e., the construct of adulthood SEP based on various indicators of SEP measured during adulthood) and allow them to incorporate these latent variables along with observed variables in their models (Bartholomew et al., 2011; Bollen, 2014)) (an approach that will be used in Chapter 5). Additionally, to determine and test model estimates, SEMs simultaneously solve multiple equations which relate to the various paths that have been specified (Hayes, 2013).

Figure 4.3.1 illustrates the mediation model used to simultaneously estimate the direct relationship between adulthood SEP and grip strength and the indirect effect through occupational activity. Here, direct pathway refers to the relationship between exposure and outcome, while the indirect pathway captures the relationship between exposure and outcome through an additional variable, the mediator. The total effect is the overall effect between exposure and outcome, captured through the direct and indirect pathways.

Figure 4.3.1: Pathway model to examine the mediating role of occupational activity on the association between adulthood SEP and grip strength in men.



Direct path (exposure-outcome): c
Indirect path (exposure-mediator-outcome): a * b
Total effect (direct path + indirect path): c + (a * b)
Proportion mediated: Indirect path / Total effect

SEMs were built using *Lavaan* (Rosseel et al., 2022) in R program (R Core Team, 2013). Initially, the mediating role of the variables that attenuate most of the associations between SEP and grip strength was examined. Subsequently, with occupational class I or II as the reference category, the mediating effect of occupational activity on the relationship between being a skilled manual worker and grip strength was further interrogated. Both models were adjusted for adult height. All observed variables were standardised prior to the analysis. Accounting for the non-normality present in the data, model estimation was performed using the maximum likelihood estimation with robust standard errors and a *Satorra-Bentler* scaled test statistic (Maydeu-Olivares, 2017). Structural Equation Models were run across 50 imputed datasets and were then pooled using *runMI* function from *semTools* package (Jorgensen et al., 2022). Pathway diagrams were presented with effect estimates, which were standardised regression coefficients with bootstrapped 95% CI's. The proportion mediated by occupational activity was also presented (Figure 4.3.1); this was estimated as the indirect effect over the total effect (indirect effect/total effect) (Baron and Kenny, 1986).

4.3.2.4 Missing data

It was assumed that data in the BCS70 were missing at random, and the systematic differences between the missing data and observed could be imputed by other variables available in the BCS70 (Tarek and Wiggins, 2014). Therefore, to reduce selection bias, sex-stratified multiple imputation with chained equations was used (Tilling et al., 2016) to impute missing values in the explanatory factors and covariates (missing data ranged from 0.9% (height at age 46y) to 27% (father's education at age 5y)) in the sample with valid data on grip strength (including those 70 individuals unable for health reasons with imputed values) (N=7,617). Appendix Table B.4.1 contains the variables used in multiple imputations and the proportion of missing data and the methods used to predict missing data in these variables, and Appendix Table B.5.1 contains the variables used in multiple imputations and the proportion of missing data, and the methods used to predict missing data in these variables. As a larger number of imputations have been suggested in settings where high statistical power is needed, 50 imputations were utilised (Graham et al., 2007). Analyses were run on the 50 imputed datasets created, and estimates were combined using Rubin's rule (Little and Rubin, 2017). Results from observed and imputed data sets were similar (Tables B.7.1 and B.7.2), and both analyses are presented in this thesis.

4.3.2.5 Sensitivity analyses

Sensitivity analyses were conducted to check that the results presented were robust and not influenced by the analytical decisions made. These additional analyses were done to test whether the following decisions impacted the results: 1) the inclusion of participants who completed grip strength assessment sat down or with the arm supported (N=727); 2) the inclusion of participants who were unable to complete their grip strength assessment due to health reasons (N=70); 3) the inclusion of participants who reported disability at age 46 years according to the European Statistics of Income and Living Conditions classification (severely hampered (n=452) or missing information disability (N=3)).

All analyses in this thesis were conducted using R version 4.0.3 (R Core Team, 2013), and data were manipulated and visualised using the Tidyverse packages

(H. Wickham, 2017). The *lm* function from base R was used to run the linear regression models (R Core Team, 2013). The *mice* package in R was used to handle missing data (Buuren and Groothuis-Oudshoorn, 2011).

4.4 Results

4.4.1 Childhood and adolescent SEP and grip strength

There was evidence that all associations between childhood and adolescent SEP indicators and grip strength varied by sex (p-values for sex interactions <0.05) — Appendix Tables B.6.1 and B.6.2). For that reason, all results are presented sex-stratified — Figures 4.4.1 and 4.4.2, and Appendix Tables B.6.1 and B.6.2 show the sex-stratified associations between childhood and adolescent SEP indicators and grip strength.

4.4.1.1 Women

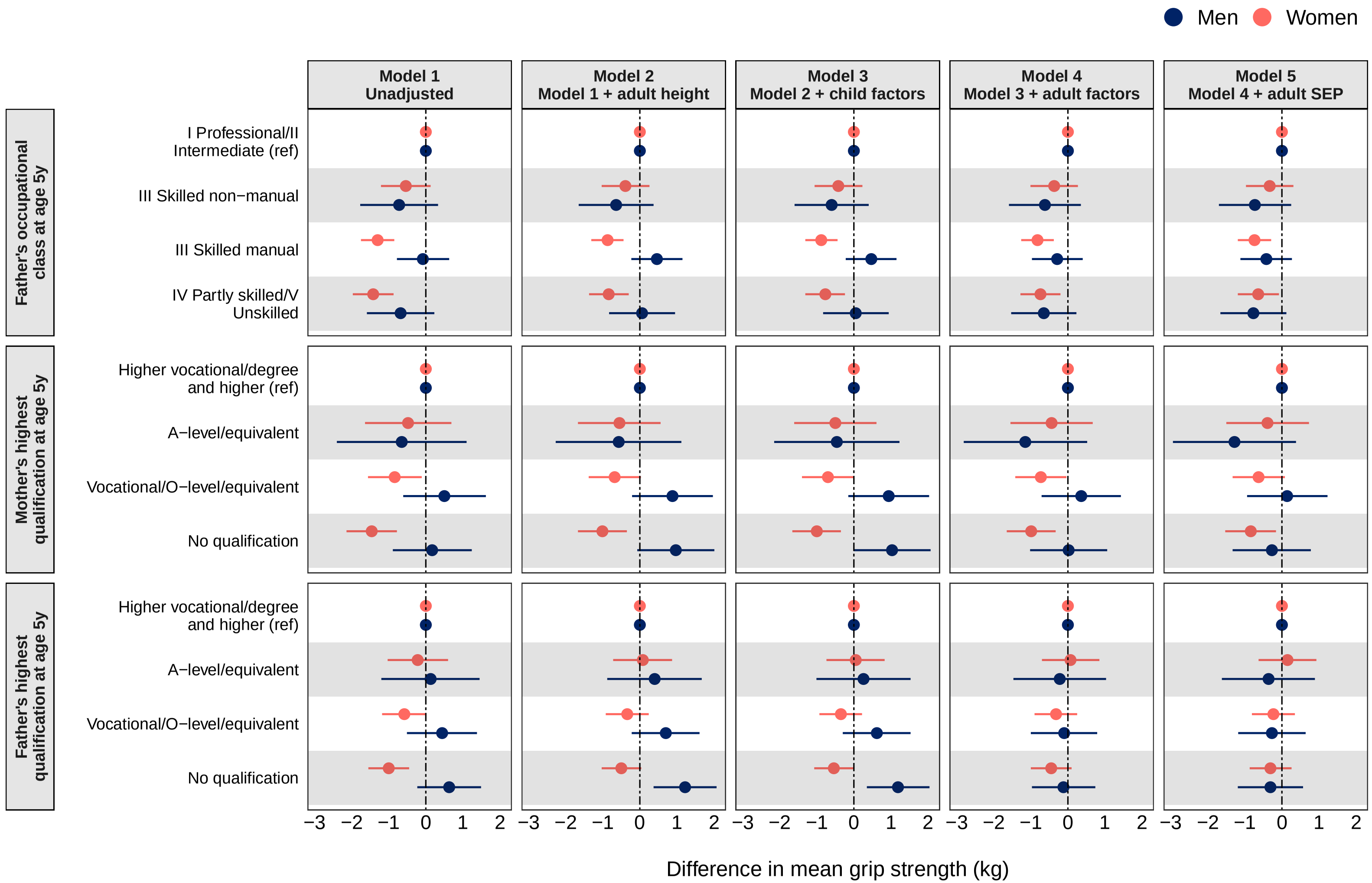
Among women, in unadjusted analyses, lower childhood and adolescent SEP were associated with weaker grip strength. This was observed for parent's occupational class and educational levels, and all relationships showed a linear gradient (Linear trend: p<0.001). When models of the associations between father's occupational class and parental education at age five years and grip strength were adjusted for covariates, associations of lower father's occupational class and mother's highest qualification with weaker grip strength were partly attenuated. However, even after adjustment for adult SEP, modest associations remained (Figure 4.4.1). For example, in the unadjusted model, women whose mothers had no qualifications at age five years had mean grip strength 1.46kg (95% CI: -2.14, -0.78) lower than women whose mothers were educated to vocational/degree or higher, and in the fully adjusted model, this difference was -0.99kg (-1.65, -0.33) — Appendix Tables B.6.1. However, associations between lower father's highest qualification and weaker grip strength were fully attenuated after adjustment for adult height (Figure 4.4.1). Associations between father's occupational class remained after adjustment for adult SEP; for example, in the adjusted model, women whose fathers were in occupational class IV/V had a mean grip strength of 1.42kg (Model

1: -1.97, -0.87) lower than women whose fathers were in occupational class I/II. In the fully adjusted model, this difference was -0.64kg (Model 5: -1.19, -0.08) — see Appendix Table B.6.1. In adolescence, lower father's occupational class at age 16 years was associated with weaker grip strength in women. After adjustments, associations were partially attenuated but remained (see Figure 4.4.2 and Appendix Table B.6.2).

4.4.1.2 Men

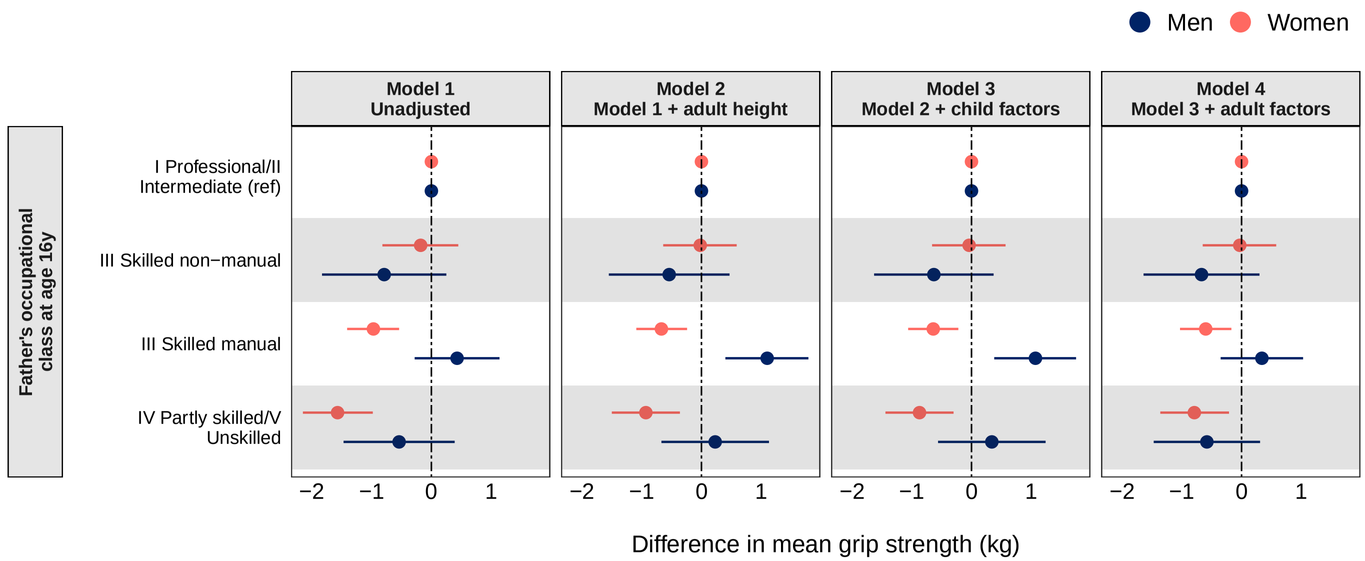
Figures 4.4.1 and 4.4.2, and Appendix Tables B.6.1 and B.6.2 show the sex-stratified associations between childhood and adolescent SEP indicators and grip strength at age 46 years in men. For father's occupational class and mother's highest qualification, there was no clear evidence of an association between any of the indicators of childhood or adolescent indicators of SEP and grip strength in men (Figures 4.4.1 and 4.4.2). However, for father's highest qualification, there were no associations in the unadjusted model. But associations appear in the height-adjusted model and then fully disappear in the model adjusted for adulthood factors. For instance, in the height-adjusted model, participants whose fathers had no qualification were 1.22kg (0.37, 2.07) weaker than participants whose fathers had a degree (Appendix Table B.6.1). Once associations were adjusted for adulthood factors, the difference became 0.12kg (-0.97, 0.74).

Figure 4.4.1: Associations between childhood socioeconomic position and grip strength (linear regression models stratified by sex).



Note: results are combined from analyses run across 50 imputed datasets.

Figure 4.4.2: Associations between and adolescent socioeconomic position and grip strength (linear regression models stratified by sex).



Note: results are combined from analyses run across 50 imputed datasets.

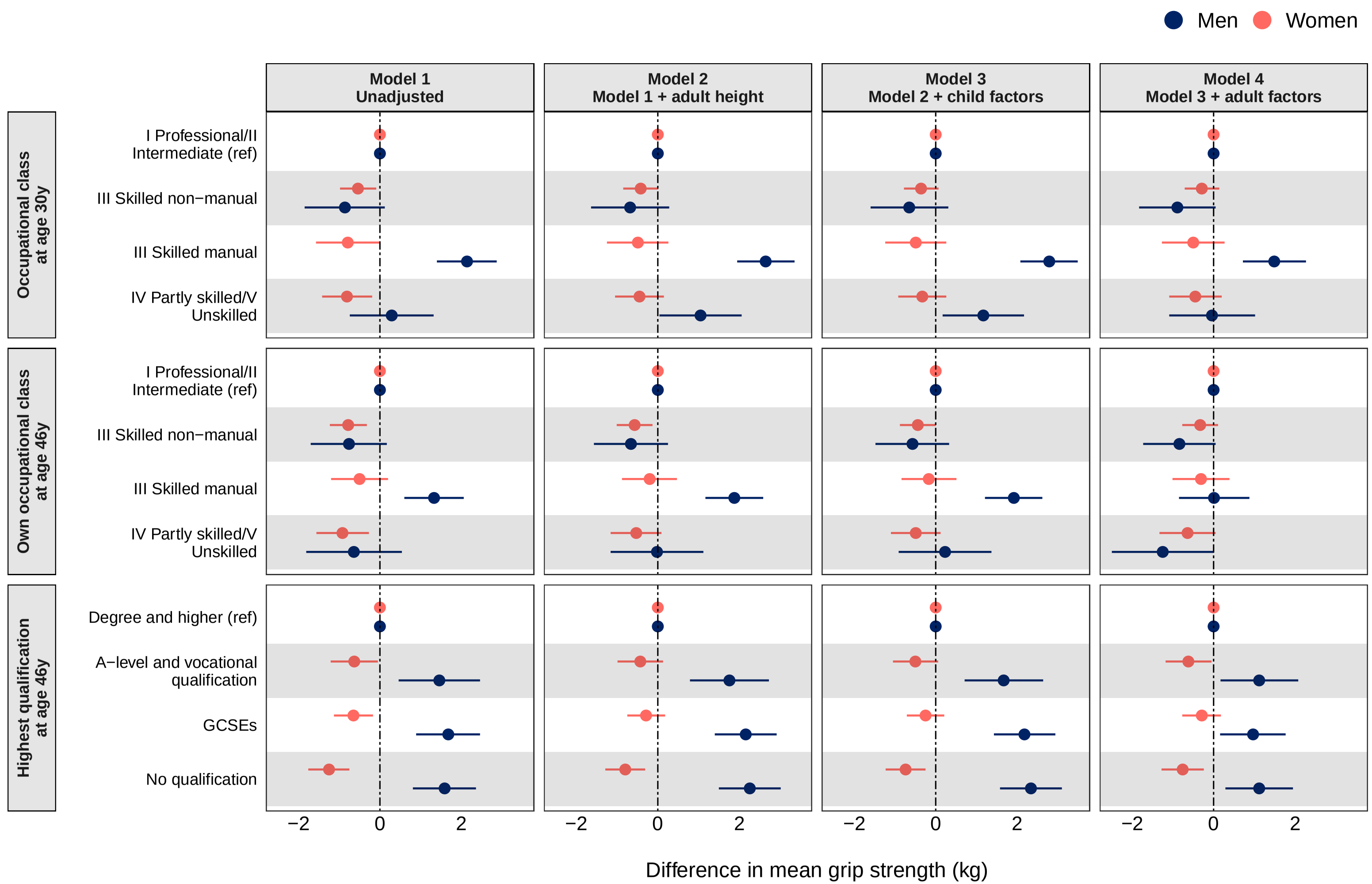
4.4.2 Adulthood SEP and grip strength

As for indicators of childhood and adolescence SEP, there were also interactions between sex and adulthood SEP indicators, and so the associations between adulthood SEP indicators and grip strength (see Tables B.6.3 and B.6.3) are sex-stratified.

4.4.2.1 Women

In women, lower levels of all indicators of SEP in adulthood were associated with weaker grip strength, and there was a linear trend in all associations (Figure 4.4.3). At ages 30 and 46 years, associations between lower occupational class and weaker grip strength in women were fully attenuated after adjustments. At age 30 years, the association was fully attenuated after adjustment for adult height (Figure 4.4.3); however, at age 46 years, it was childhood factors that fully attenuated the association (Figure 4.4.3). To illustrate this, women with occupational class III Skilled Non-manual at age 46 years had a mean grip strength 0.92kg lower (95% CI: -1.56, -0.27) than women in class I/II; when adjusted for childhood factors, this difference was 0.53 kg (-1.16, 0.09) (Appendix Table B.6.3). In contrast, the association of lower educational attainment at age 46 years and weaker grip strength was partially attenuated after adjustments, but an association remained in the final model (Appendix able B.6.3).

Figure 4.4.3: Associations between adulthood socioeconomic position and grip strength (linear regression models stratified by sex).



Note: results are combined from analyses run across 50 imputed datasets.

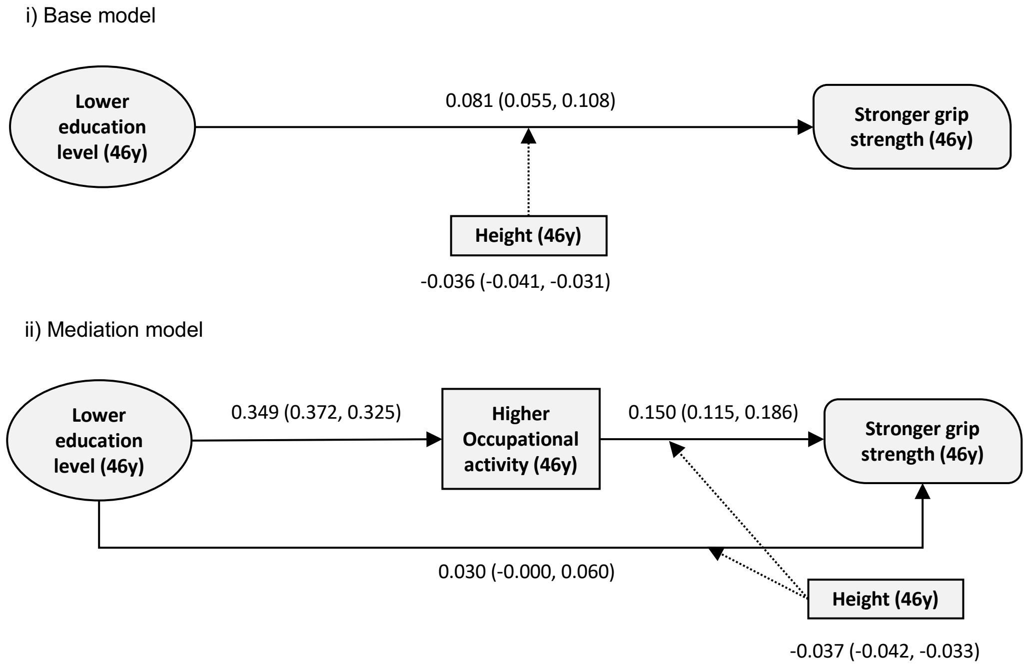
4.4.2.2 Men

Associations between occupational class and grip strength were in the opposite direction for men compared with those for women. At ages 30 and 46 years, there was evidence of a non-linear association between higher own occupational class and stronger grip strength; men in skilled manual occupations had a stronger grip than men in professional/intermediate occupations (Figure 4.4.3). Associations at age 30 years remained, although they were partially attenuated after adjustments (Figure 4.4.3 and Appendix Table B.6.3). However, associations at age 46 years were fully attenuated after adjustments for adult factors (see Figure 4.4.3 and Appendix Table B.6.3). For example, men in III Skilled Manual occupations at age 46 years had a stronger grip than men in I/II occupations (unadjusted regression coefficient: 1.33 kg (0.60, 2.06)). This association strengthened after adjustment for height (Model 2: 1.88 kg; 1.17, 2.59) and childhood factors (Model 3: 1.92 kg; 1.21, 2.62), but the inclusion of adulthood factors fully attenuated the association (Model 4: 0.01 kg; -0.85, 0.88) — see Figure 4.4.3 and Appendix Table B.6.3. When each adulthood covariate was added individually to the model (see Appendix Table B.6.4), occupational activity at age 46 years largely explained this attenuation.

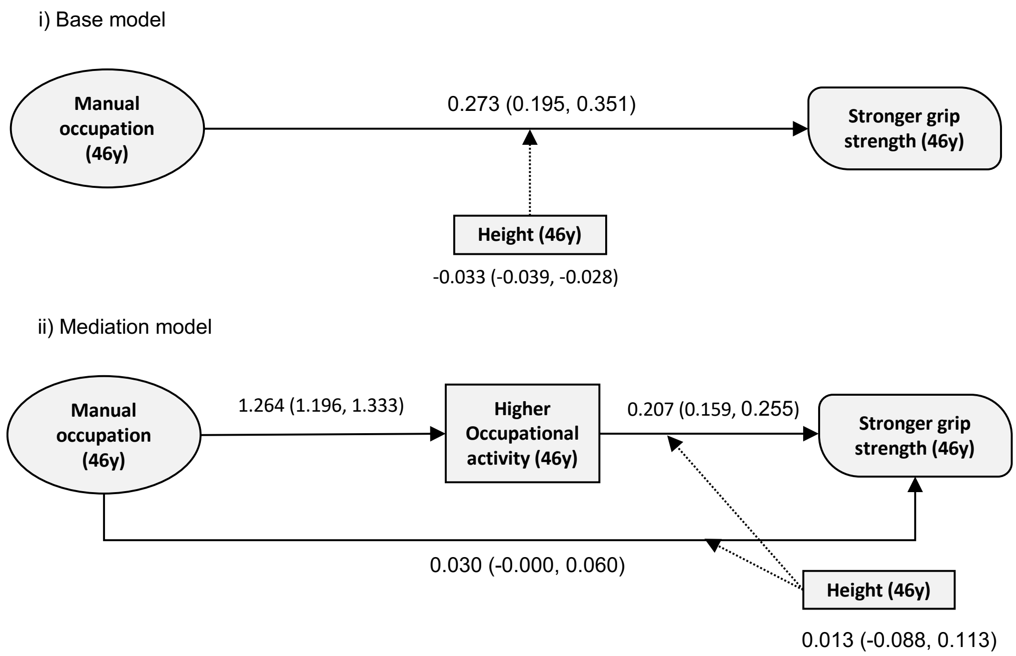
Consistent with the finding that lower levels of SEP in adulthood may be associated with stronger grip in men at age 46 years, an association between lower levels of educational attainment and stronger grip was also observed (Figure 4.4.3). Here, adjustment for height and childhood covariates strengthened the associations, while adulthood covariates attenuated it. Although partially attenuated, an association between lower levels of education and stronger grip was still observed after all adjustments. For example, in the unadjusted model, men with no formal qualifications had 1.59kg (0.81, 2.36) stronger mean grip than men educated to a degree level or higher, which was attenuated to 1.12kg (0.29, 1.95) after adjustment for all covariates (Appendix Table B.6.3).

Figure 4.4.4: Estimates from path models examining the mediating role of occupational activity in the association between own educational level and being a skilled manual worker with grip strength in men.

(a) Educational level



(b) Being a skilled manual worker



Model i) adjusted for height; Model ii) adjusted for height and occupational activity at 46y. Effect estimates are standardised regression coefficients with bootstrapped 95% CI's. Being a manual worker results in a unit increase in occupational activity/grip strength (kg); a unit increase in occupational activity results in a unit increase in grip strength (kg). Results are pooled from SEM models run across 50 imputed datasets.

4.4.3 Social mobility

As seen in Table 4.4.1, when the binary categorisations were used for women, social mobility results were in line with the reported associations between lower occupational class and weaker grip strength in women. Those in the Low-Low category were 0.79kg (-1.36, -0.22) weaker than those in the High-High category. A large proportion of women went from the Low to High category (43%), and these women were 0.75kg (-1.18, -0.32) weaker than women in the High-High level. However, social mobility associations were slightly different when using High, Medium, and Low categorisation as some categories were underpowered (Table 4.4.1).

Women in the Medium-Medium category had a mean grip strength of 1.00kg (-1.59, -0.41) lower than those in the High-High category. Similarly, women in the Medium-Low (-1.12kg; -1.97, -0.27) and Low-Medium (-1.07kg; -1.86, -0.29) categories had a weaker grip than women in the High-High category. In men, those who transitioned from High to Medium categories were 1.60kg (0.43, 2.76) stronger than men in the High-High category. In contrast to women, men in the Medium-Medium category were 1.33kg (0.44, 2.21) stronger than men in the High-High category. There were no differences between other categories in relation to the reference category (Table 4.4.1).

Table 4.4.1: Associations between tracking of occupational class from childhood to adulthood and grip strength at age 46 years in women in the BCS70 (height-adjusted linear regression models in women, N=3,922).

	%	Coefficient (95% CI)
Occupational class mobility (from age 5 to 46yrs)†		
High-High	32.2	0.00 (ref)
High-Low	7.0	-0.03 (-0.84, 0.78)
Low-High	43.2	-0.75 (-1.18, -0.32)
Low-Low	17.6	-0.79 (-1.36, -0.22)

%: the proportion of women in that category; Participants unable to complete the grip strength tests for health reasons were included (n=70). † Social mobility variable categorisation: High category includes those in class I or II and III NM; Low category includes those in class IV or V and III M; Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table 4.4.2: Associations between tracking of occupational class from childhood to adulthood and grip strength at age 46 years in the BCS70 (height-adjusted linear regression models stratified by sex).

	Coefficient (95% CI)			
	%	Women (N=3,922)	%	Men (N=3,695)
Occupational class mobility (5 to 46yrs)†				
High-High	16.6	0.00	19.0	0.00
High-Medium	9.8	-0.22 (-0.96, 0.52)	9.8	1.60 (0.43, 2.76)
High-Low	2.0	0.15 (-1.30, 1.59)	1.2	0.65 (-2.12, 3.43)
Medium-High	20.6	-0.55 (-1.16, 0.06)	23.4	0.28 (-0.62, 1.18)
Medium-Medium	24.8	-1.00 (-1.59, -0.41)	25.4	1.33 (0.44, 2.21)
Medium-Low	7.8	-1.12 (-1.97, -0.27)	5.0	0.26 (-1.27, 1.78)
Low-High	6.4	-0.63 (-1.49, 0.24)	5.0	0.79 (-0.72, 2.31)
Low-Medium	8.6	-1.07 (-1.86, -0.29)	8.8	0.72 (-0.54, 1.97)
Low-Low	3.4	-1.01 (-2.20, 0.19)	2.3	-0.20 (-2.49, 2.09)

%: the proportion of men and women in that category; Participants unable to complete the grip strength tests for health reasons were included (n=70). †Social mobility variable categorisation: High category includes those in class I or II and III NM; Low category includes those in class IV or V and III M; Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

4.4.4 *Mediating role of occupational activity*

Figure 4.4.4a displays the mediation model examining the role of occupational activity on the association between own highest qualification level and grip strength in men. In the height-adjusted model, lower educational level was associated with a stronger grip (standardised regression coefficients: 0.081, 95% CI: 0.055, 0.108; $p<0.001$) — the standardised regression coefficient suggests that a decrease in education level is associated with an increase in grip strength of 0.081kg (see base Model A in Figure 4.4.4a). In the mediation model (Figure 4.4.4a; Model B), the association between lower education level and a stronger grip in men was largely explained by occupational activity (standardised regression coefficients: 0.030, 95% CI: -0.000, 0.060; p=0.051). Presented in Table 4.4.3, the mediating role of occupational activity largely explained the relationship between lower education levels and stronger grip strength in men (63.7%; 95% CI: 37.6, 89.8).

As can be seen in Figure 4.4.4b, in the height-adjusted model (Model i), there was evidence of an association between being a skilled manual worker at age

46 years and stronger grip strength in men (standardised regression coefficients: 0.273, 95% CI: 0.195, 0.351; *p*<0.0.01); being a skilled manual worker was associated with an increase of 0.273kg in grip strength to being in occupational class I/II. Associations no longer existed once adjusted for occupational activity at age 46 years (0.013, 95% CI: -0.088, 0.113; *p*=0.804) — see Model ii in Figure 4.4.4b. When quantifying the proportion mediated, higher occupational activity mediated 95.4% (60.3, 130.3) of the association between being a skilled manual worker and stronger grip strength in men when compared to men of occupational class I/II (Table 4.4.3).

Table 4.4.3: Pathway results for the total, direct and indirect effects of adulthood SEP and grip strength in men.

Mediation Model	Coefficient* (95% CI)	P-value	Proportion mediated (%)†
Highest qualification‡			
Direct effect	0.030 (-0.000, 0.060)	0.051	-
Indirect effect	0.052 (0.065, 0.040)	<0.001	63.7 (37.6, 89.8)
Total effect	0.082 (0.109, 0.055)	<0.001	-
Manual occupation††			
Direct effect	0.013 (-0.088, 0.113)	0.804	-
Indirect effect	0.262 (0.200, 0.324)	<0.001	95.4 (60.3, 130.3)
Total effect	0.275 (0.195, 0.354)	<0.001	-

Note: Results are pooled from SEM models run across 50 imputed datasets.
* Effect estimates are standardised regression coefficients with bootstrapped 95% CI's;
† Proportion mediated = indirect effect (mediated) /total indirect effect*100;
‡ Mediation direction: Lower education level →Higher Occupational activity →Stronger grip;
†† Mediation direction: Manual occupation →Higher Occupational activity →Stronger grip.

4.4.5 *Sensitivity analyses*

Results from sensitivity analyses were similar to those described in sections 4.4.1 and 4.4.2, suggesting that the presented analyses are unlikely to be impacted by the: 1) inclusion of participants who completed grip strength assessment sat down or with the arm supported (Appendix Table B.7.3); 2) inclusion of participants who were unable to complete their grip strength assessment due to health reasons (Appendix Table B.7.4); 3) the inclusion of participants who were severely hampered or had missing information on disability (Appendix Table B.7.5).

4.5 Discussion

4.5.1 Summary of main findings and fit with hypotheses

The hypotheses presented in Section 4.2 were partially supported. As hypothesised, lower SEP in childhood, adolescence and adulthood was associated with weaker grip strength at age 46 years in the BCS70 for women. In men, it was hypothesised that lower childhood, adolescence, and adulthood would also be associated with stronger grip strength. However, this hypothesis was only supported for adulthood SEP, as men in manual occupations had a stronger grip than men in higher occupational classes. Finally, social mobility did play an important role in explaining the associations observed for women, while important factors, including height and occupational activity, explained a large proportion of the observed associations in men. However, not all associations were explained by the inclusion of covariates, such as those found between father's occupational class and mother's highest qualification and grip strength in women.

There were sex-specific associations between childhood, adolescent and adulthood SEP and grip strength at age 46 years. In women, there was evidence of associations between lower adolescent, childhood and adulthood SEP and weaker grip strength, and many of these were robust to adjustments for body size and childhood and adulthood factors. Despite some tracking of SEP from childhood to adulthood in women, in the fully adjusted linear regression models, associations between father's occupational class and parental education in childhood grip strength were not fully explained by adjustment for adulthood SEP.

In men, there was no evidence of associations between childhood and adolescent SEP and grip strength. The non-linear association between own occupational class at age 46 years and grip strength was fully mediated by occupational activity; though, the non-linear association between own occupational class at age 30 years and grip strength remained after adjustments. Associations between lower educational attainment at age 46 years and stronger grip strength were also mediated by occupational activity, but a modest association remained in the final model.

4.5.2 Comparison of main findings with the existing literature

There were associations between lower childhood, adolescent and adulthood SEP and weaker grip strength in women. These patterns of associations were also demonstrated by the social mobility analyses, showing that women who transitioned from Low to High occupational class remained weaker than those in the High-High social mobility category. Moreover, the fact that associations for occupational class in adulthood were fully attenuated, but associations in childhood and adolescence remained after adjustment, suggests that factors experienced in early life remain important for grip strength in adulthood in women. In previous studies, where associations were observed, lower SEP was typically associated with weaker grip strength, which is consistent with our findings for women (Cheval et al., 2018; Cheval et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Starr and Deary, 2011; Weinstein, 2016). However, this is the first-time robust associations between prospectively ascertained childhood, adolescent and adulthood SEP and grip strength in middle-aged women have been reported.

Although the findings of associations between lower adulthood SEP and stronger grip in men contrast with what has been reported in many previous studies in older adults (Birnie et al., 2011a; Cheval et al., 2018; Cheval et al., 2019; Hurst et al., 2013; Kuh et al., 2019; Petersen et al., 2018; N. Smith et al., 2019; Starr and Deary, 2011; Weinstein, 2016), findings in this chapter are consistent with evidence from previous studies. These studies include results from Swedish male military personnel aged 18 years (Silventoinen et al., 2009) and middle-aged men in the UKHLS (Carney and Benzeval, 2018), where an association existed between lower SEP and stronger grip in men. Taken together, these reports suggest that in men, associations between SEP and grip strength may change direction with age, and lower SEP could be associated with weaker grip strength at older ages, as already shown in the UKHLS (Carney and Benzeval, 2018). Using the data from UKB, Chapter 6 of this thesis will examine in detail whether associations between manual occupations and stronger grip strength in men of high occupational activity exist at older ages.

4.5.3 *Explanation of findings*

In considering potential explanations of the consistent associations between lower childhood, adolescent and adulthood SEP and weaker grip in women, it is necessary to consider the different factors that could be acting on pathways between SEP across life and grip strength in midlife. This is because SEP indicators are distal factors (i.e., experienced much earlier in life than the outcome) (Power and Hertzman, 1997), and therefore associations would be expected to be mediated by more proximal factors that are socioeconomically patterned and relate to subsequent grip strength. In identifying these factors, it is important to consider the complex biological and social pathways that have been proposed to explain socioeconomic differences in health outcomes (Kelly-Irving and Delpierre, 2021). For instance, in the case of grip strength, there are likely to be a range of factors and pathways implicated, including those related to growth and development (both in utero and across childhood and adolescence), and the factors that drive this (i.e. nutrition and exposure to hormones), attainment of adult body size and composition, health behaviours (including physical activity) and health status (Bridger Staatz et al., 2021; Elhakeem et al., 2015; Galobardes et al., 2006a; Hardy et al., 2013; Stringhini et al., 2017). Although it was possible to adjust for some of these factors in the analyses (including body size and composition, health status and physical activity), there are others that were not adjusted for, such as differences in sex hormones and diet across life, which could explain some of the associations that remained in the fully adjusted models.

While similar pathways in the association for women may also operate in men, findings in this chapter suggest that other important factors are countering some of the potentially adverse effects of low SEP on men's grip strength in midlife. As occupational activity in adulthood caused the greatest attenuation of the associations between indicators of adult SEP and grip strength, this would suggest that occupational activity may be responsible for the associations observed in men. In support of these findings, formal mediation analyses showed that occupational activity mediated nearly all the associations observed in men who were skilled manual workers (compared to men in occupational class I/II) and a high proportion of the associations we see in those of lower educational level. These results are consistent with findings from a study of Danish men aged 59 years, which reported an association between higher levels of specific types of occupational activity (kneeling) and stronger grip in men (Moller et al., 2013). Occupational activity has historically been linked with premature mortality (Coenen et al., 2018); however, a recent nationwide prospective cohort study in Norway found a dose-response relationship between higher levels of occupational activity and longevity in men that was explained by adjustments including SEP, body size, health status and healthy behaviours (Dalene et al., 2021). An umbrella review prepared for the 2020 *World Health Organisation Physical Activity Guideline Development Group* found occupational activity to protect against most health-related outcomes, including cancers, heart disease, and type 2 diabetes (Cillekens et al., 2020). The findings reported in these studies may help explain our results of higher grip strength in men with higher occupational activity, thus highlighting the potentially protective effects of occupational activity in middle-aged men. To further illustrate this, the protective aspect of occupational activity for men is also evident when testing the role of social mobility in explaining the association between lower occupational class and stronger grip in the BCS70. Men who transitioned from High to Medium occupational class had higher grip strength than men in the High occupational class category, both in childhood and adulthood.

An explanation for why occupational activity may be protective for men but not women could be due to the fact that there were more men than women in manual occupations. Also, manual occupations are often high in occupational activity, and there are different types of occupational activity within these manual occupations. For instance, a similar number of men and women did jobs that involved physical work, and more women than men did standing occupations (20.1% vs 10.7, respectively). However, more men than women did heavy manual work (8.6% vs 0.9%, respectively), further highlighting the importance of specificity in the type of physical activity that could be protective to adverse effects of socioeconomic adversity on muscle strength.

4.5.4 *Methodological considerations*

The findings presented in this chapter address an important research gap in the literature by examining the associations between childhood, adolescent and adulthood SEP and grip strength in younger adults from a more recently born cohort than in previous studies. Sex differences were formally tested in the associations between SEP and grip strength, which is important, as the systematic review by Birnie et al. indicated that sex differences might be a potential source of variation between studies of the association between childhood SEP and grip strength (Birnie et al., 2011a).

Another key strength of the work presented in this chapter is that a large, population-based sample that was nationally representative at birth with prospectively ascertained SEP indicators and several potentially important covariates from multiple time points was used. Nonetheless, as in all longitudinal studies, the BCS70 has experienced attrition, which may have introduced bias. BCS70 participants who contributed data at age 46 years were more likely to be women, be taller, less likely to be current smokers and have a higher lifetime SEP than those lost to follow-up (Centre for Longitudinal Studies, 2020). However, the analytic sample was maximised, and potential bias due to missing data was minimised by using multiple imputation. Here, sex-stratified multiple imputation was used to account for the sex- interaction in the associations between childhood, adolescent and adulthood SEP and grip strength (Tilling et al., 2016). By using multiple imputation, the assumption that data were missing at random was made, though it has to be acknowledged that this may not have been the case. However, a range of auxiliary variables predictive of missingness within the BCS70 in the multiple imputation were used (K. Lee et al., 2021; Mostafa and Wiggins, 2015). Other limitations include the inability to examine associations between SEP and grip strength by ethnicity, as much of the BCS70 was white-British, owing to the limited ethnic diversity of Great Britain in the 1970s. This makes it difficult to fully generalise findings from this chapter to today's population in Great Britain, although the BCS70 cohort does provide important new insights on the associations between childhood, adolescent and adulthood SEP and grip strength that complement findings from older cohorts because of their exposure to more contemporaneous social and political factors.

4.5.5 Summary

Sex differences in the associations between childhood, adolescent and adulthood SEP and grip strength were found in a relatively large, nationally representative population of middle-aged British adults. Findings highlight the need to identify age and sex-specific interventions to tackle inequalities across life in important age-related conditions related to weakness. In women, as lower SEP in childhood and adulthood was associated with weaker grip strength, strategies to reduce their exposure to socioeconomic adversity across life are likely to benefit their grip strength at midlife. For men, lower SEP in adulthood was associated with stronger grip at age 46 years, related to higher levels of occupational activity, with a non-linear association for occupational class. Evidence from the oldest British birth cohort, born in 1946, suggests that an association between lower lifetime SEP and weaker grip emerges as the cohort age (there is limited evidence of association at age 53 years, but an association is seen at 60-64 and 69 years) (Hurst et al., 2013; Strand et al., 2011a). This suggests that the association in BCS70 may change with age, especially as there is evidence that the protective effects of occupational activity may recede by the time of retirement (Savinainen et al., 2004; Walker-Bone et al., 2016). As this could relate to either reductions in levels of beneficial activity and/or the accumulation of wear and tear related to heavy manual work, further research is needed to identify the types of interventions that may be most effective in ensuring that men of lower SEP maintain any midlife strength advantage into later life.

In the next chapter, using data from the same cohort (BCS70), the relationships between childhood, adolescent and adulthood SEP and standing balance are examined. Then in Chapter 6, some of the avenues for further research established when interpreting the findings in this chapter on the associations between SEP and grip strength will be interrogated using UK Biobank. Including the need to investigate age, sex, and ethnicity differences in the associations between adulthood SEP and grip strength. The Chapter will also examine whether associations between adulthood SEP and grip strength in men of high occupational activity exist at older ages.

CHAPTER 5

Mediators of the associations between SEP and standing balance performance

This chapter outlines the work undertaken to examine the associations between childhood and adulthood SEP and standing balance performance at age 46 years and the pathways that may mediate these associations using BCS70 data. The initial part of the chapter summarises the literature on associations between childhood SEP and standing balance performance; the chapter then continues with the methodology used to answer its questions, and finally, the results and discussion section are presented.

5.1 Introduction

Standing balance is an important marker of musculoskeletal health and function. Being able to balance while standing is an essential component of many physical tasks of everyday living. Poorer standing balance performance has been linked with increased risk of disability, fractures, hospitalisations, premature mortality, and falls in later life (Blodgett et al., 2022b; R. Cooper et al., 2011b; R. Cooper et al., 2014; Ganz et al., 2007; Muir et al., 2010; Nofuji et al., 2016; Soriano et al., 2007). There is a large body of research linking lower childhood SEP with poorer adult health (Galobardes et al., 2008; Pollitt et al., 2005; Poulton et al., 2002; Strand and Kunst, 2007), and standing balance is no exception to this (Birnie et al., 2011a). Childhood SEP may seem relatively far removed from balance ability in adulthood, but previous findings have shown that the ability to balance is largely developed in childhood (Blodgett et al., 2022a). Therefore, unravelling the associations between childhood SEP and adult standing balance performance before the onset of age-related decline in balance is important for developing early preventative strategies for poorer balance in older age.

5.1.1 Findings from previous studies

In Chapter 2, a review of studies exploring the relationship between childhood SEP and standing balance performance was presented. The review indicated that the associations between lower childhood SEP and weaker standing balance performance in adulthood are inconsistent (Birnie et al., 2011a; Blodgett et al., 2020; Hurst et al., 2013; Kuh et al., 2006; Murray et al., 2013; Petersen et al., 2018; Strand et al., 2011a). In 2011, the authors of a systematic review assessed the association between childhood SEP and standing balance performance (Birnie et al., 2011a). They harmonised the results from published and unpublished studies. The pooled analyses showed that lower childhood SEP was associated with weaker standing balance performance (as measured by the ability to balance on one leg for 5 seconds) in the age-adjusted model only. However, when adult SEP was taken into account, these associations were fully explained. For instance, in the age-adjusted model, the odds of being unable to balance for five seconds on one leg were 1.50 (95% CI: 1.06, 2.14) when comparing individuals with the lowest SEP to those with the highest SEP. When adjusted for adult SEP, the association was fully mitigated (odds ratio of inability to stand for 5 seconds: 1.06; 95% CI: 0.86, 1.30). The review found moderate heterogeneity between studies (I^2) = 47.5%), which was attributed to differences in cohort effects, study design, and methodological artefacts.

The most comprehensive analyses on the relationship between childhood SEP and standing balance performance were conducted on the NSHD, the oldest British birth cohort study, with five studies published (Blodgett et al., 2020; Hurst et al., 2013; Kuh et al., 2006; Murray et al., 2013; Strand et al., 2011a). Two of these studies were included in Birnie et al.'s (2011b) systematic review (Birnie et al., 2011b; Kuh et al., 2006). In these complementary analyses, a lower childhood SEP was linked with poorer standing balance performance at age 53 years (Kuh et al., 2006; Murray et al., 2013; Strand et al., 2011a). The associations were fully attenuated by adult education and occupation (Strand et al., 2011a). Additional studies on the same cohort also demonstrated robust associations between lower SEP and poorer standing balance performance at older ages, including at ages 60–64 years (Hurst et al., 2013). Longitudinal studies further showed associations between lower childhood SEP and poorer standing balance performance at ages 53, 60-64, and 69 years, with the associations becoming weaker with age (Blodgett et al., 2020).

Additionally, there have been investigations into the relationship between life course SEP and balance performance in two other British studies: the *Boyd Orr* and *Caerphilly* cohorts. The studies (Birnie et al., 2011b; Hurst et al., 2013) aimed to examine the relationship in adults aged between 63 and 86 years. The *Boyd Orr* cohort found that lower childhood SEP was associated with poorer standing balance performance, regardless of behavioural factors and health status. However, no such association was found in the *Caerphilly* cohort, which only included men. The life course model showed that the negative effects of SEP on standing balance performance accumulate over time in the *Boyd Orr* cohort. Meanwhile, a study of Danish adults aged 48–58 years found no association between childhood SEP and standing balance performance (Petersen et al., 2018).

5.1.2 *Between-study heterogeneity*

Explanations for the varying findings in studies, such as in the Danish study, the *Caerphilly* cohort, and those reviewed by Birnie et al. (2011a), where some find an association while others do not, could potentially be attributed to differences in the measurement and modelling of standing balance performance (e.g., continuous measurement of time spent balancing versus binary measurement of the ability to balance on one leg for 5 seconds), period and cohort effects, and differences in modelling SEP. For example, the use of slope indices of inequality, which takes into account differences in the distributions of SEP indicators and has the statistical power to detect trends (Strand et al., 2011a), could affect the results. Additional factors include differences in the method of ascertaining childhood SEP, as in the Birnie et al. (2011a) review, where nine out of eleven studies had retrospectively ascertained childhood SEP (Birnie et al., 2011a), and the *Caerphilly* cohort and one of the cohorts in the Danish study had done the same (Birnie et al., 2011b; Petersen et al., 2018). Reliance on retrospective recall for ascertaining study exposure could introduce non-differential misclassification, whereby associations can be biased.

5.1.3 Need for mediation analyses

Despite these analyses, there are still notable gaps in our understanding of how childhood and adulthood SEP and standing balance performance may be associated. Indeed, as childhood SEP is a distal factor, it is expected that more proximal factors, such as cognition and body size (Blodgett et al., 2020), could mediate the childhood SEP association with standing balance performance (Kelly-Irving and Delpierre, 2021). However, the factors that may mediate these associations have not been formally examined within the literature. Furthermore, as adulthood SEP has previously been shown to attenuate the associations observed between childhood SEP and standing balance performance (Birnie et al., 2011a; Kuh et al., 2006; Strand et al., 2011a), the mediating factors between adulthood SEP and standing balance performance need to also be fully interrogated. Investigating these pathways, particularly at earlier ages, may provide insights to develop policies and interventions to help maintain or improve standing balance performance in adults before the onset of age-related decline.

5.2 Chapter aims and research questions

In this chapter, the associations between childhood and adulthood SEP and standing balance performance at age 46 years in the BCS70 were investigated. Where associations were found, the extent to which these associations were mediated by potentially important factors, including body size, neurodevelopmental factors, adulthood SEP, health behaviours and health status, was tested. Based on findings from previous studies described above, it was hypothesised that both lower childhood and adulthood SEP would be associated with poorer standing balance time. Additionally, it was anticipated that associations between childhood SEP and standing balance time would be mediated by adulthood SEP. Other factors, such as BMI and cognition, were considered possible mediators of childhood SEP and standing balance time. To address these aims, the following questions were examined:

1. Are there associations between indicators of childhood and adulthood SEP and standing balance at age 46 years in the BCS70, and do they vary by sex?
2. Does tracking of SEP from childhood to adulthood explain any observed associations?
3. If associations exist, to what extent do specific factors across life mediate these associations?

5.3 Methods

5.3.1 Variables used in analyses

Similar to Chapter 4, this chapter used data from the BCS70, which has been described in Chapter 3. The indicators of childhood SEP used were father's occupational class, mother's and father's educational levels, and family housing tenure at age five years. For adulthood SEP, own occupational class, own educational level, own income after tax, and housing tenure at age 46 years were used. Additionally, the binary High-Low categorisation for social mobility was used — Section 3.1.7.3 contains the full categorisation of these SEP indicators. Potential mediators used in analyses were selected a priori based on previous literature (Birnie et al., 2011a; Blodgett et al., 2020; A. Cooper et al., 2015; R. Cooper et al., 2020; Kuh et al., 2009; Kuh et al., 2006), these were risk factors that were socioeconomically patterned and that were also known to be associated with standing balance performance in adulthood (See Section 3.1.7.4 for the categorisation of these covariates). Variables included in childhood, at age ten years, were BMI, childhood cognition, coordination, number of health conditions and leisure-time physical activity. In adulthood, the variables used were BMI, height and occupational activity ascertained at age 46 years, as well as the number of health conditions, cognition, leisure-time physical activity, smoking status, and sedentariness at age 42 years. See Sections 3.1.5 and 3.1.7.3 for the full presentation and description of standing balance measurement, explanatory variables and the covariates used in this chapter.

5.3.2 *Statistical analyses*

5.3.2.1 Main associations

To test the associations between each indicator of childhood and adulthood SEP and standing balance performance, multinomial logistic regression models were used. The childhood SEP indicators used in the main analyses were father's occupational class and parental education levels at age five years, while the adulthood SEP indicators were own occupational class and education level at age 46 years. The Eyes Closed <15sec category was used as the reference group, and the relative risk ratios (RRR) were reported along with 95% confidence intervals. Formal tests of interactions between sex and each of the indicators of SEP were conducted; if there was evidence of sex-interaction (based on the cut-point $p<0.05$), models were stratified by sex. Otherwise, analyses were adjusted for sex. There were two models; Model 1 was an unadjusted sex-stratified or sex-adjusted model (based on sex-interaction results) and Model 2 included additional adjustment for height. Linear trends were assessed using likelihood ratio tests.

5.3.2.2 Social mobility

To test the association of social mobility from childhood to adulthood with standing balance performance, a sex-adjusted multinomial regression testing the association between occupational class from childhood to adulthood (using the variable described in Table 3.1.7 of Chapter 3) and standing balance performance was conducted.

5.3.2.3 Mediation Analysis

Where associations were observed in the main associations using multinomial logistic regression models, mediation analyses were then conducted to investigate the role of the potential mediators outlined above in the relationship between childhood SEP and standing balance performance using SEM in the *Lavaan* R package. Structural Equation Models can carry out mediation analysis with latent variables — the strength and limitations of using SEMs is discussed in Section 4.3.2.3 of Chapter 4. In all models, the outcome was standing balance time categories, which were treated as continuous. The initial pathway model, which shows the pathways between SEP, covariates and standing balance performance, is displayed in Figure 5.3.1.

As individual socioeconomic indicators cannot capture all of the different aspects of SEP, *Confirmatory Factor Analysis* (CFA) was used. This is a dimensionality reduction approach that allows for the modelling of measurement error and the operationalisation of a latent variable that captures overall SEP (Hayes, 2013). In the CFA models, latent variables, which captured the unobserved constructs of childhood and adulthood SEP, were initially developed using childhood and adulthood SEP indicators in the main associations, plus income and housing tenure. To test some of the requirements for mediation analysis (Baron and Kenny, 1986), the following relationships were examined: 1) exposure and outcome, 2) exposure and mediator, and 3) mediator and outcome. Once these requirements had been tested and those variables that met these requirements had been identified, mediation analysis with childhood SEP as an exposure was conducted. In addition, using only covariates in adulthood, there was a secondary mediation analysis to test the mediators of the association between adulthood SEP and standing balance performance, whereby only adulthood covariates were included. All observed variables were standardised prior to the analysis. To handle the non-normality of the dataset, model estimation was performed using the maximum likelihood estimation with robust standard errors and a *Satorra-Bentler* scaled test statistic (Maydeu-Olivares, 2017).

All mediation models were adjusted for height and sex if there was no evidence of sex interaction in multinomial logistic regression models. The fit of the mediation models was tested by computing the following indices: robust *Comparative Fit Index* (CFI), robust *Root Mean Square Error of Approximation* (RMSEA) and *Standardized Root Mean Square Residual* (SRMR) (Hooper et al., 2008). For CFI, a good fit was determined by a value greater than 0.95, and a value greater than 0.90 indicates a satisfactory fit. While an RMSEA below 0.06 and an SRMR of 0.05 indicate a good fit (Schreiber et al., 2006). The proportion mediated was presented — this was calculated by the indirect effect divided by the total effect (indirect effect/total effect).

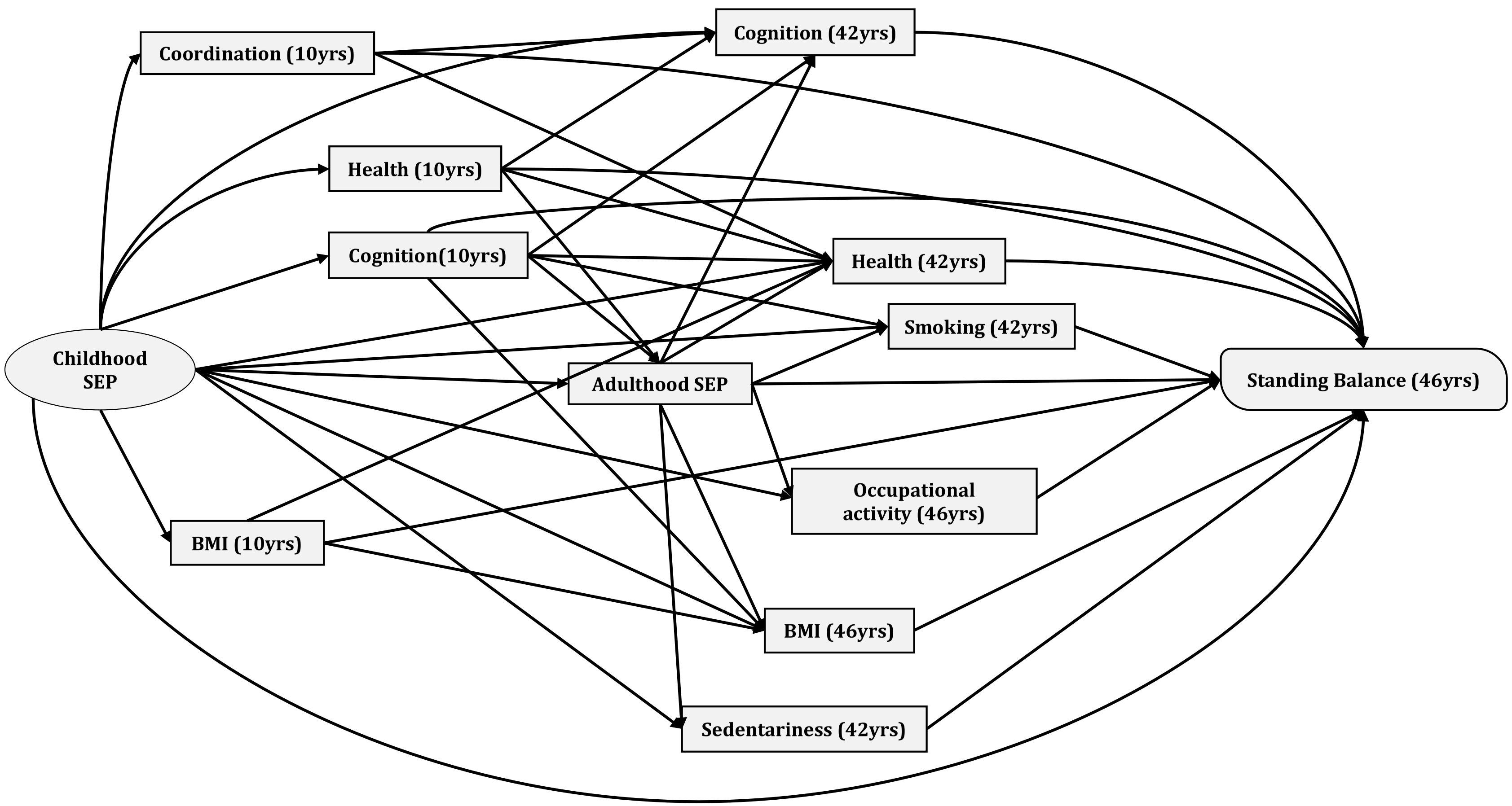
5.3.2.4 Missing data

The level of missingness ranged between 0.7% (housing tenure at 46 years) and 27.0% (father's education)- see Appendix Table B.4.2. It was assumed that data were missing at random. Based on this first assumption, it can then be assumed that the systematic differences between the missing and observed data can be explained by the rich data in the BCS70 (Appendix Table B.5.2) (Mostafa and Wiggins, 2015), multiple imputation models with chained equations were thus used to impute missing data. This is an approach that samples imputed values from the posterior predictive distributions of missing data (Little and Rubin, 2017). Imputation was run on the analytical sample (N=7,591), which included the 228 participants who were unable for health reasons and whose values were imputed with zero. Fifty imputed data sets were created, and all analyses were run across these data sets, with estimates pooled using Rubin's rules (Little and Rubin, 2017). Similar to the analyses for grip strength, results from the imputed and the observed datasets were the same (see Table B.7.6 in the Appendix). So both sets of analyses are presented in this thesis, but results from analyses of the imputed datasets are focused on in the main text.

5.3.2.5 Sensitivity analyses

Sensitivity analyses were conducted to test the assumptions made in the main analyses. First was a test of whether including those unable to complete the standing balance performance test due to health reasons affected the results; to investigate this, a separate analysis that excluded these individuals (n=228) was conducted. Secondly, as the Eyes closed <15sec category had many participants in it, sensitivity analysis examined whether the results were different when recategorising this group into three groups using five-second intervals. This included a rerun of the multinomial logistic regression models using the standing balance outcome with the Eyes closed <15sec category re-categorised into three categories (Eyes Closed <5sec, Eyes Closed 5-9.9sec, Eyes Closed 10-14.9sec), with Eyes Closed <5sec as the reference category.

Figure 5.3.1: The potential mediators of the association between childhood and adulthood SEP and standing balance performance at age 46 years.



5.4 Results

5.4.1 Main associations

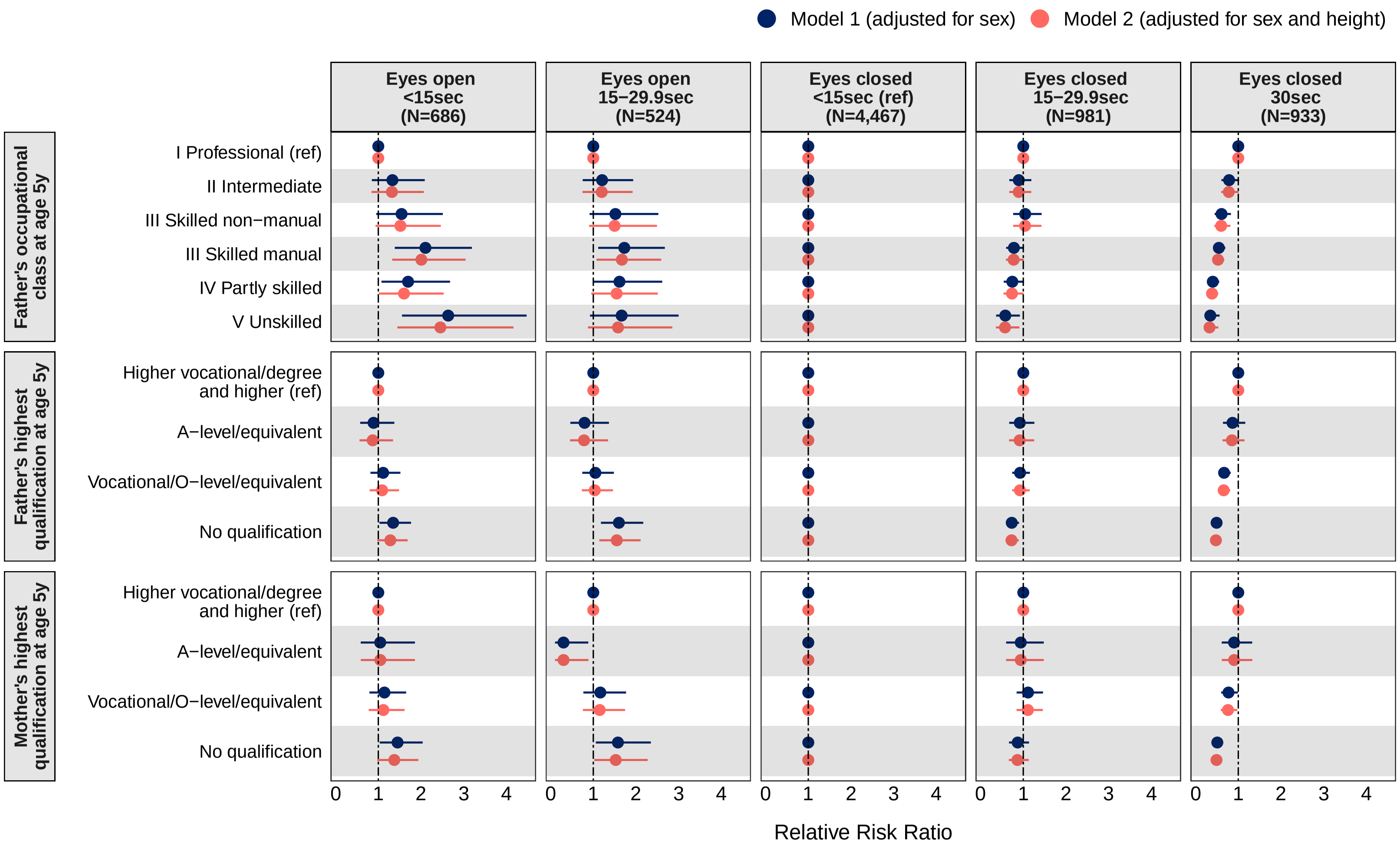
5.4.1.1 Childhood SEP and standing balance performance

Figures 5.4.1 and 5.4.2 and Appendix Tables B.6.5 and B.6.6 show the associations between childhood and adulthood SEP indicators and standing balance performance. There were no interactions between sex and any of the indicators of childhood SEP (p>0.1). In the multinomial logistic regression models, participants with lower childhood SEP were more likely to attain a poorer balance time and less likely to achieve a higher balance time than those with higher childhood SEP (Figure 5.4.1 and Appendix Table B.6.5). For example, in a sex-adjusted model, the likelihood of attaining a poorer balance (balance time of less than 15 seconds with eyes open) compared with a better balance (a time of less than 15 seconds with eyes closed; reference group) was 2.64 (95% CI: 1.55, 4.47) when comparing participants whose father's occupational class was V Unskilled with participants whose father's occupational class was I Professional. The RRR of achieving a better balance (a time of 30 seconds with eyes closed) versus a worse balance (a time of less than 15 with eyes closed) was 0.34 (0.21, 0.56). Associations were linear (p<0.05), and after adjustment for height at age 46 years, associations attenuated slightly but remained (Figure 5.4.1 and Appendix Table B.6.5).

Associations for mother's and father's highest qualification and standing balance performance followed the same pattern; participants whose mothers and fathers had no educational qualifications were more likely to have achieved poorer balance times and less likely to have achieved higher balance times than those whose mothers and fathers who were degree educated (Figure 5.4.1 and Appendix Table B.6.5). For instance, in the sex-adjusted models, among participants whose mothers did not have an educational qualification, the RRR of achieving poorer balance (a time of less than 15 seconds with eyes open) versus better balance (a time of less than 15 seconds with eyes closed) was 1.45 (1.03, 2.04) when compared with participants whose mothers were educated to degree level or higher. The RRR of achieving better balance (eyes closed for 30 seconds) versus poorer balance (a time of less than 15 seconds with eyes closed) was 0.51 (0.40, 0.65). When adjusted for adult height, associations mostly remained.

To exemplify this, after adjustment, participants whose mothers did not have an educational qualification were 1.37 times (0.98, 1.94) more likely to achieve poorer balance (a time of less than 15 seconds with eyes open) versus better balance (a time of less than 15 seconds with eyes closed) than participants whose mothers were educated to a degree level or higher (Figure 5.4.1 and Appendix Table B.6.5, Model 2). For father's highest qualification, associations were linear in all balance categories. Additionally, associations were linear for most categories for mother's highest qualification, except for the Eyes Closed 15-29.9sec category.

Figure 5.4.1: Associations between childhood SEP and standing balance time at age 46 years in the BCS70 (N=7,591).

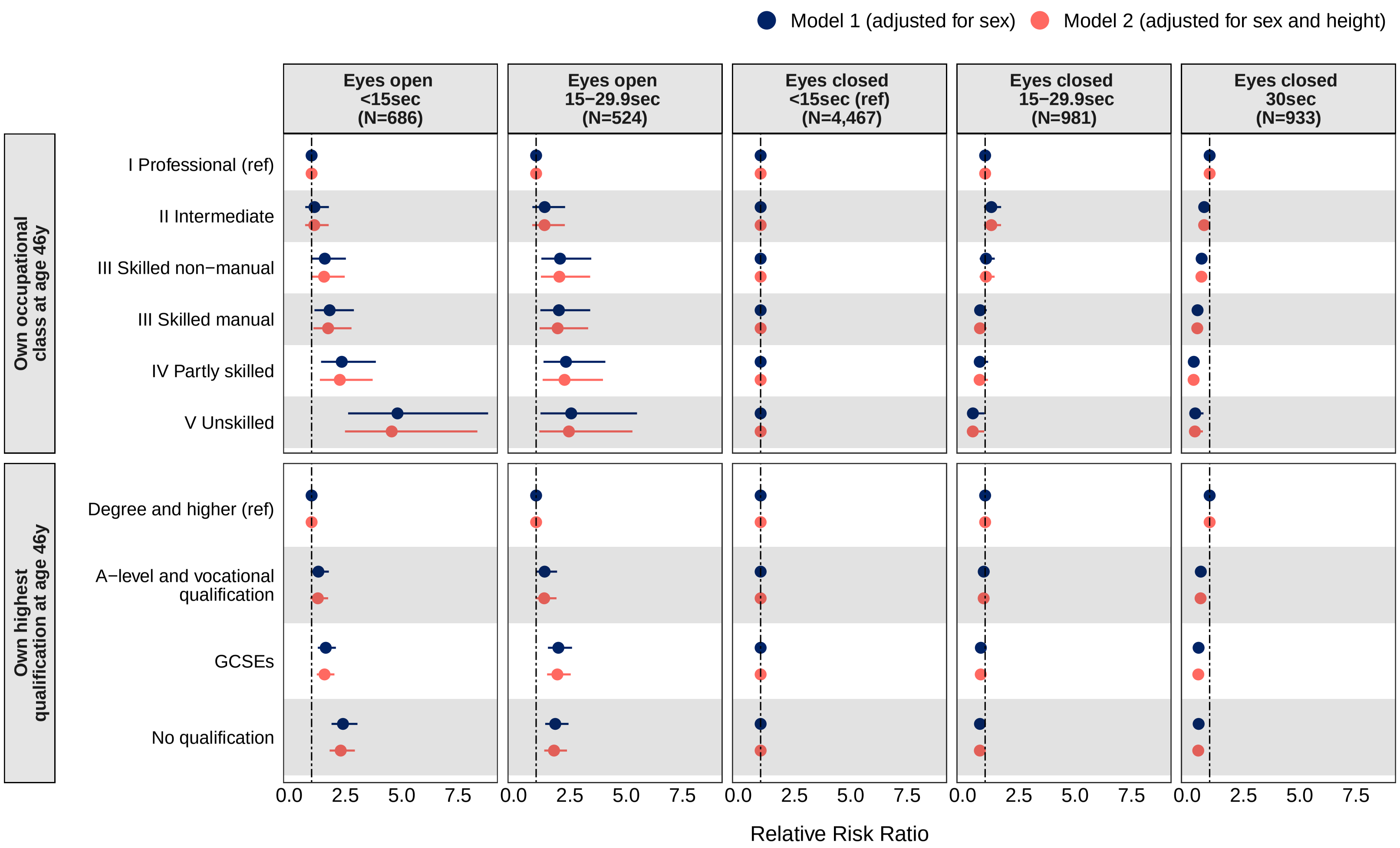


Notes: results are combined from analyses run across 50 imputed datasets.

5.4.1.2 Adulthood SEP and standing balance performance

Similar to childhood SEP, lower levels of adulthood SEP were also associated with poorer standing balance performance at age 46 years, with no evidence of sex-interaction (p>0.08). Lower occupational class at age 46 years was associated with poorer performance in standing balance tests (Figure 5.4.2 and Appendix Table B.6.6), with those in occupational class V Unskilled more likely to have achieved a poorer balance time and less likely to have achieved a better balance time than those who were in occupational class I Professional. To illustrate this, the RRR of poorer balance (a time of less than 15 seconds with eyes open) compared with better balance (a time of less than 15 seconds with eyes closed) was 4.81 (2.62, 8.84) when comparing occupational class V Unskilled with I Professional. The RRR of achieving a better balance (a time of 30 seconds with eyes closed) versus a poorer balance (a time of less than 15 seconds with eyes closed) was 0.36 (0.18, 0.71). Once adjusted for height, associations were attenuated slightly but remained nonetheless. Associations were also similar for own highest qualification at age 46 years and standing balance time, with participants who had a degree or higher more likely to have achieved better balance time and less likely to have achieved a poorer balance time than those who had no qualifications (Figure 5.4.2 and Appendix Table B.6.6).

Figure 5.4.2: Associations between adulthood SEP and standing balance time at age 46 years in the BCS70 (N=7,591).

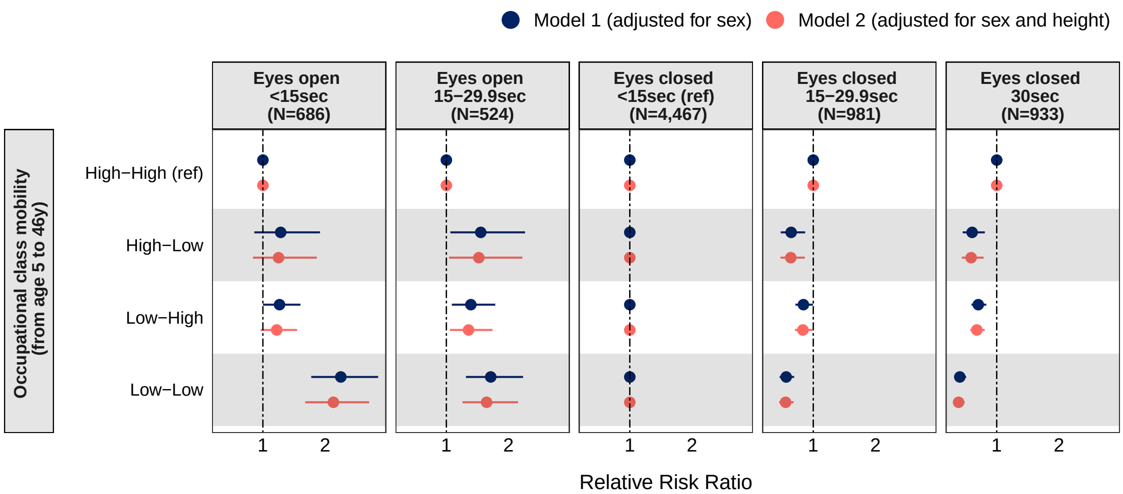


Notes: results are combined from analyses run across 50 imputed datasets.

5.4.2 *Social mobility*

As there were associations between childhood and adulthood SEP and standing balance performance, the role of social mobility in explaining these relationships was examined. As can be seen in Figure 5.4.3 and Appendix Table B.6.7, those in the High-High category had better balance performance than those in High-Low, Low-High and Low-Low social mobility groups. For example, in individuals who were in low occupational class in childhood and stayed in low occupational class in adulthood were 2.25 (1.78, 2.85) times more likely to achieve poorer balance (less than 15 seconds with eyes open) than better balance (less than 15 seconds with eyes closed) when compared with individuals who were in high occupational class during childhood and adulthood. Similarly, in participants with low childhood and adulthood occupational class, the RRR of achieving a better balance (30 seconds with eyes closed) versus poorer balance (less than 15 seconds with eyes closed) was 0.41 (0.33, 0.51) than participants in high occupational class during childhood and adulthood. While not quite as large as the relationship in the Low-Low group, participants in the High-Low and Low-High were also more likely to achieve poorer balance and less likely to achieve better balance when compared with participants in the High-High category.

Figure 5.4.3: Sex-adjusted associations of occupational class from childhood to adulthood and standing balance time at age 46 years in the BCS70 (N=7,591).



Notes: results are combined from analyses run across 50 imputed datasets.

5.4.3 Mediation analysis

5.4.3.1 Latent construct and mediation model assumptions

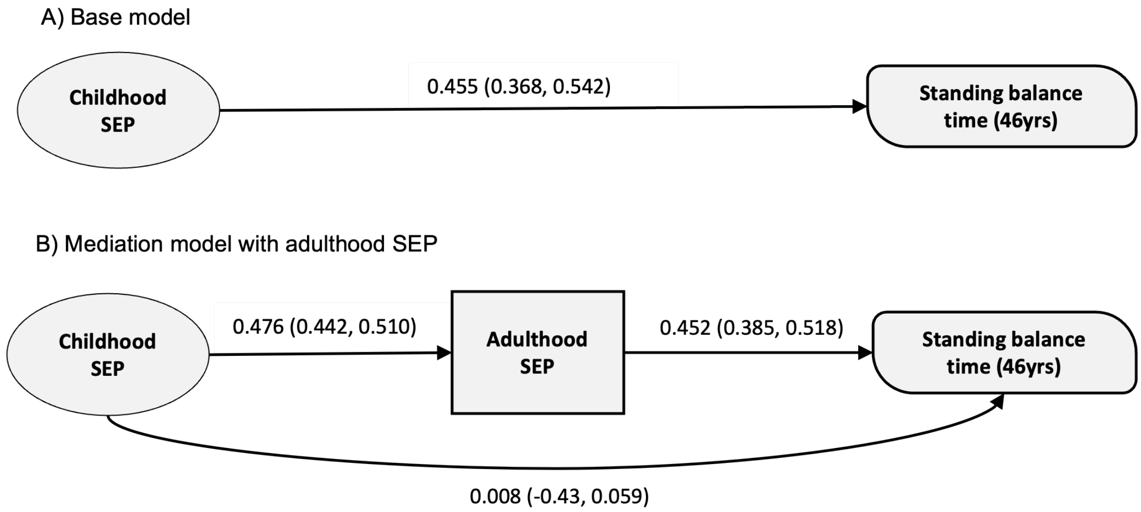
To examine mediators of the association between lower childhood and adulthood SEP and poorer standing balance, SEMs were built. Figure 5.4.4 displays the standardised measurement model for childhood and adulthood SEP and details how each observed SEP indicator is associated with the latent variable. The fit for the measurement model for the childhood and adulthood SEP latent construct was good (Model fit: CF1 = 0.970; RMSEA = 0.040; SRMR < 0.029). Appendix Table B.6.8 displays the sex and height-adjusted regression coefficients, which test Baron and Kenny's criteria for mediation (Baron and Kenny, 1986). Examining the exposure and mediator relationship for childhood SEP, childhood leisure-time physical activity (coefficient: 0.001; 95% CI: -0.020, 0.017), and adulthood leisure-time physical activity (coefficient: 0.015; -0.065, 0.036) did not meet the requirements for inclusion in the childhood SEP and standing balance performance mediation model. Similarly, adulthood leisure-time physical activity did not meet the requirements for inclusion in the mediation model for adulthood SEP (p=0.995). All other indicators described in Section 5.3.1 of this chapter met the criteria to be included as mediators.

5.4.3.2 Childhood SEP as an exposure

As shown in Figure 5.4.5, in the sex and height-adjusted model, there was an association between lower childhood SEP and poorer standing balance time (regression coefficient: 0.455 (95% CI; 0.368, 0.542)) – with a single increase in childhood SEP; there was a 0.455 increase in standing balance performance. However, when adulthood SEP was included in the model, the observed association was fully explained (regression coefficient= 0.008; -0.043, 0.059).

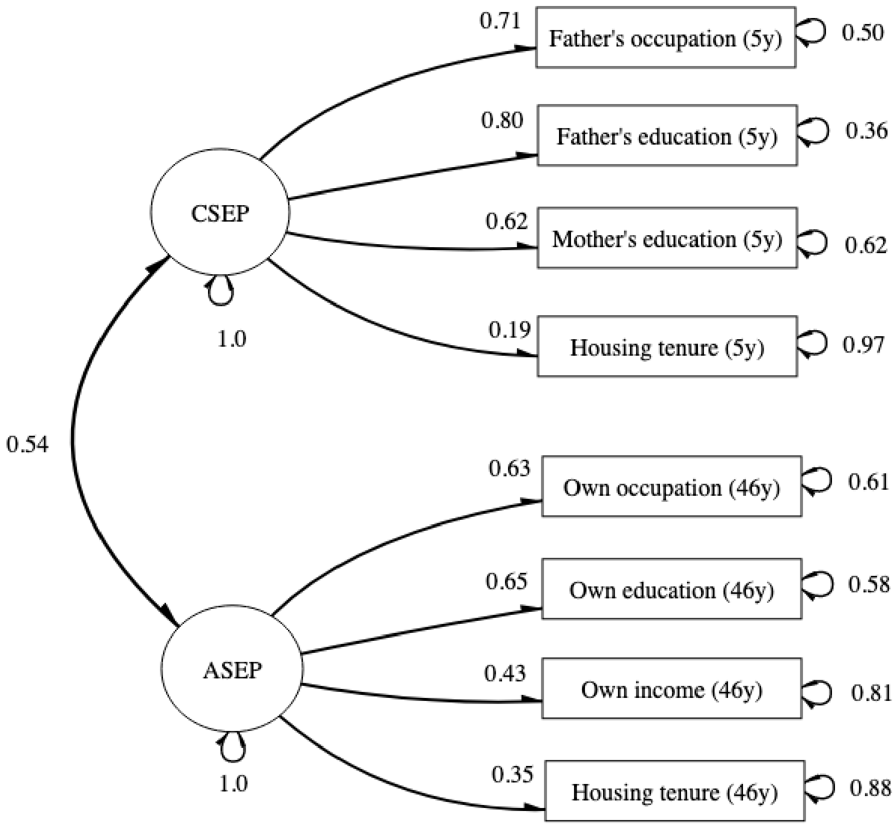
Table 5.4.1 present the results for the SEM model examining the mediators of the association between childhood SEP and standing balance time, which satisfactorily fit the data (model fit: CF1 = 0.910; RMSEA = 0.032; SRMR = 0.036). In this mediation model, the interrelationships between the covariates are considered; see Figure B.6.1in the Appendix for pathways coefficients between covariates in the mediation model. As seen in Table 5.4.1, adulthood SEP explained the majority of the association between childhood SEP and standing balance performance (proportion mediated: 57.8%; 95% CI: 43.3, 72.3). Additional mediators included adulthood BMI 13.3% (10.4, 16.3), childhood cognition (10.9%; 6.1, 15.7), adulthood sedentariness (3.9%; 1.3, 6.5), adulthood health status (3.6%; 2.0, 5.3), childhood coordination (3.2%; 1.3, 5.0), smoking (3.1%; 1.6, 4.5) and childhood BMI (1.1%; 0.1, 2.0). The factors which did not appear to play an important role in mediating the association between childhood SEP and standing balance performance were childhood health status, occupational activity and adulthood cognition ($p>0.08$).

Figure 5.4.5: Base model of the association between childhood SEP and standing balance time, and mediation model with adulthood SEP included.



Note: Basic mediation model with pathway coefficients displaying: Model A) Childhood SEP and standing balance performance at 46y adjusted for sex and height at 46y; Model B) Childhood SEP and standing balance performance at 46y adjusted for sex, height at 46y and adulthood SEP. The coefficients represent standardised regression coefficient which quantifies the amount a mediator/outcome increases if the mediator/exposure was increased by a unit of 1.

Figure 5.4.4: Standardised measurement model detailing the construction of childhood and adulthood SEP latent construct.



Circles represent latent variables, rectangles represent measured variables, and values next to lines show standardised relationships (loadings). Round arrows denote residual variances, and the arrow between childhood and adulthood SEP represents covariance. Model fit statistics are CF1 = 0.970, RMSEA = 0.040, and SRMR < 0.029.

Table 5.4.1: Mediation model testing the mediators for the association between lower childhood SEP and poorer standing balance performance at age 46.

Mediation Model	Pathway/direction of mediation	Coefficient†(95% CI)	% Mediated‡
Childhood SEP (CSEP)			
Direct effect	CSEP = Balance	0.007 (-0.046, 0.060)	-
Total Indirect effect (mediators)	CSEP = Mediators = Balance	0.301 (0.259, 0.342)*	-
Total effect	Direct effect + Total indirect effect	0.310 (0.261, 0.358*	-
Mediators§			
Adulthood SEP (ASEP)	↓ CSEP = ↓ ASEP = Poorer balance	0.179 (0.145, 0.213)*	57.8 (43.3, 72.3)
Adulthood BMI (46yrs)	↓ CSEP = ↑adult BMI = Poorer balance	0.041 (0.033, 0.05)*	13.3 (10.4, 16.3)
Childhood cognition (10yrs)	↓ CSEP = ↓ childhood cognition = Poorer balance	0.034 (0.02, 0.047)*	10.9 (6.1, 15.7)
Adulthood Sedentariness (42yrs)	↓ CSEP = ↑sedentariness = Poorer balance	0.012 (0.004, 0.020)*	3.9 (1.3, 6.5)
Adulthood health status (42yrs)	↓ CSEP = ↓ adult health = Poorer balance	0.011 (0.006, 0.016)*	3.6 (2.0, 5.3)
Childhood coordination (10yrs)	↓ CSEP = ↓ coordination = Poorer balance	0.01 (0.004, 0.016)*	3.2 (1.3, 5.0)
Smoking (42yrs)	↓ CSEP = ↑likelihood of smoking = Poorer balance	0.01 (0.005, 0.014)*	3.1 (1.6, 4.5)
Childhood BMI (10yrs)	↓ CSEP = ↑BMI = Poorer balance	0.003 (0.00, 0.006)*	1.1 (0.1, 2.0)
Childhood health status (10yrs)	↓ CSEP = ↑childhood health = Poorer balance	0.002 (0.00, 0.005)	0.8 (-0.1, 1.7)
Occupational activity (OA) (46yrs)	↓ CSEP = ↑OA = Better balance	-0.01 (-0.022, 0.001)	-3.2 (-7.2, 0.7)
Adulthood cognition (42yrs)	↓ CSEP = ↓ adult cognition = Poorer balance	0.011 (-0.006, 0.027)	3.4 (-1.9, 8.8)

Note: Results are pooled from SEM models run across 50 imputed datasets; Mediation model goodness of fit: Childhood SEP (CF1 = 0.910; RMSEA = 0.032; SRMR = 0.036); * $p<0.05$); †Effect estimates are standardised regression coefficients with bootstrapped 95% CI's; ‡Proportion mediated = indirect effect (mediated) /total indirect effect*100; §The presented results are for a single model and any pathway shown takes into account for the interrelationships between the different mediators.

5.4.3.3 Adulthood SEP as an exposure

Similar to childhood SEP, the mediation model for adulthood SEP satisfactorily fitted the data (model fit: CF1 = 0.921; RMSEA = 0.038; SRMR = 0.039). Lower adulthood SEP was associated with poorer standing balance time (regression coefficient: 0.862; 95% CI= 0.770, 0.955), with modest associations remaining even after childhood SEP was taken into account (0.330; 0.243, 0.418).

As can be seen in Table 5.4.2, the factors that partially mediated the observed association between lower adulthood SEP and poorer standing balance performance included occupational activity, which negatively mediated 9.8% (-18.0, -1.6) of the effect; negative mediation exists as with each unit increase in adulthood SEP, there was a decrease in occupational activity, and with each unit decrease in occupational activity, there was a decrease in standing balance time. Smoking accounted for 7.5% (3.5, 11.5) of the observed association, and additional mediators were adulthood health status (4.7%; 2.6, 6.7), adulthood BMI (4.5%; 2.2, 6.7) and adulthood sedentariness (3.7%; 1.3, 6.0). For adulthood cognition, there was no evidence of a mediating role in the association between lower adulthood SEP and poorer standing balance performance (p>0.1). Appendix Figure B.6.2 contains the pathway coefficients in the mediation model.

5.4.4 Sensitivity analyses

Findings from the sensitivity analysis, which excluded those unable to perform the standing balance performance test due to health reasons (Appendix Table B.7.7), were similar to the main analyses. Similarly, the seven-category standing balance outcome results were not different from the results of the five-category standing balance outcome (Appendix Table B.7.8). Therefore, using the five-category standing balance outcome did not impact our results.

Table 5.4.2: Mediation model testing the mediators for the association between lower adulthood SEP and poorer standing balance performance at age 46.

Mediation Model	Pathway/direction of mediation	Coefficient†(95% CI)	% Mediated‡
Adulthood SEP (ASEP)			
Direct effect	ASEP = Balance	0.330 (0.243, 0.418)*	-
Total indirect effect (mediators)	ASEP = Mediators = Balance	0.056 (0.006, 0.105)*	-
Total effect	Direct effect + Total indirect effect	0.386 (0.327, 0.445)*	-
Mediators§			
Occupational activity (OA) (46yrs)	↓ ASEP = ↑OA = Better balance	-0.038 (-0.072, -0.004)*	-9.8 (-18.0, -1.6)
Smoking status (42yrs)	↓ ASEP = ↑likely of smoking = Poorer balance	0.029 (0.014, 0.044)*	7.5 (3.5, 11.5)
Adulthood health status (42yrs)	↓ ASEP = ↓ adult health = Poorer balance	0.018 (0.01, 0.026)*	4.7 (2.6, 6.7)
Adulthood BMI (46yrs)	↓ ASEP = ↑BMI = Poorer balance	0.017 (0.008, 0.026)*	4.5 (2.2, 6.7)
Adulthood Sedentariness (42yrs)	↓ ASEP = ↑sedentariness = Poorer balance	0.014 (0.005, 0.023)*	3.7 (1.3, 6.0)
Adulthood cognition (42yrs)	↓ ASEP = ↓ adult cognition = Poorer balance	0.015 (-0.006, 0.036)	3.9 (-1.5, 9.4)

Note: Results are pooled from SEM models run across 50 imputed datasets; In this mediation model, childhood SEP and childhood factors including body size and healthy behaviours were included as covariates; Mediation model goodness of fit: Adulthood SEP (CF1 = 0.921; RMSEA = 0.038; SRMR = 0.039); * Statistically significant (p<0.05); †Effect estimates are standardised regression coefficients with bootstrapped 95% CI's; ‡Proportion mediated = indirect effect (mediated) /total indirect effect*100; §The presented results are for a single model and any pathway shown takes into account for the interrelationships between the different mediators.

5.5 Discussion

5.5.1 Summary of main findings and fit with hypotheses

As hypothesised, there were associations between lower childhood and adulthood SEP and poorer standing balance performance at 46 years. Childhood SEP associations were fully explained by adulthood SEP, childhood BMI, cognition, adulthood BMI, health status, sedentariness, coordination and smoking. Adulthood SEP associations were partially explained by occupational activity, BMI, sedentariness, health status and smoking. Further, there was evidence of continuity of SEP from childhood to adulthood, which could explain why a large proportion of the association between childhood SEP and poorer standing balance performance was mediated by adulthood SEP.

5.5.2 Comparison of main findings with the existing literature and explanations

5.5.2.1 Childhood and adulthood SEP and standing balance performance

Findings in this chapter advance the available evidence of an association between lower childhood SEP and poorer balance performance at a younger age than was examined in previous studies. Associations between lower childhood SEP and poorer standing balance performance in the BCS70 are similar to those found in the NSHD from ages 53 to 69 years (Blodgett et al., 2020; Hurst et al., 2013; Kuh et al., 2006; Murray et al., 2013; Strand et al., 2011a), and the *Boyd Orr* at older ages (Birnie et al., 2011b). In addition to this, findings reported in this chapter were different to those from a Danish study consisting of The *Metropolit Cohort* (Petersen et al., 2018), which included only boys born in the 1950s and had utilised father's occupational class, and the *Copenhagen Perinatal Cohort* which had boys and girls born in the 1960s and had used parental social class. Therefore, observed differences between our findings and the Danish study could be due to a cohort effect and/or different in the indicators used to ascertain childhood SEP.

In the following subsections, the covariates that mediated around 10% or more of the associations between childhood and adulthood SEP and standing balance performance will be discussed.

5.5.2.2 Tracking SEP

This chapter adds novel insights to the current evidence base on the associations between childhood SEP and standing balance performance by formally examining the mediators of these associations. In the association between lower childhood SEP and poorer standing balance performance, adulthood SEP and other childhood and adulthood factors, including adulthood BMI and cognition, fully explained these associations. There was evidence to suggest that SEP tracked from childhood to adulthood, and that this tracking largely explained findings of associations between childhood SEP and standing balance performance. For instance, when the association between lower childhood SEP and poorer balance performance was adjusted for adulthood SEP only, adulthood SEP completely mediated the observed association. However, in the final mediation model that took into account the interrelationships between the different mediators, adulthood SEP mediated over half of the observed association between lower childhood SEP and poorer standing balance performance. This was further confirmed through additional analyses, which showed a cumulative association of lower childhood and adulthood SEP on poorer standing balance time at age 46 years.

These results are similar to findings from a systematic review (Birnie et al., 2011a) whereby adulthood SEP explained observed associations between lower childhood SEP and poorer standing balance performance. Results are also similar to those of the *Boyd Orr* cohort (Birnie et al., 2011b), which showed that the adverse effects of lower SEP on standing balance performance accumulate across life. Indeed, childhood SEP is a distal factor that impacts many factors across life that are important for standing balance performance. Adulthood SEP is a continuation of childhood SEP, hence why it is the strongest indirect pathway in the association between childhood SEP and standing balance performance. In line with the social mobility findings, which meant that SEP tracked from childhood to adulthood, the continuity of SEP from one generation and life stage to another means that the resources, opportunities, and social and educational capital available to an individual during childhood are likely to follow them through to adulthood (Horgan, 2009; Mazumder, 2005).

After the inclusion of the adulthood mediators, there is still a large proportion of the direct effect between adulthood SEP and standing balance time that remains to be explained. This unexplained direct effect suggests that there may be other important mediators (Zhao et al., 2010). A potential omitted variable is knee pain; it is socioeconomically patterned and has previously been linked with poor standing balance performance (Blodgett et al., 2020; Kiadaliri et al., 2017). This omitted variable could explain some of the association between adulthood SEP and standing balance, as knee pain can make it difficult to maintain standing balance as it can impair muscle function and coordination.

There could also be residual mediation related to the limitation of some of the measures used. An example of this could be leisure-time physical activity, which is socioeconomically patterned, and lower levels of it are associated with poor standing balance performance (Blodgett et al., 2020; R. Cooper et al., 2011c; Elhakeem et al., 2015). In the BCS70, leisure-time physical activity did not meet the definition of a mediator, as it was not associated with SEP. Therefore, leisure-time physical activity was not included in the mediation models. This could be due to the fact that it was a self-report measure that only captured the frequency dimension of leisure-time physical activity. In support of this claim, previous findings from the BCS70 showed that lower childhood SEP was associated with lower participation in leisure-time physical activity using a composite variable that indicated the frequency, duration and intensity of ten physical activities over eight weeks at age 34 years (Juneau et al., 2014).

5.5.2.3 Body mass index

Adulthood BMI was a mediator in the associations between lower childhood and adulthood SEP and poorer standing balance performance. Within the literature, lower SEP is often associated with higher levels of BMI, especially in more recently born cohorts (Bann et al., 2018; Norris et al., 2020; Senese et al., 2009), and higher BMI is often associated with poorer performance in standing balance (Blodgett et al., 2020). Moreover, childhood BMI also mediated the association between childhood SEP and standing balance performance (proportion mediated: 13.3%, 95% CI; 10.4, 16.3), though not as much as adulthood BMI (1.1%; 0.1, 2.0). The low mediating effect of childhood BMI compared to adulthood BMI could be due to the change in trends in socioeconomic inequalities in BMI over time, with evidence showing inequalities progressively increasing with older ages in several British birth cohort studies (Bann et al., 2018; Norris et al., 2020).

5.5.2.4 Cognition

Cognition is essential to standing balance performance (Blodgett et al., 2020; Kuh et al., 2009). Standing balance requires cognitive processing of somatosensory feedback, which is the sum of afferent signals from distal body regions, such as the sole of the feet, muscle spindles and Golgi tendon organs of active muscles and other sensory inputs, including vestibular and visual providing information about the body's position and movements (Chapman et al., 1987; Manto et al., 2012; Wolpert and Kawato, 1998; Wolpert and Miall, 1996). In the mediation analyses, childhood cognition was the third-largest mediator in the association between childhood SEP and standing balance time. Childhood SEP is related to childhood cognition as parental education, and socioeconomic circumstances could determine access to opportunities and resources for the activities that are fundamental for a child's cognitive and coordination development (Hoffmann, 2018; A. Sullivan and Brown, 2015; Vandorpe et al., 2012). Adulthood cognition was less likely to mediate the association between childhood SEP and standing balance performance. An explanation could be that, as childhood cognition was ascertained at age ten years, just before the peak attainment of standing balance in early adolescence (Peterson et al., 2006), cognition could have its strongest association with standing balance during childhood as the underlying physiological requirements of balance (including neurocognitive processes) are established early in life and then track (Blodgett et al., 2022a)

5.5.2.5 Occupational activity

Similar to the findings in Chapter 4 on grip strength, occupational activity was the largest mediator between adulthood SEP and standing balance performance. It is a negative mediator in this association, as lower adulthood SEP is associated with higher occupational activity, and higher occupational activity is associated with better standing balance performance. Within the literature, occupational activity is related to jobs that require manual and physical work (Beenackers et al., 2012; Prince et al., 2020; Steele and Mummery, 2003), and individuals in occupations that have high balance demands do better in standing balance performance than individuals in jobs that do not place importance on balance abilities (Birnie et al., 2011b; Punakallio, 2003).

Findings from the *Boyd Orr* show that lower adulthood occupations that are high in occupational activity were associated with better balance performance than in adulthood occupations that are lower in occupational activity (Birnie et al., 2011b). In the relationship between occupational activity and standing balance performance, specificity is important. For example, research on occupations high in occupational activity has shown that construction workers have better balance than firefighters (Punakallio, 2003). Both groups had better balance performance than home and nurse care workers, who spent more time on their feet (Punakallio, 2003).

5.5.3 Methodological consideration

One of the key strengths of the work presented in this chapter is that the mediators between childhood and adulthood SEP and standing balance performance were examined in a younger and relatively healthy cohort than previously done (Birnie et al., 2011a; Birnie et al., 2011b; Blodgett et al., 2020; Hurst et al., 2013; Kuh et al., 2006; Murray et al., 2013; Strand et al., 2011a), making it possible to disentangle associations and their pathways before the onset of age-related diseases. Moreover, the findings in this chapter show that while childhood SEP may play an important role in standing balance performance, there are still opportunities to reduce inequalities in balance by intervening on factors in adulthood such as BMI, occupational activity and sedentary behaviour. As previously discussed in Section 4.5.4 of Chapter 4, additional strengths of the work presented in this chapter include the use of a cohort that is nationally representative at birth with prospectively ascertained SEP, with many childhood and adulthood life course factors. Similarly, the disadvantages of using the BCS70 are the same for this chapter. As with most population-based studies, attrition is a key disadvantage faced by the cohorts in this chapter (something that will be discussed in detail in Chapter 7). However, selection bias related to complete case analyses was minimised using multiple imputation methods to account for data assumed to be missing at random.

Additional limitations include modelling standing balance time through categorisation. There was a ceiling effect in both the eyes open and eyes closed balance measures (measured continuously), as the maximum time for both tests was 30 seconds. As a result, all participants did not progress to the eyes closed test, which meant that categorisation was the only viable way of including people who did both measures in the same variable. Therefore, modelling standing balance time through categorisation impacted the variability needed to detect differences in the association between SEP and standing balance performance (this will be further discussed in Chapter 7). Moreover, a large proportion of the study participants were in the Eyes Closed <15sec group. Findings from sensitivity analyses, which further re-categorised this group into additional groups, show that associations were identical in both categorisations (5 vs 7 group categorisation). Another methodological limitation could be the use of traditional mediation methods, as it does not account for potential interactions between the exposure and the mediator (MacKinnon et al., 2020). Causal mediation, which uses counterfactual modelling, is an alternative approach that accounts for these draws (MacKinnon et al., 2020; VanderWeele, 2015). However, given that latent constructs were used and mediators with varying interrelationships were included, it was not possible to use causal mediation methods. Therefore, as it is flexible and has features that fit the needs of the questions of this thesis, SEM methods were better suited to the analyses of this chapter (Hayes, 2013).

5.5.4 Summary

In this chapter, using data from the BCS70, the associations and pathways between childhood and adulthood SEP and standing balance performance at age 46 years were examined. There was evidence of an association between lower childhood SEP and poorer balance performance. The pathways tested show that these associations were explained mainly by adulthood SEP, but also by neurocognitive factors, health status and body size. Similarly, there were associations between lower adulthood SEP and poorer standing balance performance. These associations were partially mediated by factors including occupational activity, body size, health status, and behavioural factors, including smoking and sedentariness. Therefore, policies and interventions aiming to improve inequalities in balance outcomes in adulthood should consider these pathways; further implications of this work will be discussed in Chapter 7 of this thesis. In the next chapter, findings and research questions raised in Chapter 4 are further examined in the next Chapter; this involves examining the intersectional inequalities in SEP, age, sex and ethnicity on grip strength within the UKB.

CHAPTER 6

Intersectional inequalities in grip strength within the UK Biobank Study

Building on findings from Chapter 4, this chapter aims to further interrogate inequalities in grip strength using data from the UK Biobank study. It investigates possible socioeconomic and ethnic differences in grip strength and the interactions between socioeconomic position and ethnicity, and also examines whether these associations vary by age and sex. Additionally, this chapter builds upon the findings of Chapter 4 by investigating whether physical activity in the occupational domain explains any association between occupational class and grip strength in working-age men.

6.1 Introduction

There are clear age differences in maximal grip strength across the life course (Andersen-Ranberg et al., 2009; R. Cooper et al., 2011a; Dodds et al., 2014; Dodds et al., 2016; Frederiksen et al., 2006; Lindle et al., 1997; Seino et al., 2014; Spruit et al., 2013) — grip strength levels increase through childhood and adolescence, peak in midlife, before gradually decreasing thereafter. There are also sex differences in maximum grip strength, with men having higher mean levels of maximum grip strength than women across adulthood (Andersen-Ranberg et al., 2009; R. Cooper et al., 2011a; Dodds et al., 2014; Frederiksen et al., 2006; Lindle et al., 1997; Seino et al., 2014; Sialino et al., 2019; Spruit et al., 2013). Furthermore, findings from Chapter 4 using the BCS70 show that the associations between SEP and grip strength are different for men and women, with men in manual occupations having higher grip strength levels at age 46 years than men in higher SEP occupations. Differences in the relationship between SEP and grip strength are often attributed to several key covariates including body size, health status, and physical activity in the occupational domain (discussed in detail in Chapters 2 and 4). However, the extent to which the associations between SEP and grip strength vary by ethnicity remains unclear.

Evidence shows that there are ethnic differences in maximum grip strength (Arokiasamy and Selvamani, 2018; Arokiasamy et al., 2021; Dodds et al., 2016; Duchowny et al., 2017; Haas et al., 2012; S. Jones et al., 2020; Leong et al., 2016; Leong et al., 2015; McGrath et al., 2019; Ntuk et al., 2017; Ong et al., 2017; Thorpe et al., 2016; Woo et al., 2014), and previous literature has suggested that these differences may be due to variations in anthropometric factors such as height, adiposity and muscle quality (Deurenberg et al., 1998; Goodpaster et al., 2006; Heymsfield et al., 2016; Koopman et al., 2015; Rantanen et al., 1998; Silva et al., 2010; Yap et al., 2001), as well as social and environmental factors (Duchowny et al., 2017; Haas et al., 2012; Thorpe et al., 2016). In addition, socioeconomic factors such as occupation, education and levels of deprivation may also vary by ethnicity. Nevertheless, there is clear evidence that demonstrates disparities in health that are associated with ethnicity and socioeconomic position, with minoritised ethnic groups experiencing inequalities that are significantly larger than those experienced by non-minoritised ethnic groups (Davey Smith et al., 2000; Ren et al., 1999; Ward et al., 2004; D. Williams et al., 1997). Given these ethnic differences in SEP and grip strength, there is a need to investigate associations between adult SEP and grip strength by ethnicity. Examining the interactions between age, sex, ethnicity and SEP in relation to maximal grip strength requires an intersectional perspective.

6.1.1 Intersections and interactions

Intersectionality, which was introduced in Section 1.3, helps us understand how different social identities, like age, sex, ethnicity, and socioeconomic position, can affect an individual's health. It shows that these identities intersect and can compound to create unique health outcomes. In the last decade, there has been an emergence of quantitative intersectionality, enabled by the development of new methodological approaches (Bauer et al., 2021; Guan et al., 2021). This allows for the examination of complex relationships between socioeconomic adversity and other intersecting social identities through the testing of statistical interactions.

Social identities may have either additive or multiplicative effects on variables of interest. In the case of additive effects, the effect of each social identity is independent of the other, and their combined impact is equal to the sum of their individual effects. On the other hand, in the case of multiplicative effects, the effect of one social identity on the outcome variable changes depending on the level of the other social identity, resulting in a non-linear relationship between the two (Greenland, 2009). Social identities are often treated as additive factors in quantitative health research. However, if interaction effects are not appropriately considered in analyses, it can lead to inaccurate estimates of the relationship between variables and incorrect conclusions about the strength of that relationship (Bauer et al., 2021; McCall, 2005).

The presence of multiplicative effects can be formally examined through the test of statistical interactions. If present, they can be handled by including interaction effects in the analysis or through stratification (Greenland, 2009; VanderWeele and Knol, 2014). An example of the importance of considering multiplicative effects in health research can be seen in a study that examines sex and racial bias in cardiac catheterisation in the USA (Schulman et al., 1999). In their analyses, the authors did not include interaction terms for ethnicity and sex. They concluded that men and white participants were more likely than women and black participants to be referred for cardiac catheterisation. However, in a secondary analysis that included interaction terms to consider the combined effects of ethnicity and sex, it was found that Black women were the only group with lower odds of referral (Bowleg and Bauer, 2016). This highlights the importance of considering the multiplicative nature of group-level identities in research.

6.1.2 Intersectionality and grip strength

To date, there has only been one study on intersectional inequalities in grip strength (Holman et al., 2022). Using the UK Biobank study, Holman et al. (2022) showed that the intersection of age, sex, ethnicity, and education accounted for more of the variation in grip strength than neighbourhood deprivation, and there are clear differences in grip strength levels by ethnicity. For instance, Caribbean men in less deprived neighbourhoods had the highest levels of grip strength, while Indian and Pakistani women from the most deprived neighbourhoods had the lowest grip strength levels (Holman et al., 2022). This study was one of the first to use quantitative intersectional methods in examining inequalities in markers of healthy ageing within a UK population. Instead of focusing on a single measure, the study employed multiple markers of healthy ageing, also including blood sugar levels, and levels of inflammatory markers. The authors presented the social patterning of grip strength but did not consider covariates that vary by age, sex, and ethnicity, which may be socially patterned, such as height and adiposity. The role of health and behavioural factors, including co-morbidities, smoking, sedentary behaviour and leisure-time, and occupational physical activity, in these intersectional differences, has therefore yet to be fully interrogated.

The paucity of evidence on ethnic differences in the associations between adult SEP and grip strength could be due to limited ethnic diversity in the study samples typically used to study SEP differences in grip strength. This is exemplified by the analyses in the BCS70 presented in Chapter 4, where it was not feasible to examine ethnic differences because of the low number of participants from minoritised ethnic groups in the cohort (there were 200 people from minoritised ethnic groups in the BCS70, and 986 participants with missing ethnicity data). Additionally, in a study of ethnic differences in physical function by age using data from the UKHLS (E. Williams et al., 2020), despite oversampling minoritised ethnic groups in the UKHLS, there were not enough participants from minoritised ethnic groups with grip strength measurements to examine this. Therefore, analyses instead focused on self-reported measures of physical function to better understand the lived experiences of participants.

Taking an intersectional lens to examine inequalities in grip strength is important as it captures the complex and multidimensional ways different social identities and economic factors interact, which reflects the *real world*. Embracing this complexity in experience and embodiment is useful for population-level interventions, as it allows policies to be tailored and targeted to meet the needs of different high-risk groups (Bauer, 2014; Bowleg, 2012; Holman et al., 2021).

6.1.3 Age-differences

In Chapter 4, associations of adulthood occupational class and educational level with grip strength were found in a middle-aged population of British adults (BCS70): lower occupational class and educational level were associated with weaker grip strength among women. Conversely, for men, lower occupational class and educational level were associated with a stronger grip, largely explained by higher levels of occupational activity in skilled manual occupational groups. Within the literature, evidence points to a change in the direction of the association at older ages (Carney and Benzeval, 2018; Hurst et al., 2013; Kuh et al., 2019; Strand et al., 2011a). In previous analyses, using data from the UKHLS in participants aged 16 to 99 years, it was shown that there was an association between higher educational level and stronger grip in middle-aged men. However, this association changed direction at older ages, with lower education associated with weaker grip strength (Carney and Benzeval, 2018).

In findings from the NSHD, the oldest British birth cohort, associations between lower lifetime occupational class and educational level with weaker grip was found as the cohort aged. For example, there were mixed associations at age 53 years (Kuh et al., 2019; Strand et al., 2011a), but associations between lower SEP and weaker grip strength were seen at age 60-69 years (Hurst et al., 2013; Kuh et al., 2019). Moreover, several other studies also show associations between lower adulthood occupational class and weaker grip strength at older ages. These studies include the Hertfordshire Cohort Study at age 59-73 years (Syddall et al., 2009), the *Lothian Birth Cohorts 1921* at age 79-87 years (Starr and Deary, 2011), and the *Survey of Health Ageing and Retirement in Europe* at age 65-90 years (Kröger et al., 2016). Although there is consistent evidence in these studies, and some evidence showing a change in association with age, indicating lower SEP is associated with weaker grip strength at older ages, there is still a gap in evidence to determine the existence of associations between occupational class and grip strength in men across various age groups within the same study cohort, and whether physical activity in the occupational domain can explain these differences, as shown in Chapter 4. This is particularly important for men in manual occupations, as they may become vulnerable to muscle weakness during retirement when the protective effects of occupational activity diminish. Therefore, gaining knowledge about these patterns of associations at older ages may inform the development of targeted interventions.

6.2 Chapter aims and research questions

The work in this chapter builds on findings from previous literature and addresses some of the gaps highlighted in Chapter 4. It examines the possible socioeconomic and ethnic differences in grip strength and the interactions between socioeconomic position and ethnicity, and also examines whether these associations vary by age and sex. The chapter also investigates whether these associations are explained by several important factors in adulthood. Additionally, the chapter examines associations between occupational class and grip strength, whether these associations exist across various age groups, and if higher occupational activity levels explain them.

As intersectional inequalities have been shown to contribute to differences in grip strength levels in adulthood (Holman et al., 2022), it was hypothesised that there would be associations between adulthood SEP and grip strength in the UKB. However, it was expected that these associations would vary in strength and direction by sex, age, and ethnicity. As previously shown in the UKHLS (Carney and Benzeval, 2018) and Chapter 4 of this thesis, it was hypothesised that there would be associations between lower educational level and higher grip strength in men but not in women. For women, it was hypothesised that lower educational level would be associated with weaker grip strength. As the IMD is a composite SEP indicator capturing neighbourhood deprivation, it was anticipated that associations would be different from those of educational level. Additionally, it was hypothesised, based on existing literature, that Black participants would display higher levels of grip strength, while South Asian participants were likely to show the lowest levels. These differences were expected to be explained by differences in height, adiposity, health status and behavioural factors.

In Chapter 4, there was evidence that lower occupational class was associated with higher grip strength in men, primarily explained by higher levels of occupational activity in the skilled manual occupational group. As such, it was hypothesised that in the UKB, manual occupations would be associated with higher grip strength in men, and higher occupational activity levels would play an important role in these associations. Additionally, as there is evidence showing associations between lower occupational class and higher grip strength changing direction with older age in men (Hurst et al., 2013; Kröger et al., 2016; Kuh et al., 2019; Strand et al., 2011a), it was also hypothesised that the associations in men of higher occupational activity in the UKB would weaken with age and possibly change direction. To investigate these hypotheses, the following questions are examined:

1. Is there a relationship between SEP and grip strength at baseline in the UKB and does this vary by age and sex?
2. Is there a relationship between ethnicity and grip strength at baseline in the UKB and does this vary by age and sex?
3. Are there interactions between SEP and ethnicity in their relationships with grip strength?
4. If there are relationships in Questions 1 and 2, to what extent do important factors in adulthood, including height, adiposity and health and behavioural factors, explain these relationships?
5. Is there a relationship between occupational class and grip strength in working-age men?
6. If there is a relationship in Question 4, is it observed across different age groups, and is it explained by higher occupational activity levels?

6.3 Methods

6.3.1 *Variables used in analyses*

In this chapter, the analyses presented used data from the UKB's baseline wave. The analytic sample included 497,844 men and women with complete grip strength data at baseline and information on age and ethnicity. The main explanatory variables used in the analyses were highest qualification, IMD, and occupational class. Anthropometric variables included height, waist-to-hip ratio, and body fat percentage. The health covariate used was co-morbidity, while the covariates for behavioural factors were smoking status, sedentary behaviour, physical activity, and occupational activity. The measurement, categorisation, and description of the outcome, explanatory variables, and covariates were presented in Chapter 3 (Section 3.2.7).

6.3.2 Statistical analyses

Given that previous studies, including the work presented in Chapter 4, have shown sex differences in SEP and grip strength associations (Birnie et al., 2011a; Carney and Benzeval, 2018), it was decided a priori that all analyses would be sex-stratified. Formal tests of interaction were conducted to investigate whether the associations of SEP and ethnicity with grip strength varied by age. Formal tests of interaction were also conducted to assess whether the associations between SEP and grip strength varied by ethnicity. Considering the large statistical power of the UKB, there was potential to detect statistically significant effects that were not meaningful (Lin et al., 2013; Siontis and Ioannidis, 2011). Therefore, a decision was made not to solely rely on p-values in the interpretation of the tests of interaction, as they can be misleading (Amrhein et al., 2019; G. Sullivan and Feinn, 2012). Formal interaction tests were supplemented with an examination of the regression results and interaction plots using forest plots. If meaningful interaction effects were observed, models were stratified by age or/and ethnicity; if not, models were adjusted for age and/or ethnicity.

Linear regression models were first used to test the sex-specific associations between both indicators of adulthood SEP (IMD and highest qualification achieved) and grip strength (Question 1); models were also run to examine whether these associations varied by age (Question 1). Additional models were then used to examine the sex-specific relationship between ethnicity and grip strength at baseline, and whether they varied by age (Question 2). Following up on Question 1, models were run to test whether there were interactions between SEP and ethnicity in their relationships with grip strength (Question 3). Finally, associations between occupational class and grip strength were examined among working men of working age (65 years and below) (Questions 5 and 6). It was decided a priori to stratify the analyses by age in order to test for age-related differences in the associations between occupational class and grip strength. Therefore, no formal test of interaction was undertaken for these analyses.

All regression models were adjusted sequentially (Question 4), and the models were: Model 1) unadjusted (or age-adjusted if there was no overall evidence of age interaction); Model 2) height; Model 3) adiposity (waist-to-hip ratio and body fat percentage); Model 4) health and behavioural risk factors (co-morbidity, smoking status, sedentary behaviour, leisure-time physical activity, and physical activity in the occupational domain). For highest qualification and IMD, there was an additional model (Model 5) which adjusted for ethnicity if no overall evidence of ethnicity interaction was observed between these two variables. To understand the contribution of each covariate in the association between occupational class and grip strength decompositional models of Model 4, which individually adjusted for health and behavioural factors, were also presented (Question 6).

6.3.3 *Sensitivity analyses*

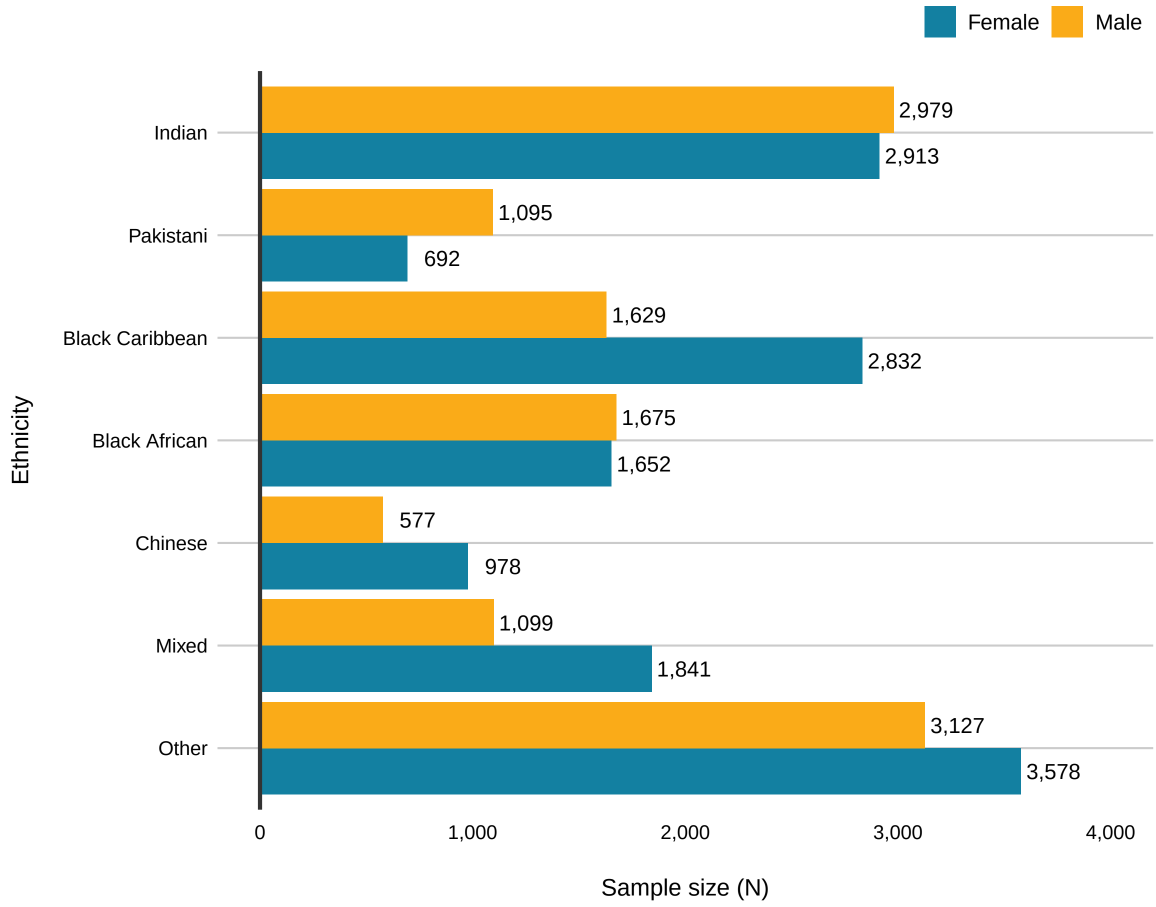
Sensitivity analyses were conducted to check that the results presented were robust and not influenced by the analytical decisions made. Firstly, to test the impact of including participants who were unable to complete the grip strength assessment due to health reasons (N=269) (as described in Chapter 3, Section 3.2.7.3), analyses testing the main associations between SEP and grip strength were rerun on a sample excluding these participants. Secondly, to evaluate the influence of the coding decisions for ethnicity, an additional analysis was carried out using an alternative coding of ethnicity as per Holman et al. (2022), which included more categories as displayed in Figure 6.3.1.

6.3.4 *Missing data*

The UKB data had missing data ranging from 7.7% for occupational activity to 0% for occupational class. To prevent selection bias as a result of complete case analysis, multiple imputation was used to impute missing values for participants with complete data on grip strength, sex, age, and ethnicity, including 269 individuals unable to provide valid data due to health reasons (total N=497,844). See Appendix Table C.1.1 for the proportion of missing data in each variable, and Appendix Table C.2.1, which compares the distributions of variables included in the multiple imputation models by the completeness of data.

The stratified multiple imputation method used in the BCS70, to account

Figure 6.3.1: Alternative categorisation of ethnicity minoritised ethnic groups, along with the sample size of each group in the UKB.



for sex interactions observed in Chapter 4, was not sufficient to account for the multiple interaction effects in UKB, which includes possible age, sex, ethnicity, and SEP interactions. A more complex approach, the *Classification and Regression Tree* method, was used for multiple imputation to handle the large number of interactions in the UKB data imputation to handle the large number of interactions in the UKB data (Burgette and Reiter, 2010). This approach, which uses a recursive partitioning decision tree, can handle both continuous and categorical variables and accurately model complex, nonlinear structures in large datasets without assuming parametric distributions or requiring data transformations (Burgette and Reiter, 2010; Doove et al., 2014). This method has been shown to produce reliable inferences compared to other multiple imputation methods, such as predictive mean matching and logistic regression (Burgette and Reiter, 2010; Doove et al., 2014).

Given that multiple imputation methods are often computationally expensive for large datasets, 12 imputations were utilised. Analyses were run on the 12 imputed datasets created, and estimates were combined using Rubin's rule (Little and Rubin, 2017). As the results from observed and imputed datasets were similar (Appendix Table C.4.1), only results from analyses run on imputed datasets are presented in the main text.

6.4 Results

The descriptive results for the outcome, explanatory variables and covariates are described fully in Section 3.2.7 of Chapter 3.

6.4.1 What are the overall associations between the different indicators of SEP and grip strength?

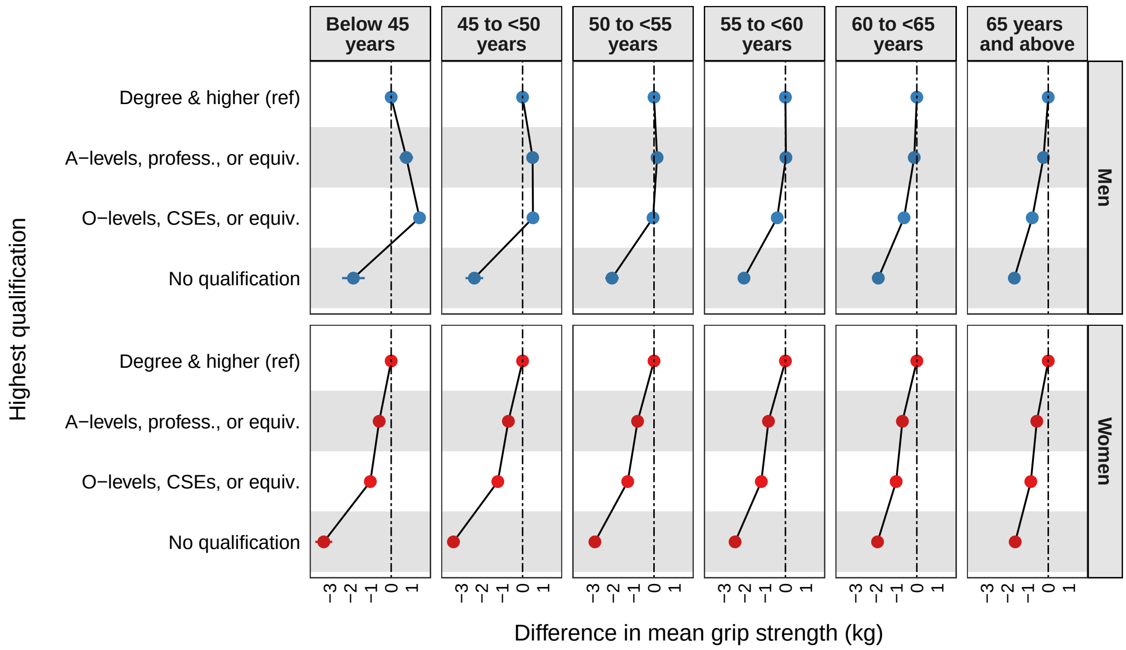
6.4.1.1 Interactions between SEP and age group

To ensure that age is appropriately accounted for in the main tests of the associations between SEP and grip strength, the first step involved testing for the interaction of age in the relationship between SEP and grip strength. When examining the interactions between age and educational level, the results from the formal test of interaction were statistically significant in men and women (p<0.0001). As presented in Figure 6.4.1a and Appendix Table C.3.1, there was an association between lower educational level and weaker grip strength in women. These patterns of associations were consistent across the age groups and so considering the total sum of evidence, the age interaction effects observed for women were considered to be not meaningful. Therefore, analyses in women were adjusted by age. In men, results from the formal test of interaction were consistent with the trends seen in the forest plot, as the pattern of association changes direction with age. Accordingly, analyses between educational level and grip strength were stratified by age in men.

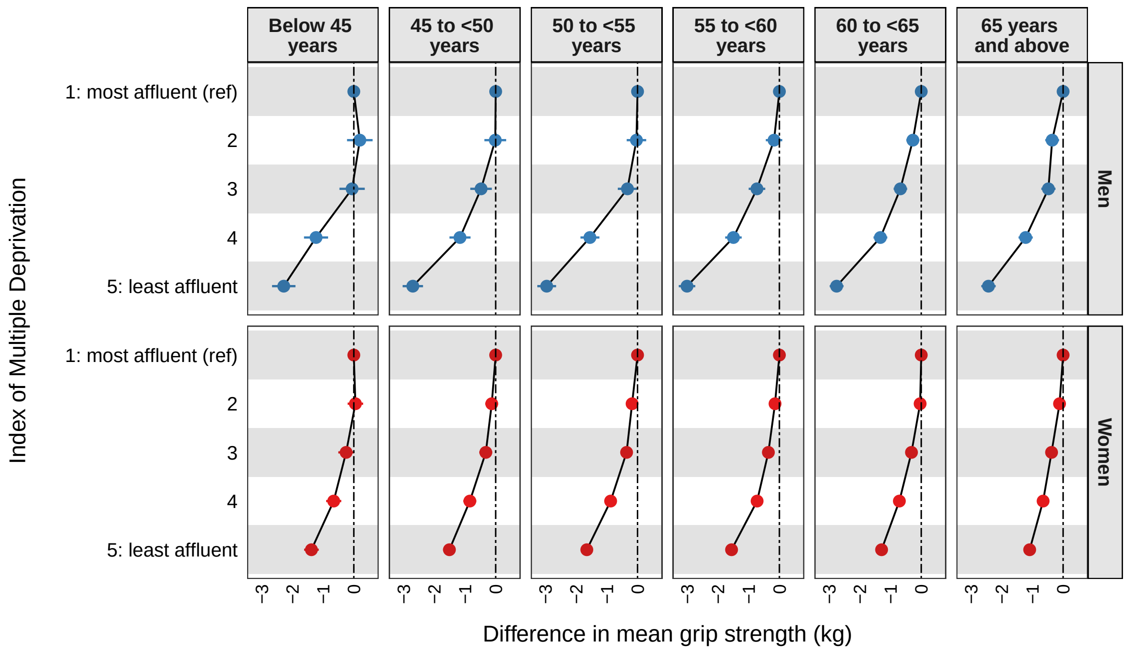
For the association between IMD and grip strength, there were statistically significant age interactions, as indicated by the formal test of interaction in men and women (p<0.0001). However, these results were inconsistent with those of the forest plot (Figure 6.4.1b and Appendix Table C.3.1), which show similar patterns of association between lower IMD and weaker grip strength in men and women across the age groups. Given these two pieces of evidence, the interaction effects observed for the IMD were not considered meaningful. As such, a decision was made to adjust the IMD and grip strength analyses in men and women by age.

Figure 6.4.1: Forest plots showing the associations between SEP and grip strength in men and women in the UKB stratified by age group.

(a) Highest qualification



(b) IMD



Note: results are combined from analyses run across 12 imputed datasets.

6.4.1.2 Associations between SEP and grip strength

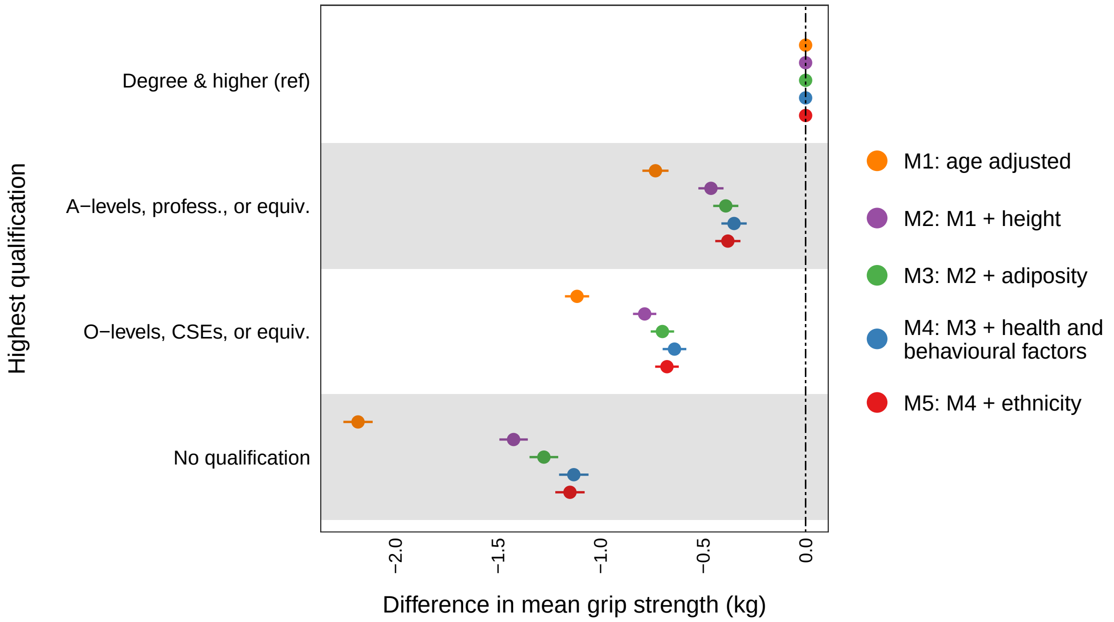
6.4.1.2.1 Women

Figure 6.4.2 displays the relationship between educational level and grip strength in women (see Appendix Table C.3.2). The figure also includes results for ethnicity, which will be discussed in Section 6.4.3.2. There was a relationship between lower education level and weaker grip strength in women, with a graded effect (based on visual interpretation of plots). In the age-adjusted model, women with no qualifications had a mean grip strength 2.18kg (95% CI; -2.25, -2.11) lower than those with a degree or higher. After adjusting for height, the difference was -1.42kg (-1.49, -1.35), and in the height and adiposity adjusted model the difference in grip strength reduced to -1.28kg (-1.35, -1.21). In the model adjusted for height, adiposity and health and behavioural risk factors, the difference was -1.13kg (-1.20, -1.06). Lower IMD was also associated with weaker grip strength in women, as shown in Figure 6.4.3 and Appendix Table C.3.4. The associations were graded, with those in the lowest fifth of IMD showing the weakest grip strength when compared with the highest fifth in the age-adjusted model (-1.41kg; 95% CI; -1.48, -1.33). Associations in women were attenuated once adjusted for height (Model 2: -0.85kg; -0.92, -0.78), height and adiposity (Model 3: -0.69kg; -0.76, -0.62), and height, adiposity and health and behavioural risk factors (Model 4: -0.52kg; -0.59, -0.45).

6.4.1.2.2 Men

There were non-linear associations between education level and grip strength in men. Men with no qualifications were weaker than those with a degree or higher qualification, while men with secondary or post-secondary education (A-level or O-levels) displayed higher grip strength levels than those with a degree or higher. Men with no qualifications had weaker grip strength than men with a degree or higher in all age groups, except for those below 45 years (-0.12kg; -0.43, 0.68) and those aged between 50 and 54 years (-0.28kg; -0.62, 0.06) (see Figure 6.4.4 and Appendix Table C.3.3). Men aged below 50 years with A-level or O-level qualifications had stronger grip strength than men with a degree or higher, as seen in the unadjusted models where men aged between 45 and 49 years with

Figure 6.4.2: Associations between highest qualification and grip strength in 271,122 women in the UKB.

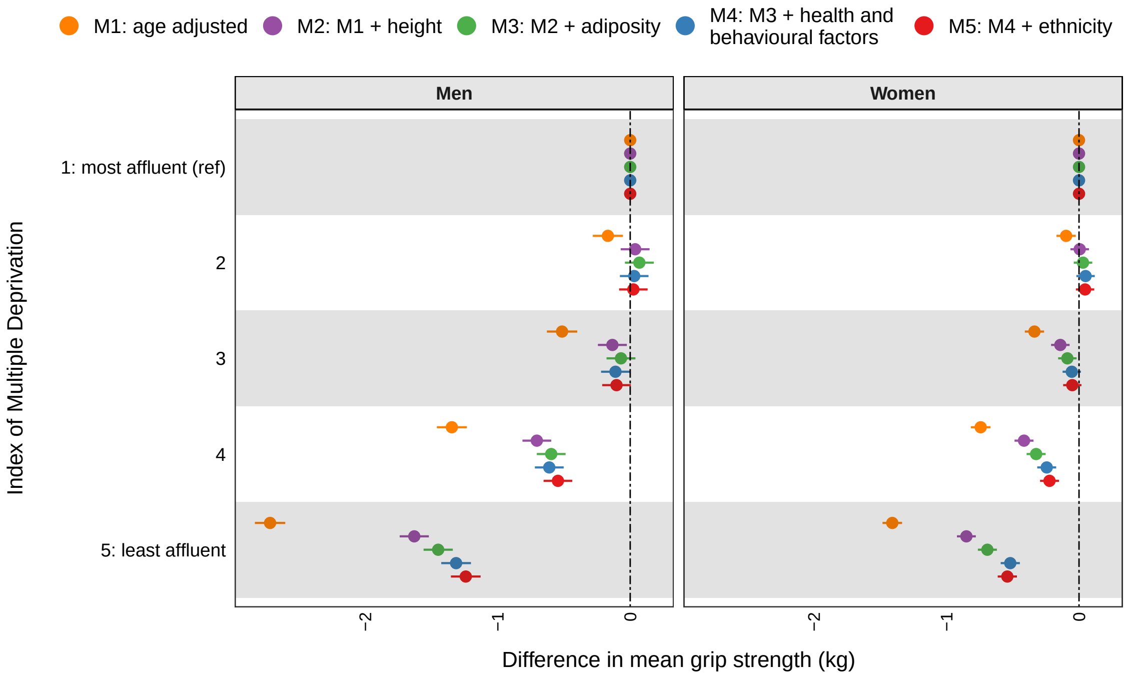


Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

an O-level qualification were 0.51kg (0.25, 0.76) stronger than men with a degree or higher. Adjustments for height (Model 2: 0.99kg; 0.75, 1.23) and height and adiposity (Model 3: 1.17kg; 0.92, 1.41) strengthened these associations, while adjustments for height, adiposity and health and behavioural risk factors attenuated these associations (Model 4: 0.74kg; 0.47, 1.00) (Figure 6.4.4 and Appendix Table C.3.3). The grip strength advantage of men with O-level qualifications disappears with age and changes direction at age 65 years and above, with men in the O-level categroy being 0.48kg (-0.68, -0.29) weaker than men with a degree or higher in Model 4 (see Figure 6.4.4 and Appendix Table C.3.3). In contrast, the grip strength advantage of men whose highest qualification was A-level persisted through old age, with these men being 0.22kg (0.02, 0.42) stronger than men with a degree or higher at age 65 years and above in the model adjusted for health and behavioural risk factors (see Model 4 in Figure 6.4.4 and Appendix Table C.3.3).

Similar to women, there was a graded association between lower IMD and weaker grip strength in men (Figure 6.4.4 and Appendix Table C.3.3), with each

Figure 6.4.3: Associations between IMD and grip strength in 497,844 men and women in the UKB.



Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

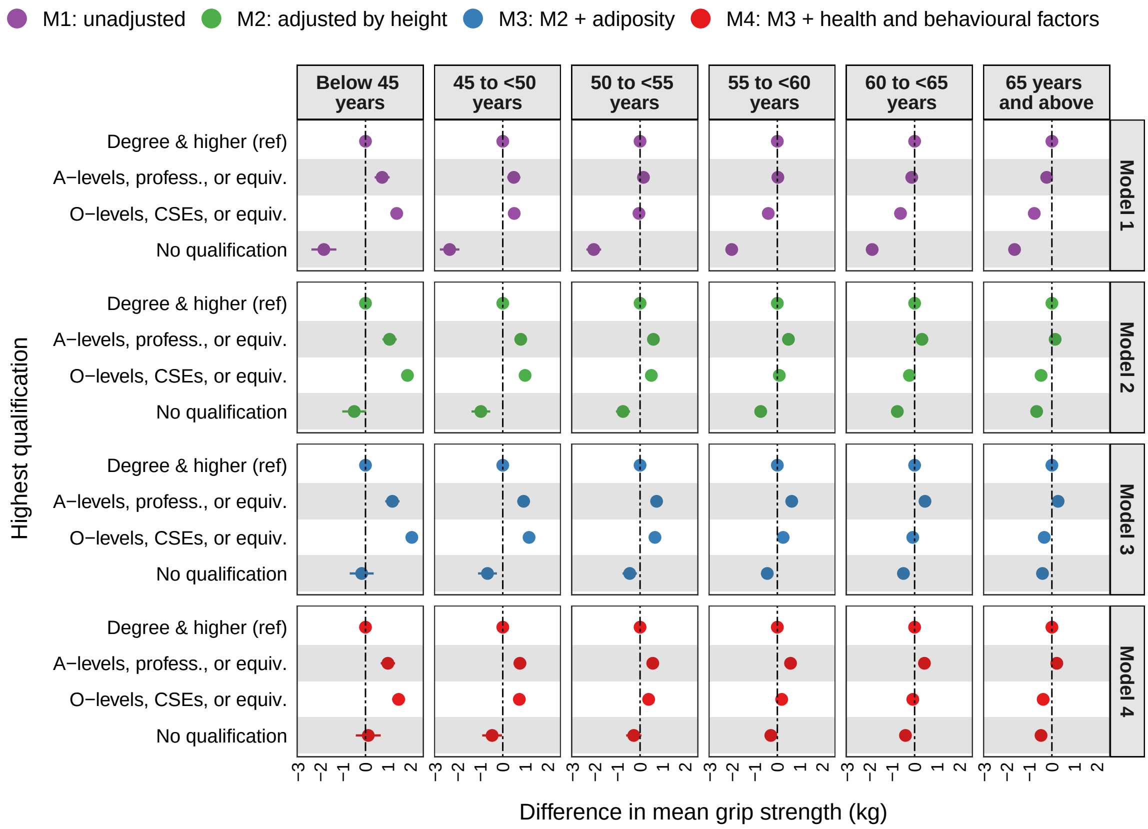
decrease in IMD level resulting in a reduced grip strength level. For example, men who lived in the lowest quintile were 2.72kg (-2.83, -2.60) weaker than men who lived in the highest quintile. After the inclusion of height, adiposity, and health and behavioural risk factors, associations were attenuated but remained (Model 4: -1.31kg; -1.43, -1.20).

6.4.2 *What are the overall associations between ethnicity and grip strength?*

6.4.2.1 Interactions between ethnicity and age group

In the formal tests of interactions between age group and ethnicity, the results were statistically significant in men and women (p<0.001). However, when examining the associations between ethnicity and grip strength by age using data visualisation, as presented in Figure 6.4.5 and Appendix Table C.3.5, the patterns

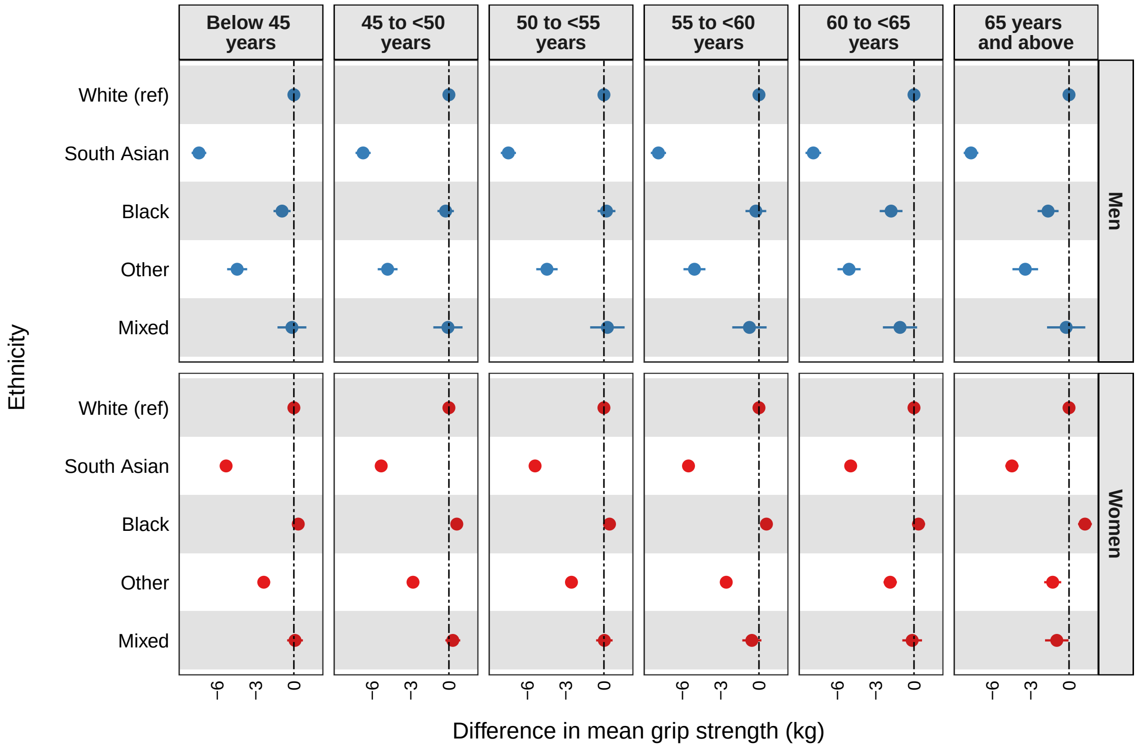
Figure 6.4.4: Associations between highest qualification and grip strength in 226,722 UKB men stratified by age.



Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational. activity.

of associations for men and women appeared to be similar across the age groups. This suggests that the statistical tests of interaction may be detecting small effects that could be due to the variability in grip strength across the age groups that are not meaningful. Therefore, considering these results, a decision was made to adjust the associations between ethnicity and grip strength in men and women for age.

Figure 6.4.5: Forest plot showing the age interaction in the associations between ethnicity and grip strength in men and women in the UKB by age group



Note: results are combined from analyses run across 12 imputed datasets.

6.4.2.2 Associations between ethnicity and grip strength

6.4.2.2.1 Women

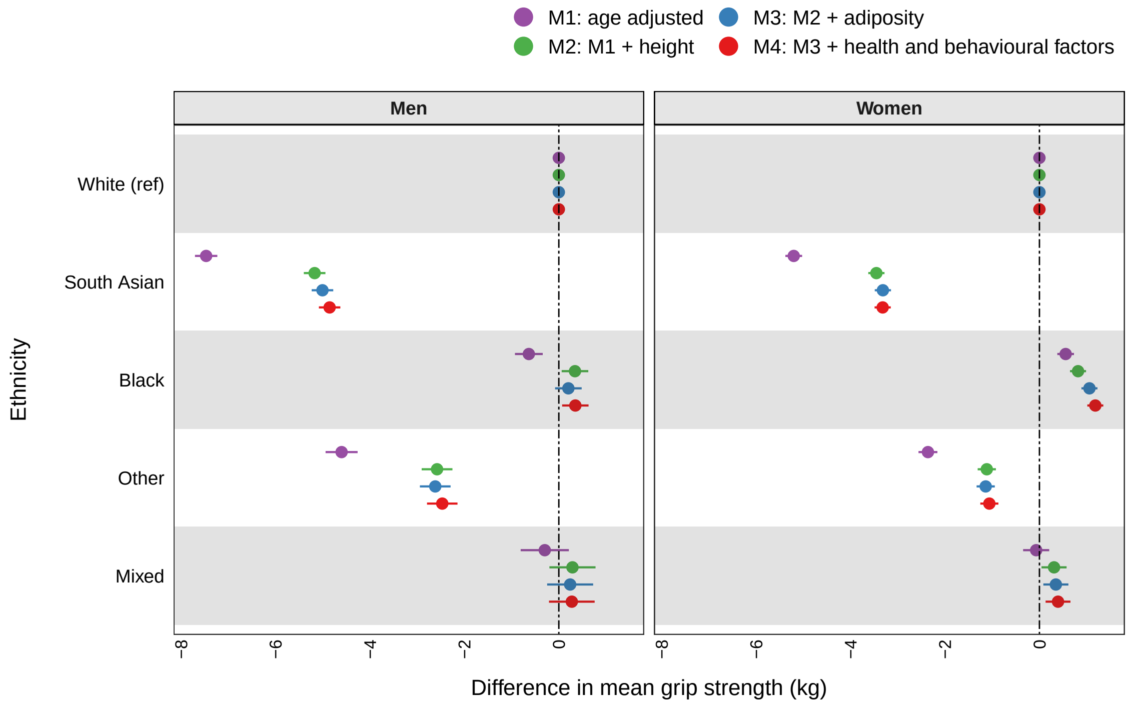
Figure 6.4.6 and Appendix Table C.3.6 present the results for the associations between ethnicity and grip strength. There were clear ethnic differences in grip strength levels for women. South Asian women and women in the 'other ethnicity' category were weaker than White women. However, Black women and women in the 'mixed ethnicity' category were stronger than White women. For example, in the age-adjusted model, White women had a mean grip strength 5.20kg higher (-5.38, -5.03) than South Asian women. This difference was reduced when adjusted for height (Model 2: -3.45kg; -3.62, -3.28) and height and adiposity (Model 2: -3.32kg; -3.49, -3.14). Adjustment for height, adiposity and health and behavioural risk factors did not alter the difference in grip strength between the two groups (Model 4:

-3.32kg; -3.49, -3.15). Conversely, Black women were 0.56kg (0.38, 0.73) stronger than White women in the age-adjusted model (Model 1), and these associations were strengthened once adjusted for height (Model 2: 0.82kg; 0.65, 0.99), height and adiposity (Model 3: 1.06kg; 0.89, 1.23) and height, adiposity and behavioural risk factors (Model 4: 1.18kg; 1.01, 1.35) (Figure 6.4.6 and Appendix Table C.3.6). In the age-adjusted model, there was no statistically significant difference in mean grip strength between White and women in the 'mixed ethnicity' category. However, after adjusting for height, women in the 'mixed ethnicity' category had a mean grip strength 0.31kg higher (0.04, 0.58) than White women. This difference increased slightly after adjusting for all covariates (Model 4: 0.39kg; 0.13, 0.66).

6.4.2.2.2 Men

In men, differences in grip strength by ethnicity were also observed. South Asian men and men in the 'other ethnicity' category were weaker than White men. No differences were seen between White men and men in the 'mixed ethnicity' category. Black men were stronger than White men once important covariates were included in the models (Figure 6.4.6 and Appendix Table C.3.6). In the age-adjusted model, the mean grip strength difference between South Asian and White men was -7.47kg (-7.71, -7.23). Adjusting for height attenuated this difference to -5.17kg (-5.40, -4.94), and in Model 4, the difference was -4.85kg (-5.08, -4.63). Black men had a mean grip strength of 0.63kg (-0.93, -0.34) lower than White men (age-adjusted model). When adjusted for height, these associations changed direction, and Black men had a mean strength of 0.34kg (0.06, 0.62) higher than White men. Once height and adiposity were considered, there was no notable grip strength difference between Black and White men (0.20kg; -0.08, 0.48). However, differences re-emerged when health status and behavioural risk factors were also included in the model. It is worth noting that the difference is relatively modest - Black men had a mean grip strength of 0.35kg (0.07, 0.63) higher than White men (Figure 6.4.6 and Appendix Table C.3.6).

Figure 6.4.6: Associations between ethnicity and grip strength in 497,844 men and women in the UKB.



Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

6.4.3 Do the associations between SEP and grip strength vary by ethnicity?

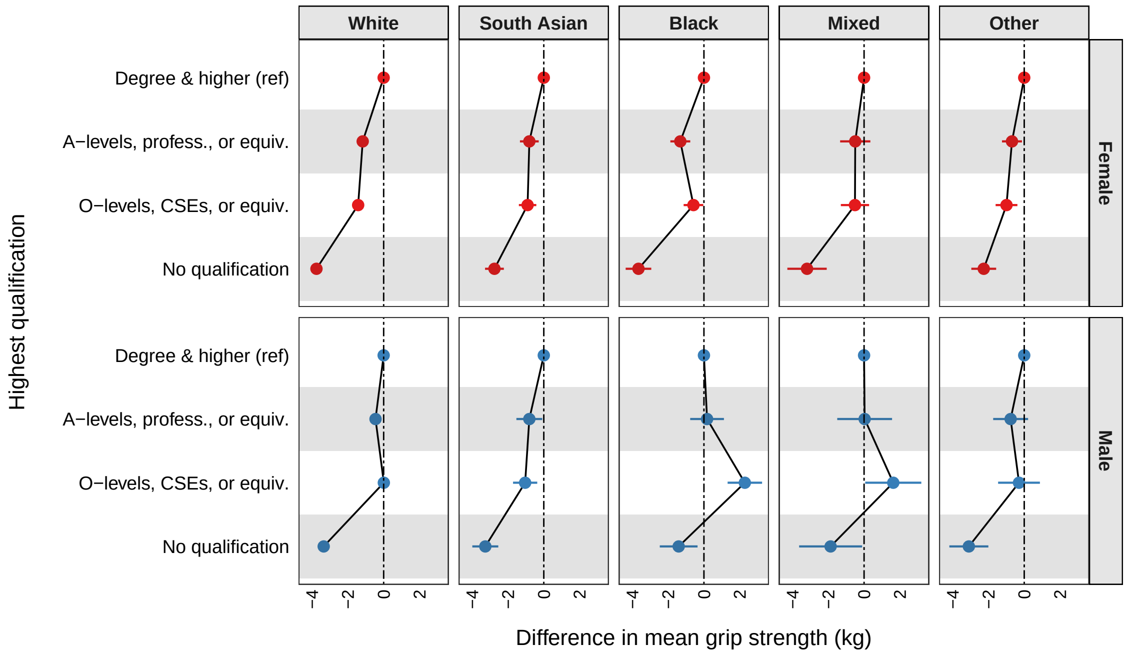
6.4.3.1 Ethnicity and SEP interactions

The results of formal tests of interaction between SEP and ethnicity were statistically significant for educational level and IMD (p<0.001). However, when examining the patterns of associations, it appeared that the SEP and ethnicity interactions could exist in some results and not others due to the varying scale of associations in the different ethnic groups. As shown in Figure 6.4.7a and Appendix Table C.3.7, there is no compelling evidence of an interaction between education and ethnicity for women, but there does appear to be evidence of one for men. For example, the patterns of associations between educational level and grip strength appear the same among women across the ethnic groups (Figure 6.4.7a and Appendix Table C.3.7). However, for men, the patterns of associations varied across ethnic groups. For instance, Black participants with O-level qualifications were stronger than participants with a degree or higher. Conversely, this was in the opposite direction in South Asian participants with O-level qualifications, as men of South Asian ethnicity heritage in the O-level qualifications group had weaker grip strength than men in the degree or higher group (Figure 6.4.7a and Appendix Table C.3.7). Therefore, associations between educational level and grip strength for women were adjusted for ethnicity while the models for men were stratified by ethnicity (Figure 6.4.2).

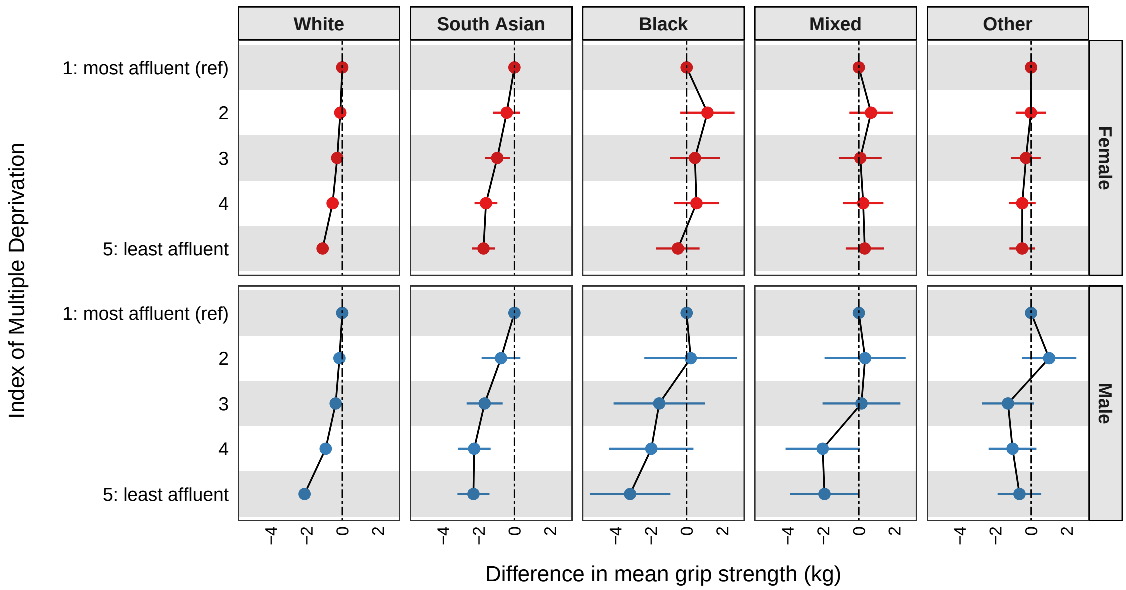
The associations between IMD and grip strength for men appeared similar across all ethnic groups (Figure 6.4.7b and Appendix Table C.3.7), hinting at the possibility of no meaningful IMD and ethnicity interaction. For women, the pattern of association was similar for White and South Asian groups. However, the direction of associations varies for Black women and women in the 'mixed ethnicity' category, though this is not significant as the confidence interval line crosses zero (Figure 6.4.7b and Appendix Table C.3.7). Hence, for women, there were no signs of an interaction between IMD and ethnicity. For men and women, a decision was made to adjust the associations between IMD and grip strength by ethnicity.

Figure 6.4.7: Forest plot showing the ethnicity interaction in the associations between SEP and grip strength in men and women in the UKB.

(a) Highest qualification



(b) IMD



Note: results are combined from analyses run across 12 imputed datasets.

6.4.3.2 Associations between SEP and grip strength by ethnicity

6.4.3.2.1 Women

As depicted in Model 5 of Figure 6.4.2 and Appendix Table C.3.2, based on the finding of no clear evidence of interaction between education and ethnicity, regression models for women examining the association between educational level and grip strength were further adjusted by ethnicity in women. In this ethnicity-adjusted model, the association between lower educational level and weaker grip strength was slightly attenuated. For instance, in the model adjusted for height, adiposity and health and behavioural factors (Model 4), women with no qualifications were 1.13kg (-1.20, -1.06) weaker than women with a degree or a higher qualification. Once Model 4 was adjusted for ethnicity, the association became -1.15kg (-1.22, -1.08) (see Model 5 in Figure 6.4.2 and Appendix Table C.3.2).

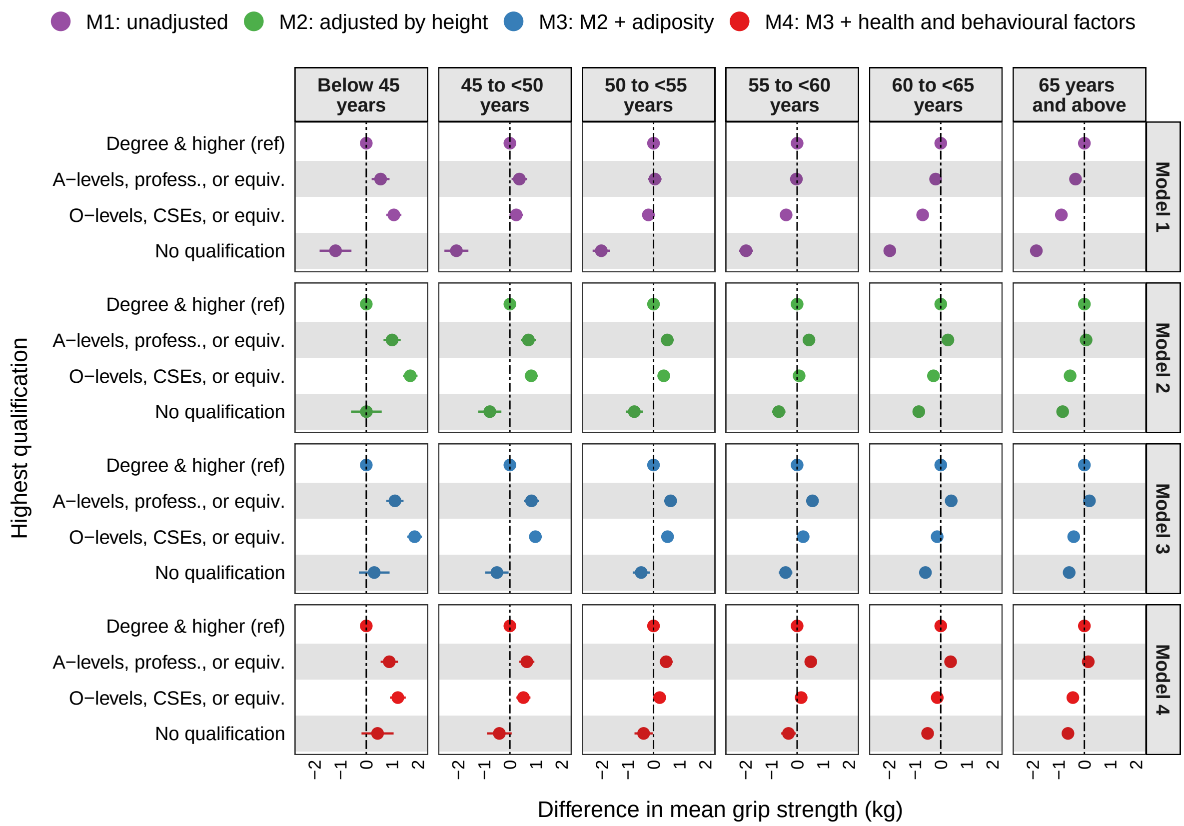
Model 5 in Figure 6.4.3 and Appendix Table C.3.4 displays the association between IMD and grip strength adjusted for ethnicity. The general association between lower IMD and weaker grip strength was attenuated when adjusted for ethnicity. To demonstrate this, in Model 4, women who lived in the most deprived areas (5th quintile) had a mean grip strength of 0.52kg (-0.59, -0.45) lower than women living in the most affluent neighbourhoods (1st quintile). In the ethnicity-adjusted model, differences were modest (-0.54kg, -0.61, -0.47) (see Model 5 in Figure 6.4.3 and Appendix Table C.3.4).

6.4.3.2.2 Men

Figures 6.4.8 to 6.4.9 and Appendix Tables C.3.8 to C.3.12 display the association between educational level and grip strength in the UKB stratified by age and ethnicity. In White men, there was a non-linear association between educational level and grip strength (Figures 6.4.8 and Appendix Table C.3.8). White men with no qualifications generally had weaker grip strength than those with a degree or higher. Compared to White men under 45 years who had a degree or higher, White men below 45 years with no qualifications had mean grip strength -1.19kg (-1.81, -0.57) weaker, though when height is considered, associations disappear (0.00kg;

-0.59, 0.60). This observed pattern within the no qualification category is similar for those aged 45 to 49 years. But at older ages, associations in the no qualification category were robust to adjustments. Those within the middle categories (A-levels and O-levels/equivalent) were stronger than those with a degree or higher, but associations reversed at older ages. In the fully adjusted model, White men under 45 years who were O-level educated were 1.22kg (0.92, 1.53) stronger than White men of similar age who had a degree or higher. At ages 45 to 49 years, the mean difference was 0.52kg (0.25, 0.80), and at 50 to 54 years, associations disappear, only to reverse at ages 65 years and above (-0.45kg, -0.66, -0.23). The advantage of stronger grip strength among men with A-level qualifications persists in White men until the age of 60 to <65 years.

Figure 6.4.8: Associations between highest qualification and grip strength in 214,541 White men in the UKB (age-stratified linear regression models).



Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

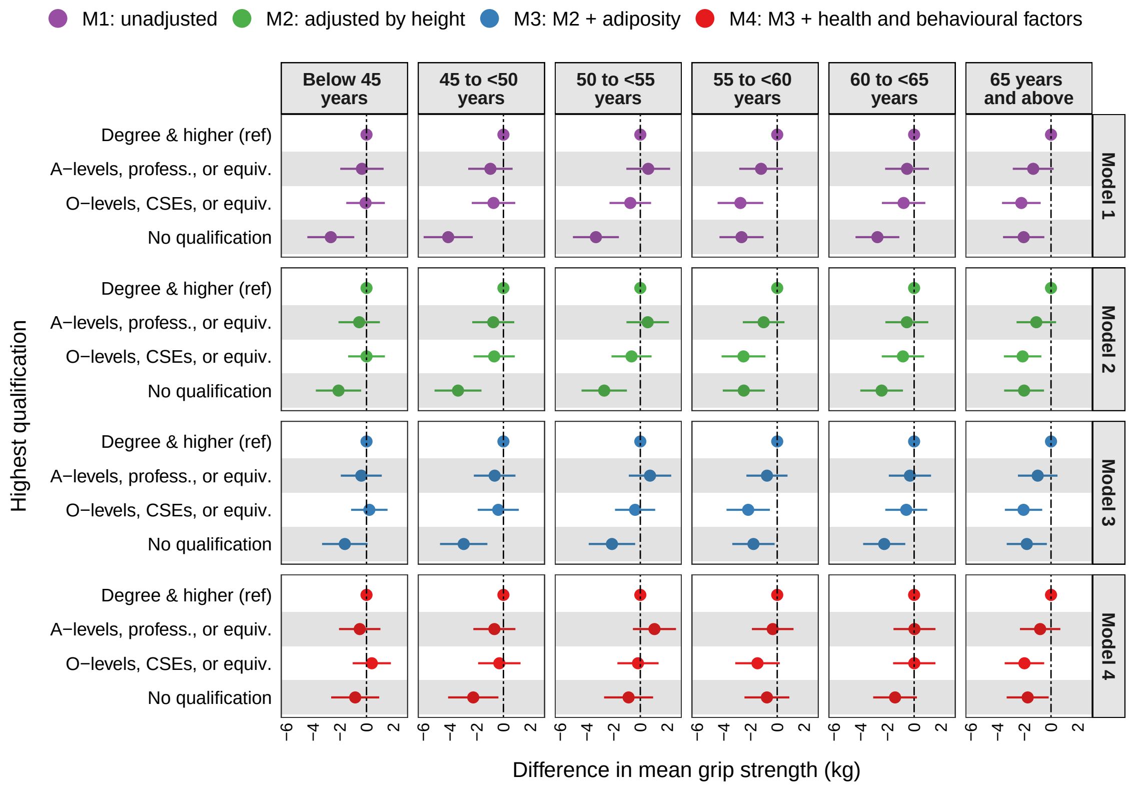
For Black men, there were no differences in grip strength levels between the no qualification and degree or higher groups (Figure 6.4.9b and Appendix Table C.3.10). However, Black men under 55 years old who had O-level or equivalent qualifications were stronger than men of the same age group with a degree or higher. For example, at ages 50 to 54 years, Black men with O-levels had a mean grip strength 2.48kg (0.34, 4.62) higher than Black men with a degree or higher. The difference was 2.30kg (0.22, 4.39) when adjusted for all the covariates. Conversely, for South Asian men, the opposite was true (Figure 6.4.9a and Appendix Table C.3.9). There were robust associations between lower educational levels and weaker grip strength across all ages, but no observed associations in the middle categories.

In men from the ‘other ethnicity’ category, there were non-linear associations between educational level and grip strength (Figure 6.4.10a and Appendix Table C.3.11). In the youngest group (below 45 years), those with O-level qualifications had lower levels of grip strength than those with a degree or higher. In the 45 to 49 years and 55 to 59 years, no qualification was associated with weaker grip strength, and associations in the 45 to 49 years group were robust to adjustments. However, in the 55 to 59 years, associations in the no qualification group were attenuated in the final model. The only association between educational level and grip strength for men of mixed ethnicity was seen at ages 45 to 49 years (Figure 6.4.10b and Appendix Table C.3.12). Here, men with A-level qualifications had a stronger grip than those with degrees. These associations were observed after adjusting for height (Model 2: 3.55kg; 0.36, 6.74) and persisted in the model adjusted for height, adiposity and health and behavioural factors (Model 4: 3.95kg; 0.66, 7.24).

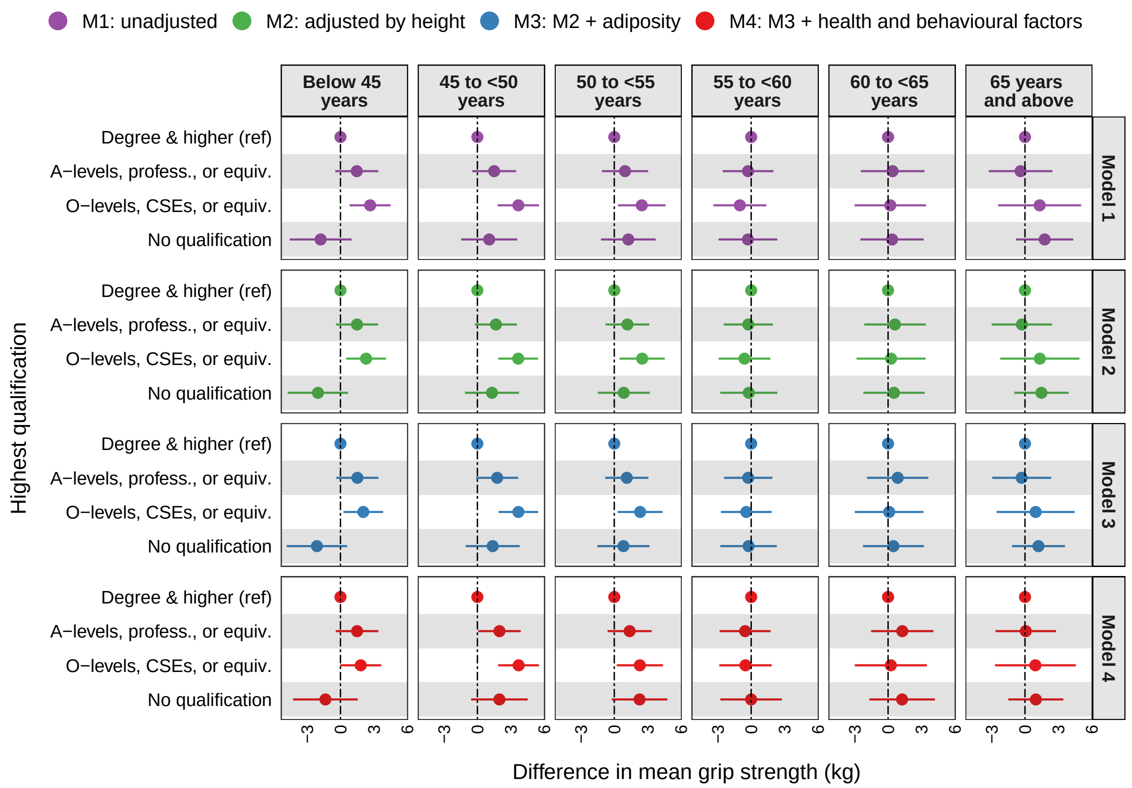
Model 5 in Figure 6.4.3 and Appendix Table C.3.4 displays the association between IMD and grip strength adjusted for ethnicity for men. Higher deprivation was associated with poorer grip strength in men, and ethnicity attenuated this relationship. For example, in Model 4, men who lived in the most deprived areas (5th quintile) were 1.31kg (-1.43, -1.20) weaker than men living in the most affluent neighbourhoods (1st quintile), but once adjusted for ethnicity, associations were attenuated (Model 5: -1.24kg; -1.35, -1.13).

Figure 6.4.9: Association of highest qualification with grip strength in South Asian and Black men in UKB (age-stratified regression).

(a) South Asian ethnicity (N=5,221)



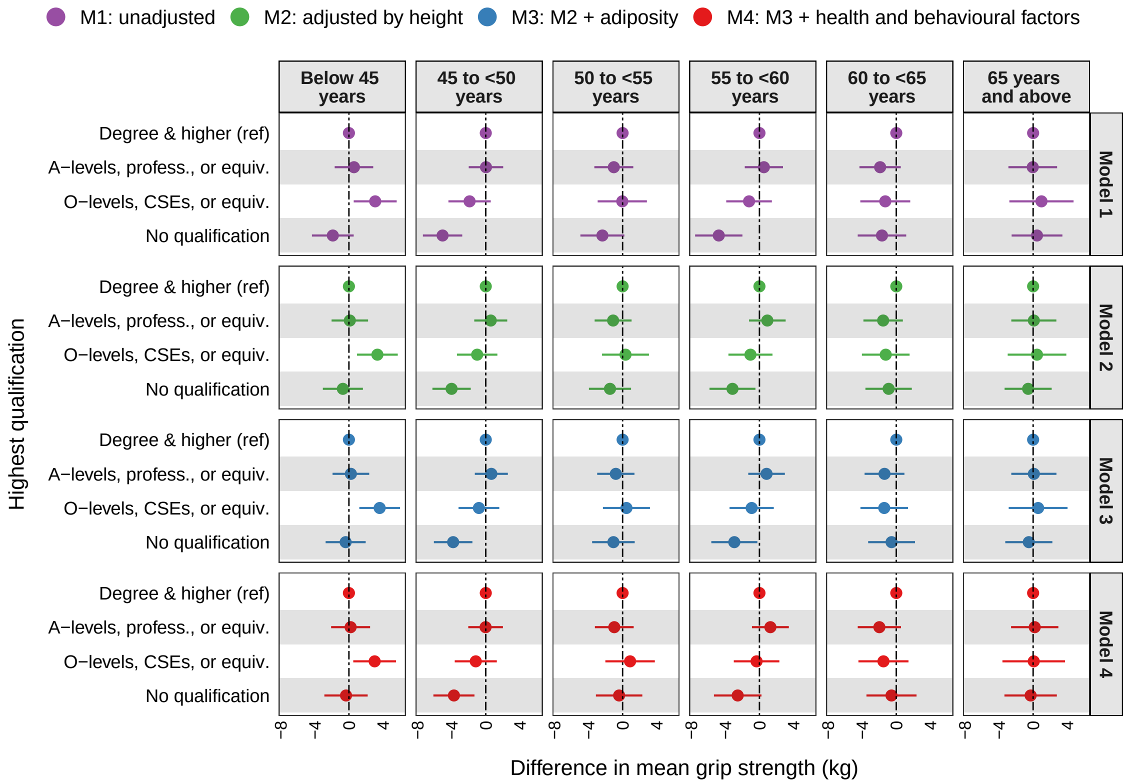
(b) Black ethnicity (N=3,355)



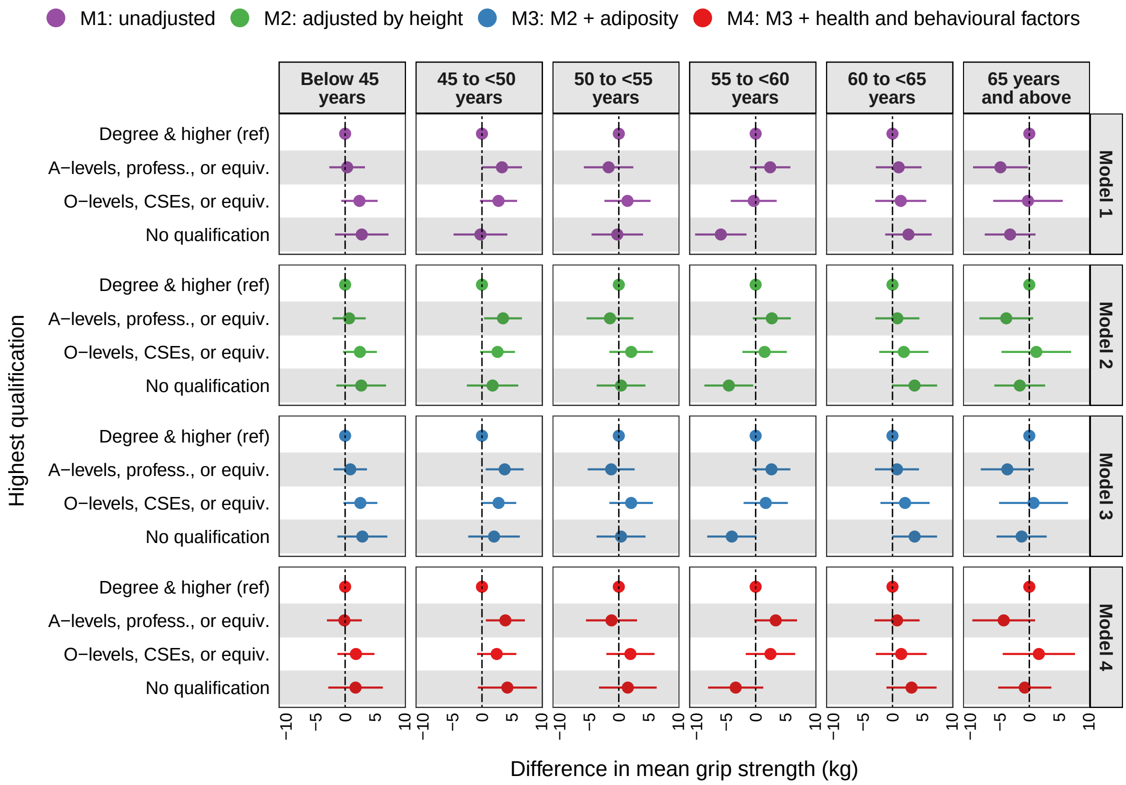
Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

Figure 6.4.10: Association of highest qualification with grip strength in mixed and other ethnicities of UKB men (age-stratified regression).

(a) Other ethnicity (N=2,506)



(b) Mixed ethnicity (N=1,099)



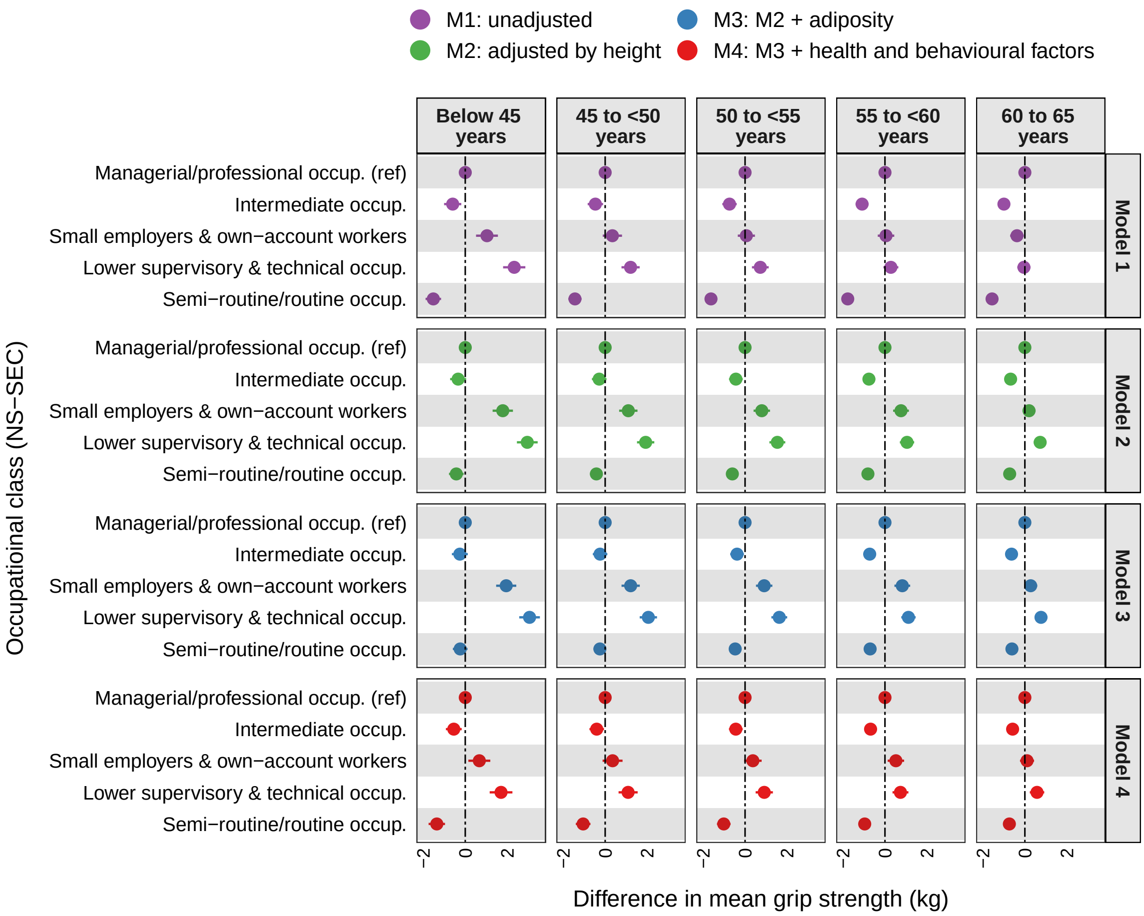
Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

6.4.4 *Does physical activity related to occupation explain any association between occupational class and grip strength in working-age men?*

Figure 6.4.11 and Table C.3.13 present the associations between occupational class and grip strength in UKB men of working age. Similar to the patterns of associations in educational level, there were non-linear associations between occupational class and grip strength. These associations showed that lowest occupational class was associated with weaker grip strength across all age groups. For example, in Model 1, men between 55 and 59 years in semi-routine/routine occupations had a mean grip strength 1.65kg (-1.92, -1.38) lower than men of similar age in Managerial/Professional occupations. These associations remained in Model 4. However, the associations between Semi-routine/routine occupations and weaker grip strength in men below 45 years and 45 to 49 years were fully attenuated in the height and adiposity-adjusted models (Model 3); nonetheless, these associations re-emerged after additionally adjusting for health status and behavioural risk factors. In Model 4, the associations between Semi-routine/routine occupations and weaker grip strength decreased with age (Model 4; Figure 6.4.11).

Men of working age who were in the Intermediate occupational class had weaker grip strength than men in Managerial/Professional occupations (shown in Figure 6.4.11 and Appendix Table C.3.13). However, those in Small employer and Lower supervisory occupations had higher mean grip strength than those in Managerial/Professional occupations. With age, this relationship becomes weaker. For example, after adjusting for height, adiposity and health and behavioural factors, men aged 55 to 59 in Lower supervisory occupations had a mean grip strength of 1.05kg (0.66, 1.45) higher than those in Managerial/Professional occupations (Model 4). Occupational activity was found to be the main factor affecting the adjustments in Model 4, as seen in Figure 6.4.12 and Appendix Table C.3.14. For example, when Model 3 was adjusted for occupational activity, men aged 55 to 59 in Lower supervisory occupations were 1.06kg (0.66, 1.46) stronger than similar-aged men in Managerial/Professional occupations. Co-morbidities, smoking status, sedentary behaviour, and physical activity had minimal effects on the observed association.

Figure 6.4.11: Associations between occupational class and grip strength in 153,324 men in the UKB stratified by age.

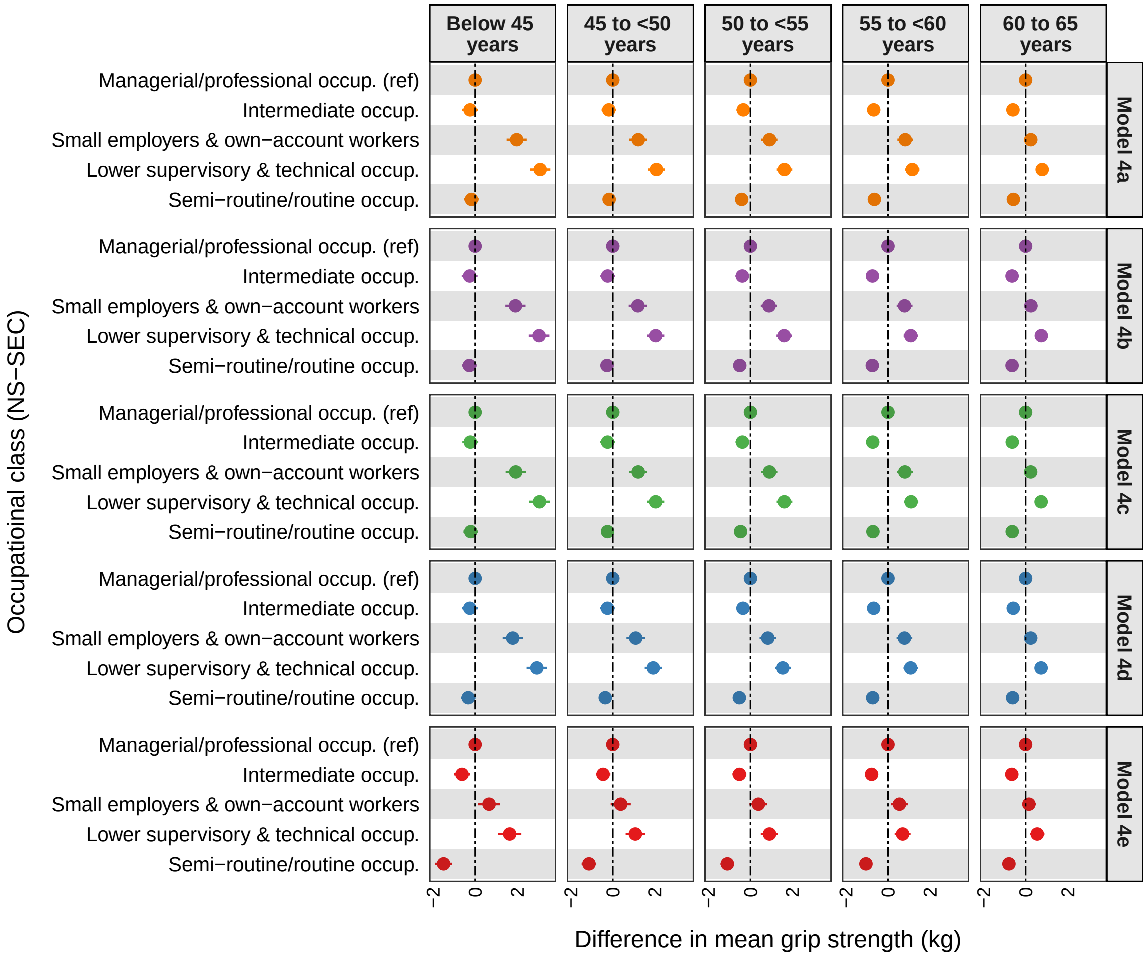


Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

6.4.5 *Sensitivity analyses*

The results of the analyses between SEP and grip strength run on a sample excluding participants without grip strength measurements for health reasons were the same as the results of the main analyses (Appendix Table C.4.4), which included these participants. Therefore, the analytical decision of allocating a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution is unlikely to have introduced bias. In the sensitivity analyses that used different categorisations for ethnicity, there were unique insights which suggest heterogeneity in grip strength levels within the current categorisations

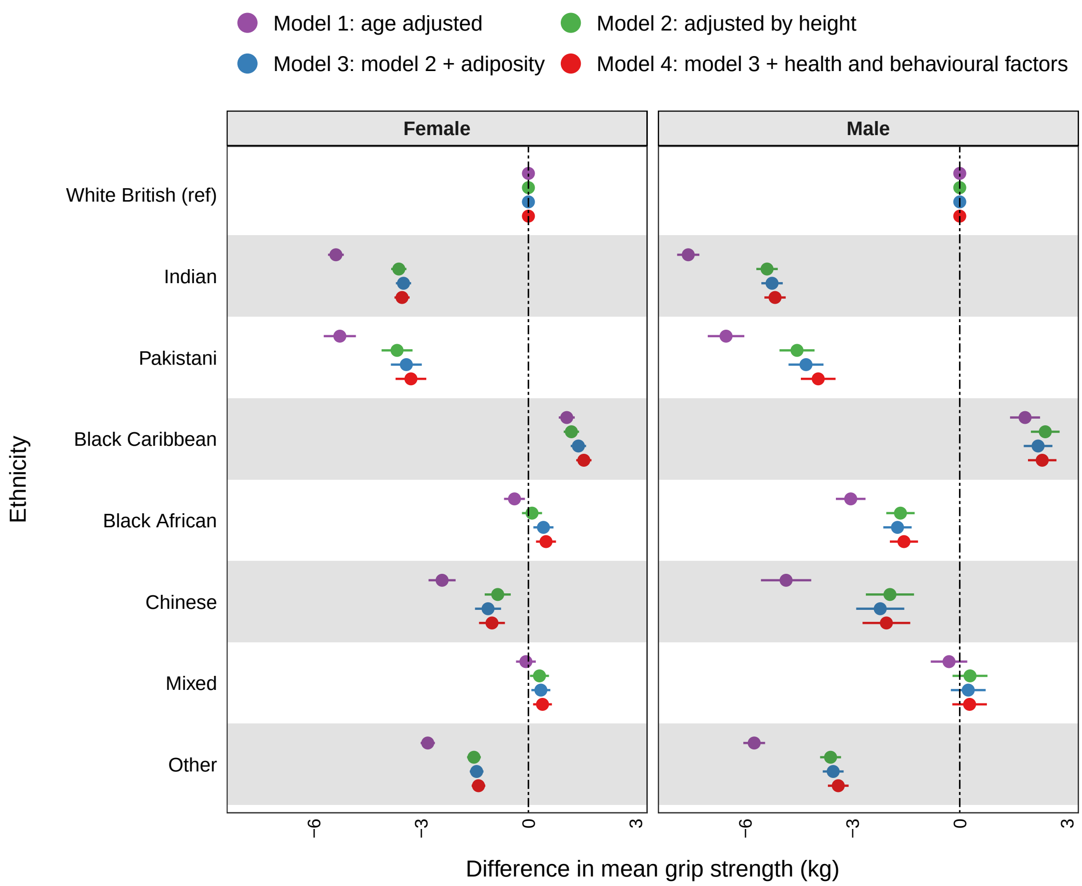
Figure 6.4.12: Associations between occupational class and grip strength in 153,324 men in the UKB with individual adjustments for health and lifestyle factors stratified by age.



Note: results are combined from analyses run across 12 imputed datasets; Model 3: height, waist-to-hip ratio and body fat percentage; Model 4a: Model 3 + co-morbidities: Model 4b: Model 3 + smoking status; Model 4c: Model 3 + sedentariness; Model 4d: Model 3 + physical activity; Model 4e: Model 3 + occupational activity. activity.

used for Black participants (which includes Black African and Caribbeans). For instance, men of Black Caribbean heritage had a higher mean grip strength than men of White ethnicity (mean grip strength difference in Model 4: 2.31kg, 95% CI; 1.91, 2.70), whereas men of Black African heritage had a lower mean grip strength than men of White ethnicity (Model 4: -1.56kg, -1.95, -1.17) – Figure 6.4.13 and Appendix Table C.4.5. This indicates that, in the original ethnicity categorisation, the grip strength advantage observed in Black ethnic men over White men is primarily driven by the higher grip strength levels of Black Caribbean men (Model 4: 0.35kg, 0.07, 0.63) – Figure 6.4.6 and Appendix Table C.3.6.

Figure 6.4.13: Sensitivity analysis to examine the impact of the different categorisations used for ethnicity in the associations between ethnicity and grip strength in the UKB.



Note: results are combined from analyses run across 12 imputed datasets; adiposity includes waist-to-hip ratio and body fat percentage; health behavioural factors include co-morbidities, smoking status, sedentariness, physical activity and occupational activity.

6.5 Discussion

6.5.1 Summary of main findings and fit with hypotheses

In the analysis of baseline data from UK Biobank, associations were observed between lower educational level and IMD with weaker grip strength in women, without any age or ethnicity interactions. In men, the non-linear association between educational level and grip strength varied by age and ethnicity, and similar patterns of associations were found for occupational class, which also varied by age. However, no age or ethnic differences were observed in the association between IMD and grip strength for men.

For women, lower educational levels and lower IMD deciles were associated with weaker grip strength. However, there were non-linear associations between educational level and grip strength in men, with age interactions observed. Men who had no qualifications were weaker than those who were degree educated, while men who had A-levels or O-levels were stronger than those with a degree or higher. These associations gradually decreased and changed direction at older ages. As hypothesised, similar patterns of associations were also seen for occupational class, and occupational activity partially explained these observed associations. However, these associations attenuated with age but did not change direction, which was in support of the hypothesis.

In partial support of the hypothesis stated in Section 6.2, participants who identified as Black or of *mixed ethnicity* had stronger grip strength compared with White participants, while South Asian participants had significantly weaker grip strength compared with White participants. For women, the associations between educational level, IMD, and grip strength did not vary by ethnicity. Similarly, the IMD and grip strength associations for men did not vary by ethnicity. However, across all ethnic groups, there were mixed associations between educational level and grip strength in men. These associations were generally non-linear for men classified as White, Black, mixed, or ‘other’ . In these groups, compared to men with a degree or higher, those with no qualifications had weaker grip strength, while those with A-level or O-level qualifications generally had stronger grip strength. In White and South Asian men, there was an association between lower educational level and grip strength, as men with no qualifications had weaker grip strength than those with a degree or higher.

6.5.2 *Associations between SEP and grip strength*

The findings in this chapter show that adulthood SEP was associated with grip strength. In the following subsections, the findings from this chapter are discussed in relation to other studies, including possible explanations for these observations.

6.5.2.1 Educational level and occupational class

The findings presented in this chapter showed a graded relationship between lower educational level and weaker grip strength in women, which was similar to the linear associations observed in Chapter 4 in middle-aged British women. Both analyses found that these associations were robust to adjustments. The associations reported for women in this chapter are also consistent with those from the UKHLS (Carney and Benzeval, 2018), where there was an association between lower educational level and weaker grip strength in women, with no age interactions. The Hertfordshire and SHARE cohort studies (Cheval et al., 2018; Syddall et al., 2009) also found educational inequalities in grip strength for women.

For women, adjusting for height largely accounted for the observed associations between lower educational level and grip strength. Since height is closely correlated with grip strength — taller individuals tend to have stronger grip (Kuh et al., 2005; Spruit et al., 2013) — and socioeconomically disadvantaged populations at birth are consistently shorter (Cavelaars et al., 2000; Howe et al., 2012; Webb et al., 2008), it is not surprising that height explains a significant portion of the variability in the association between lower educational level and weaker grip strength. In addition, the factors and pathways contributing to the associations observed in the UKB study are similar to those discussed in Chapter 4 of this thesis. However, while certain factors such as adiposity and health status and behavioural risk factors partially explained the association between lower educational level and weaker grip strength, a significant proportion of the association remains unexplained. This could be attributed to the statistical power of UKB, which can detect small differences, given its large sample size. Furthermore, the unexplained proportion of the association could be due to residual confounding factors that were not accounted for in the analysis. Unlike the BCS70 study, the UKB did not have access to life course factors, such as childhood, adolescence and earlier adulthood SEP, health, and behavioural factors, including disability, sedentary behaviour, and physical activity. Consequently, there could be residual confounding related to these factors.

In men, the relationship between educational level and grip strength varied with age and was non-linear. In the BCS70 study in Chapter 4, lower educational level was associated with stronger grip strength in British men aged 46 years. However, when other factors were considered, this relationship was found to be linear, with those who had no qualifications having stronger grip strength than those with a degree. The non-linear associations of this chapter were comparable to those of the BCS70 study in the equivalent age groups. Additionally, this study adds to the work in the BCS70 by showing that the relationship between educational level and grip strength in men changes direction with age. This pattern has also been observed in the UKHLS (Carney and Benzeval, 2018), where men with lower educational levels had stronger grip strength than men with higher educational levels in midlife. At older ages, this association changed direction and men with lower educational levels had weaker grip strength. In contrast, the Hertfordshire and SHARE cohort studies (Cheval et al., 2018; Syddall et al., 2009) found that lower educational level was associated with weaker grip strength. However, in these two studies, the middle categories were concealed as educational level was operationalised as a binary educational attainment variable, which may hide variability in the associations for these groups especially if it is non-linear.

Similarly, there was a non-linear relationship between occupational class and grip strength in men of working age in the UKB, with those in the middle occupational groups having stronger grip strength than those in higher occupational groups. Conversely, those in the lowest occupational groups had weaker grip strength than those in higher occupational groups. Educational level is known to influence future employment, and this pattern of association between occupational class and grip strength mirrors the ones seen between educational level and grip strength. Moreover, the non-linear associations driven by stronger grip in the middle occupational classes are the same as those seen in the BCS70 at age 46 (Chapter 4), where men of manual occupations displayed higher levels of grip strength. Findings are also consistent with those seen in Swedish male military personnel aged 18 years (Silventoinen et al., 2009) and middle-aged men in the UKHLS (Carney and Benzeval, 2018). Inconsistent with the hypothesis, non-linear associations between occupational class and grip strength did not change with age, but did become weaker. This suggests that the grip strength advantage of those in the middle occupational groups is existent through to age 65 years, just before retirement. Nonetheless, the available data on occupational class pertained only to those who were still working. Therefore, it was not possible to ascertain whether the occupational activity advantage observed in men with manual occupations persisted after retirement.

The potential pathways responsible for the associations between lower educational levels and occupational class with weaker grip strength in men are similar to those in women. However, the non-linear association across the groups, with higher grip strength levels observed in the middle SEP groups, is unique to men, particularly regarding the association with stronger grip. Similar to the findings observed in the BCS70, these associations seem to be influenced by the types of occupational activity that men engage in. For instance, during individual adjustments, occupational activity was found to be the main factor driving the non-linear associations in the middle occupational groups. Contrary to the BCS70, where the effect in these groups was fully explained by occupational activity, occupational activity in this study (UKB) only partially explained the observed associations in these groups. Associations remained in the lower supervisory and technical occupations, which are typically manual and physically demanding. However, there may be residual confounding because the self-reported occupational activity variable only captures current information on this factor. Some participants may have reported *never or rarely* engaging in occupational activity in their current role, but they may have engaged in physically demanding work in the past that could have contributed to their peak grip strength. To examine such effects, historical information on occupational activity is necessary.

6.5.2.2 Index of Multiple Deprivation

For both men and women, grip strength was weaker in those living neighbourhoods with higher levels of deprivation. Two previous studies have examined the relationship between neighbourhood deprivation and grip strength (Holman et al., 2022; Murray et al., 2013). Holman et al. (2022) found differences in grip strength across levels of deprivation in the UKB study, while Murray et al. (2013), who used a single measure of neighbourhood deprivation based on employment status, found no association in the NSHD study.

Deprivation measures such as IMD are calculated based on averages of individual-level or small-area data(Galobardes et al., 2006c), which may not accurately reflect individual-level material deprivation in areas that are large and socially heterogeneous. For example, individuals who are materially disadvantaged may live in affluent neighbourhoods and vice versa (Buajitti et al., 2020; Davis et al., 2023; Haynes and Gale, 2000; Pichora et al., 2018). The findings of this chapter exemplify the potential for different patterns of associations between area-level and individual-level indicators of SEP and grip strength, specifically, the differences observed in the results for education level and IMD in men. However, it is important to note that these two indicators are interrelated, and when considered together, they provide useful information on the intersectional inequalities in grip strength (Bambra, 2022). Therefore, to properly understand the role of place in the associations between SEP and grip strength, it would be useful to consider individual and area-level SEP holistically by utilising a multi-level approach that nests individuals within their neighbourhood deprivation level (Pickett and Pearl, 2001), as previously done in other studies (Holman et al., 2022; Murray et al., 2013). In the UKB study, grip strength levels varied by educational level within each level of neighbourhood deprivation (Holman et al., 2022). Nonetheless, individual intersectional inequalities, observed in the analyses from Holman et al., (2022), accounted for much of the variation in grip strength levels.

The associations between higher deprivation and weaker grip strength were robust to adjustments of individual-level factors in both sexes. This suggests residual confounding including differences in individual life course SEP that have not been fully accounted for in the study may be present. The negative psychosocial effects of neighbourhood deprivation, including increased stress and reduced social capital and support, may also contribute to these associations. These factors, which are important to individual SEP and overall health, have been well-documented in previous research (Jaarsveld et al., 2007; Kawachi, 1999; S. Wickham et al., 2014). For example, research has shown that neighbourhoods with higher levels of deprivation tend to have fewer healthy food options and less access to green spaces and exercise facilities (Gustafson et al., 2012; Humpel et al., 2002; Jaarsveld et al., 2007; McNeill et al., 2006; Schule et al., 2019).

6.5.3 *Associations between ethnicity and grip strength*

This chapter highlights notable ethnic differences in grip strength levels. Specifically, South Asian participants exhibited lower grip strength levels compared to White participants, while Black participants showed higher grip strength levels than White participants. Notably, the difference in grip strength levels between South Asian and White participants is much larger and clinically significant. These ethnic differences are consistent with previous studies conducted in the UK (S. Jones et al., 2020; Ntuk et al., 2017), and similar patterns have been observed in large-scale epidemiological studies conducted globally, such as the nationally representative *World Health Organisation's Study on global AGEing and adult health* (Arokiasamy et al., 2021) and Prospective Urban Rural Epidemiology (Leong et al., 2016; Leong et al., 2015), and a systematic review of international variations in grip strength (Dodds et al., 2016). It should be noted that there may be variations in grip strength levels among Black populations based on the country's development. For example, some studies reported that Black populations in middle-income countries have higher levels of grip strength compared to other ethnic groups (Arokiasamy et al., 2021), while others found that White Europeans had the highest grip strength levels (Dodds et al., 2016; Leong et al., 2015). Similarly, in America, Black (Afro-Caribbeans) participants have the highest recorded levels of grip strength (Duchowny et al., 2017; Forrest et al., 2018; Haas et al., 2012; McGrath et al., 2019; N. Smith et al., 2019).

In explaining the ethnic differences in grip strength, differences between South Asian and White participants in the UK were somewhat reduced when adjusted for factors such as height, adiposity, and behavioural risk factors. However, differences between these two groups remained after adjustments, with South Asian men presenting grip strengths that were 8.3 standard deviations away from the grip strength of White men, and South Asian women presenting grip strengths that were 5.8 standard deviations away from the grip strength of White women. Similarly, in the *Southall and Brent Revisited* study (S. Jones et al., 2020), South Asian participants were significantly weaker than White participants. However, in this study cohort, adjusting for factors such as physical activity, waist-to-hip ratio, and cardiovascular disease or hypertension fully explained these differences (fully adjusted difference; −3.0 kPa, 95% CI: −6.0, 0.5). Potential explanations for why associations were fully explained in the *Southall and Brent Revisited* study but not in the UKB could be due to the differences in sample size, impacting power as there were only 232 South Asian participants in the *Southall and Brent Revisited* study, and 9,748 in the UKB. Additionally, the covariates used could explain these differences, as the *Southall and Brent Revisited* study used non-fasting blood samples to account for health differences, which were not used in the UKB. The significantly weak grip strength levels observed in South Asian participants compared to White participants may have clinical implications. Moreover, South Asian populations in high-income countries not only have some of the lowest grip strength levels (Leong et al., 2016; Leong et al., 2015; Ntuk et al., 2017) but also have higher rates of health conditions such as diabetes and cardiovascular disease (Forouhi et al., 2006; Ntuk et al., 2017; Rabanal et al., 2015; Rana et al., 2014; Razieh et al., 2022; Teagle et al., 2022). In another UKB study (Ntuk et al., 2017), lower grip strength was associated with a higher prevalence of diabetes in South Asian participants. Genetic variants, physical inactivity, and diets high in carbohydrates and fats may contribute to these disparities (Babakus and Thompson, 2012; Dawkins et al., 2022; Kooner et al., 2011; Misra et al., 2009; Peden et al., 2011; Sleddering et al., 2014). To address these inequalities, culturally appropriate interventions and programs tailored specifically for South Asian communities may be effective, such as campaigns aimed at improving health through physical activity and strength training, in particular, could be developed and promoted in these populations (Shirinzadeh et al., 2019). Barriers and facilitators for such interventions are discussed further in Chapter 7.

The modest grip strength advantage among black participants were robust to adjustments, consistent with the findings of the *Southall and Brent Revisited* study, which found that Black participants had stronger grip strength than White participants, independent of other important factors such as health (S. Jones et al., 2020). Paradoxically, Black participants have the highest grip strength levels and some of the highest levels of poor health outcomes in the UKB compared to White participants (Ntuk et al., 2017; Teagle et al., 2022). The differences in grip strength between Black and White participants that remain unexplained may be related to the higher peak grip strength attained by black participants. This ethnic discrepancy in grip strength could be due to a number of factors, including differences in peak levels attained throughout the life course, which may be related to ethnic differences in occupational activity. Historical events could also play a role in this discrepancy. For example, many Black participants in the UKB study are of Caribbean descent and are similar in age to the Windrush generation who immigrated to the UK between 1948 and 1971 to help rebuild the country after World War II. The UK government actively recruited a specific group of individuals to work in various industries such as healthcare, transportation, and manufacturing. However, due to a lack of recognition of their skills in the UK, many of these individuals initially settled into lower-status jobs, such as manual labour in construction or factories (Fryer, 1984; McDowell, 2013). It is possible that some of the Caribbean men in the study may have been involved in these types of jobs, which could have contributed to the observed advantage in grip strength among Black men. Additionally, sensitivity analysis examining ethnic differences in grip strength among men where the Black category was further split into African and Caribbean (Figure 6.4.13 and Appendix Table C.4.5) found that Black Caribbean men were stronger than White men (by 8 standard deviations), and Black African men were weaker than White men (by 8 standard deviations). This suggests that there may be different factors at play within the Black population that affect grip strength levels. It is important to understand the underlying historical, cultural, and environmental factors that may contribute to the observed disparities in grip strength among Black men in order to target effective interventions in the future. These interventions should not only aim to maintain the advantage in grip strength seen among Caribbean men, but also to improve grip strength levels among African men while addressing other health inequalities in both groups (this will be discussed in detail in Chapter 7).

It is important to note that alongside environmental factors, genetic variations also play a role in the grip strength levels attained among different ethnic groups. As certain genetic variations exist within ethnic groups due to historical, environmental, and cultural factors that have influenced their genetic makeup (Auton et al., 2015; Bryc et al., 2015), and grip strength being a highly heritable trait with 65% contribution shown in heritability studies (Arden and Spector, 1997; Matteini et al., 2010; Reed et al., 1991), it is possible that some genetic variations affecting the structure and function of muscle fibres may contribute to the variation of grip strength among ethnic groups. This hypothesis is supported by a genome-wide discovery analysis that identified 16 genetic locations associated with grip strength in a sample of 195,180 individuals, including the UKB (Willems et al., 2017). These population differences in genetic variations and demographic, historical, and environmental factors that can influence grip strength levels underscore the importance of having different cut-off values for grip strength levels in definitions of sarcopenia for different ethnic populations.

Recent studies have recognised the need for ethnicity-specific cut-off points in the diagnosis of sarcopenia (Bigman and Ryan, 2021; Du et al., 2018; Duchowny et al., 2017). The findings on ethnicity-specific grip strength levels in this chapter further underscore the need for developing cut-off points for sarcopenia diagnosis and treatment that take into account ethnic variations in muscle strength, which are currently lacking in existing sarcopenia definitions (Chen et al., 2014; Cruz-Jentoft et al., 2019; Fielding et al., 2011; Studenski et al., 2014).

6.5.4 Associations between SEP and grip strength by ethnicity

In examining the intersectional inequalities of grip strength, differences in results by age and/or ethnicity were only observed in the associations for the highest qualification and grip strength in men. Ethnic differences were observed in these relationships, with non-linear associations in the different ethnic groups. Younger participants below aged 55 years, with O-level or A-level qualifications, had higher grip strength than those with degrees. There were also no significant differences observed in young South Asian participants with O-levels/A-levels; there was, however, a trend toward weaker grip strength than those with degrees or higher qualifications. Nevertheless, individuals with no qualifications generally had weaker grip strength in White and South Asian populations. These are novel insights, as ethnic differences in educational inequalities of grip strength have not been tested or reported in the previous literature.

The occupational activity advantage in younger men whose highest educational qualification is A-level/O-level discussed above is seen across most ethnic groups, except South Asian men. To speculate on the reason for this, it is possible that for South Asian men, who have the lowest grip strength amongst men in the UKB, the occupational activity advantages of those with A-level/O-level qualifications may only bring them to the same level as men who already have the advantage of a degree or higher. Compared to the other ethnic groups, other pathways between education and grip strength may exist in South Asian men, such as differential responses to occupational activity (Alkhayl et al., 2022; Knox et al., 2017) or intersectional discrimination (Ruwanpura, 2008).

In the analyses presented in this chapter, interactions were not observed in most intersections, except for associations in educational level for men with age and ethnicity variations. As a result, most relationships in the UKB were additive. This is in line with Holman et al. (2022), who found that additive effects were the main drivers of the intersectional inequalities observed in the UKB, rather than multiplicative effects. In the educational levels associations for women and IMD associations for men and women, adjustment for ethnicity is only partially explained. Further research could examine the impact of these inequalities on grip strength. By studying the effects of intersectional inequalities in childhood, adolescence, and adulthood SEP on grip strength, a deeper understanding of how these inequalities change over time and interact with demographic factors such as age, sex, and ethnicity can be gained. This information could be used to inform strategies for improving grip strength equitably for all individuals.

6.5.5 *Methodological considerations*

In this chapter, new insights on the patterns of associations between adulthood SEP and grip strength were observed. The evidence on how these associations varied by age, sex, and ethnicity was also obtained, adding to the existing body of literature. Additionally, the findings in this chapter complement and add to the work presented in Chapter 4 of the thesis. The UKB, which is highly powered due to its large sample size, is one of the few cohort studies with a sufficient number of people from minoritised ethnic groups with grip strength assessments, making it possible to interrogate both ethnic and socioeconomic differences in grip strength. This is something that has not been feasible in previous studies such as the BCS70 cohort and UKHLS (E. Williams et al., 2020) due to the limited representation of minoritised ethnic groups in the cohort, or the lack of grip strength measurements. An additional strength of the work presented in this chapter includes examining differences in associations between SEP and grip strength by age and ethnicity, as well as the use of forest plots to examine whether the statistically significant results of the test of interactions were meaningful and not due to small variations in the associations related to the large sample size of the UKB. As done in previous chapters, multiple imputation was used to impute the missing data in the UKB. More specifically, the *Classification And Regression Tree* method was used. This approach allows for the preservation of the potential interactions between age, sex, ethnicity, and SEP during multiple imputation. It does so by accurately modelling complex, nonlinear structures in large datasets without assuming parametric distributions or requiring data transformations (Burgette and Reiter, 2010; Doove et al., 2014).

In addition to the strengths mentioned previously, there are also limitations to the methods and analyses which need to be taken into account when interpreting the findings presented in this chapter. As data required for these analyses were taken from the baseline wave of UKB, with information on exposures, covariates, and outcomes collected all at once, it is difficult to examine the temporal sequence of these factors. For example, it is possible that participants may be in low occupational class as a result of health outcomes. Despite this, the results observed in SEP and grip strength are plausible as they are consistent with previous results observed in prospective studies, such as the BCS70 in Chapter 4. Despite the UKB cohort having a higher representation of minoritised ethnic groups than in other studies, there are still questions about how representative UKB is of the wider UK population, as a significant proportion of the participants were White, with higher SEP, and relatively good health (Fry et al., 2017). This lack of representation limits the generalisability of the findings to the wider UK population, and the lack of diversity in the cohort also impacted the categorisation of ethnicity. Because of the low number of minoritised ethnic groups, a common five-category categorisation was used to improve power and stratify for multiple factors (Mathur et al., 2021). This meant that heterogeneous groups were combined based on a common feature; for example, Caribbean and Black participants were categorised as Black. The limitations of this decision are highlighted in the sensitivity analyses, which show that Caribbean men are driving much of the observed association in grip strength differences in the Black category, as White men were weaker than Caribbean men but stronger than African men.

The lack of representation of minoritised ethnic groups in health research poses a major challenge to achieving health equity and addressing health disparities. Minoritised ethnic groups are disproportionately affected by health inequalities but are often underrepresented in health research, which can hinder the understanding of their unique health needs and challenges. Barriers to participation include mistrust, language and cultural barriers, racism and discrimination, and practical barriers (G. Brown et al., 2014; De las Nueces et al., 2012; Farooqi et al., 2022; Gamble, 2006; George et al., 2014; Gill et al., 2013). Even when minoritised ethnic groups do participate, accurate recording of ethnicity data remains a challenge. Addressing these barriers is crucial to understanding and addressing ethnic disparities in health and informing policies and interventions to tackle these challenges (Aspinall and Jacobson, 2007; Bignall and Phillips, 2023; G. Brown et al., 2014; De las Nueces et al., 2012; Farooqi et al., 2022; Gamble, 2006; George et al., 2014; Gill et al., 2013).

6.5.6 Summary

In this chapter, new insights were obtained that complement the work presented in Chapter 4. Different patterns of associations between SEP and grip strength were observed for men and women, and by age and ethnicity. Graded associations were seen for women in educational level and IMD, and men for IMD only, while non-linear associations were observed in the associations between educational level and occupational class and grip strength, with men in the middle SEP groups having much stronger grip strength than men in higher SEP. These non-linear associations in men were partially explained by occupational activity. Associations in educational level also varied by age and ethnicity, with South Asian men not experiencing the same occupational activity advantage as men of other ethnicities. Additionally, clear ethnic differences were observed for men and women, independent of a number of important factors in adulthood.

The findings of this chapter have potential policy and intervention implications. The association between lower adulthood SEP and weaker grip strength persists from midlife to old age among all women, indicating the need for policies and interventions that can protect them from socioeconomic deprivation and improve their grip strength throughout their lifespan. In contrast, the relationship between lower SEP and grip strength in men is non-linear and varies with age and ethnicity. Those with higher levels of occupational activity have higher grip strength levels. This highlights the nuances of policy and interventions needed to address these inequalities. Targeted interventions are required for those affected by socioeconomic inequalities in grip strength, as well as those suffering from weak grip strength, such as South Asian men and women. Additionally, interventions are needed for those with a grip strength advantage in middle age but who are vulnerable to muscle weakness later in life.

The final chapter, Chapter 7, brings together the work presented in this chapter and earlier chapters, and discusses the methodological considerations and wider implications of this body of work.

CHAPTER 7

Discussion

7.1 Overview

In this thesis, a life course epidemiological perspective has been used to examine the relationships between socioeconomic adversity at various stages of life and physical capability, specifically, grip strength and standing balance performance between ages 37 and 69. The potential significance of this work was highlighted in Chapter 1 (Section 1.4.3) where it was stated that lower levels of grip strength and balance performance have been linked to premature mortality and various other adverse health outcomes, including hospitalisations, fractures, cognitive decline, cardiovascular disease, and cancer (Celis-Morales et al., 2018; R. Cooper et al., 2011b; R. Cooper et al., 2010; Parra-Soto et al., 2022). Poor physical capability is also noted as a major contributor to functional impairments, which were the second leading cause of days absent from work over the past decade (National Health Service, 2014; Office for National Statistics, 2021). With the widening socioeconomic gap in health in the UK and the increased risk of poor physical capability with age, it is crucial to understand the role of socioeconomic adversity on these indicators. This is especially relevant given the far-reaching consequences for individuals and society.

This thesis aligns with the UK Government's agenda on productive healthy ageing, which aims to *'enhance people's lives and boost the country's productivity'* (Department for Business, Energy & Industrial Strategy, 2023). It is an important component of its *Industrial Strategy*, addressing the public health and societal challenge of an ageing population. The primary objective of this policy agenda was to minimise inequalities in healthy life expectancy, allowing individuals to live longer with good health and remain in the workforce for longer. This also aligns with the Government's most recently announced goal of driving growth in existing, new, and emerging industries, as investing in health and wellbeing is crucial for achieving this aim (Department for Business, Energy & Industrial Strategy, 2023).

In this final chapter, a summary of the main findings and implications of this thesis are discussed. The key results are summarised in Section 7.2. Additionally, the methodological considerations of this work are further discussed in Section 7.3. In Section 7.4, the policy and public health implications of the key findings are discussed, providing insights into how these results may inform decision-making and improve public health outcomes. Moreover, future research avenues are outlined in subsection 7.4.3 of the implications section. Finally, the chapter concludes with an overall summary in Section 7.5.

7.2 Summary of findings

Chapter 1 provided an overview of the context and background for the thesis. This was followed in Chapter 2 by a comprehensive literature review of studies examining the relationships between childhood SEP and objective markers of physical capability, including grip strength and standing balance performance. This chapter identified important gaps in the literature and limitations of existing studies, including inconsistent patterns of association between childhood SEP and grip strength and standing balance performance and a lack of evidence on underlying pathways, as well as a lack of studies that used prospectively ascertained SEP indicators and that examined ethnic inequalities. Chapter 3 presented the BCS70 and UKB studies, two large population-based studies from which data have been drawn and analysed to address the main aims of the thesis. The origin, strengths, and limitations of these studies were discussed, along with a description of the key variables of interest.

In Chapter 4, the BCS70 was used to address some of the limitations of previous studies identified in Chapter 2, namely the inconsistent patterns of associations between life course SEP and grip strength at younger ages, insufficient evidence in underlying pathways, and the scarcity of studies using prospectively ascertained SEP indicators. The associations between childhood, adolescent, and adulthood SEP and grip strength at age 46 years were examined. As hypothesised, lower

SEP in childhood, adolescence, and adulthood was consistently associated with weaker grip strength among women, suggesting that the lifetime association may be cumulative. In contrast, among men, no associations were found between SEP in childhood or adolescence and grip strength at age 46 years, but non-linear associations in the opposite direction were found for adulthood SEP. Men in manual occupational classes and men with A-level/GCSE qualifications had stronger grip strength compared with men in higher occupational classes and with a degree or higher, respectively, while those in the lowest educational levels and occupational classes were weaker. When different potential mediators and confounders were explored, occupational activity was identified as playing a key role in explaining the observed associations in men.

In Chapter 5, data from the BCS70 were utilised to examine the associations between childhood and adulthood SEP and standing balance performance at age 46 years, as well as the pathways that may have mediated these associations. Unlike the grip strength analyses, there was no evidence of interactions between sex and indicators of SEP in relation to standing balance performance. Lower childhood and adulthood SEP were consistently associated with poorer standing balance performance in sex-adjusted analyses. Mediation analyses suggested that the associations between childhood SEP and standing balance performance were explained by adulthood SEP, with more modest evidence of a mediating role for other factors including childhood BMI, cognition, adulthood BMI, health status, sedentariness, childhood coordination, and smoking. The associations between adulthood SEP and standing balance performance were partially explained by occupational activity and other adulthood factors including smoking, health status, BMI and sedentariness, but a large proportion of the association was left unexplained. The findings from social mobility analyses supported the results of the mediation analyses for childhood SEP. These results indicated a continuation of SEP from childhood to adulthood, which could have explained why a substantial portion of the relationship between childhood SEP and poorer standing balance performance was mediated by adulthood SEP.

In Chapter 6, data from the UK Biobank study were analysed to further expand upon the findings of Chapter 4. Intersectional inequalities in grip strength were examined by investigating socioeconomic and ethnic differences in grip strength, and then examining whether differences in associations between adult SEP and grip strength differed by age, sex, and ethnicity. Additionally, this chapter, for comparison with findings from chapter 4, evaluated whether occupational activity explained the association between occupational class and grip strength in working-age men. The results of Chapter 6 demonstrated varying patterns of associations between educational level, IMD and occupational class and grip strength for both men and women based on age and ethnicity. There were graded associations between lower educational level, IMD, and weaker grip strength in women, with no differences by age or ethnicity. Similarly, in men, only graded associations were observed between lower IMD and weaker grip strength, which also did not vary by age or ethnicity. However, the associations between educational level and grip strength in men were non-linear and varied by age and ethnicity. In line with the findings from the BCS70, men who were in the A-level/O-level categories had stronger grip strength compared with men in the degree or higher category, while men in the no qualification category were weaker. These cross-sectional associations were weaker in older than younger UKB participants, even reversing direction for the O-level group. Comparable patterns of associations were found for occupational class. Men in manual occupations displayed higher grip strength than men in managerial and professional occupations, with higher occupational activity partially accounting for the differences. These associations weakened with age, but did not reverse. In examining ethnic differences in grip strength in UKB, the associations with educational level revealed an occupational activity advantage for White, Black, and men of mixed and other minoritised ethnic groups, but not for South Asian participants. Additionally, South Asian participants were weaker than White participants, while Black participants were stronger, in both men and women. This is independent of a number of important adulthood factors including height, adiposity, health status and behavioural risk factors. The potential explanations for the findings presented in this summary section have been discussed in detail in the discussion sections of Chapters 4 to 6.

7.3 Methodological considerations

The work presented in this thesis has a number of strengths. This includes the use of a life course epidemiological perspective to understand socioeconomic differences in grip strength and standing balance performance using the BCS70 dataset. Findings from analyses of the BCS70 dataset were complemented by analyses of UKB. Another key strength was the use of the BCS70 dataset, which provides rich data across the life course, including prospectively ascertained SEP measures. This is particularly noteworthy given that many previous studies on associations between childhood SEP and physical capability have used retrospectively ascertained SEP measures (see Section 2.2.2.1). Additionally, the selection of SEP indicators in the BCS70 dataset was based on a scoping exercise exploring the appropriate SEP measures across different life stages (see Section 3.1.5). The availability of grip strength and standing balance performance data in the BCS70 dataset, as well as grip strength data in the UKB dataset, at younger ages than in many other population-based studies in the UK, offers a unique opportunity to explore socioeconomic inequalities from mid-adulthood. This allowed for the investigation of associations and their underlying pathways before the onset of age-related diseases. While it was not possible to examine the associations of prospectively ascertained childhood factors in the UKB study due to the participants being recruited only in midlife, this study has several other methodological strengths. These include a large sample size, participants covering a wide range of ages (from 37 to 69 years), and a higher number of participants from minoritised ethnic groups (although not representative of the UK's diverse population). These strengths enabled the examination of interactions between age, ethnicity and SEP in this study.

Although the BCS70 and UKB and the statistical approaches applied to analyse them have strengths, they also have limitations. Like many prospective population-based studies, the BCS70 has experienced losses to follow-up. The BCS70 had variable target sample sizes across its waves (Ketende et al., 2010), with response rates as low as 55% at age 26 years and as high as 89% at age 10 years. As discussed in Section 3.1.3, several historical factors may explain the low response rate in some waves, particularly the 10-year gap between 16 and 26 years and the transfer of consent from parents to study members. Furthermore, it was observed that men and those from socioeconomically disadvantaged groups were less likely to be retained in the BCS70 dataset, as evidenced by the comparison of samples from the first wave to those at age 42 years (Tarek and Wiggins, 2014). Loss to follow-up in the BCS70 dataset may result in overestimation or underestimation of the true associations between SEP and grip strength and standing balance performance, depending on the direction and magnitude of the bias. For instance, loss to follow-up may lead to an underestimation of the associations between lower childhood SEP and weaker grip strength in women in the BCS70, as well as lower SEP and poorer standing balance performance in both men and women. Additionally, loss to follow-up may underestimate the associations between lower adulthood SEP and lower grip strength, as well as poorer standing balance performance, given the evidence of tracking of SEP from childhood to adulthood. Multiple imputation techniques were used within the base sample who had the outcome to minimise the effects of missing data on exposure and covariates variables across the waves and prevent selection bias related to complete case analyses, as discussed in Sections 4.5.4 and 5.5.3.

A potential limitation of the UKB is its relatively low response rate, which may introduce selection bias into the sample. Around 9.2 million adults were invited to participate in UKB, of whom only approximately 500,000 responded, resulting in an overall response rate of 5.5% (Allen et al., 2012; Fry et al., 2017). The participation rate was higher among females, older individuals, individuals from White ethnic groups, and those from less socioeconomically deprived areas (Fry et al., 2017). Furthermore, the participation rates showed regional differences, with the lowest rates in West Scotland and London (Fry et al., 2017). As briefly discussed in Section 3.2.2, the low response rate and potential selection bias in the UKB could potentially lead to over- or underestimation of the true associations between adulthood SEP and grip strength, as well as affect the generalisability of its findings to the wider population (Fry et al., 2017). Despite this challenge, the findings in the UKB are consistent with those of the BCS70 (as discussed in Chapters 4 and 6). Therefore, this suggests that the associations between adulthood SEP and grip strength may be plausible. However, caution should be exercised when interpreting these results, and further research is needed to confirm the findings in other populations, particularly in terms of how the associations between adulthood SEP and grip strength vary by ethnicity in the UK.

Despite chair rise speed and walking speed being recognised as important measures of lower body strength and function, and often used alongside grip strength and standing balance performance in studies of physical capability, they were not considered in this thesis as outcome measures (Kuh et al., 2014; Roberts et al., 2011). This was due to the fact that the BCS70 and UKB datasets had only collected grip strength and standing balance performance data. Historically, chair rise speed and walking speed have been deemed important for older populations, which has led to their limited inclusion in studies involving younger people (Birnie et al., 2011a; Kuh et al., 2014; Roberts et al., 2011). If these measures capture meaningful variation at younger ages, incorporating them into early-life population studies could enable investigations of life course socioeconomic inequalities in these physical capability markers.

Grip strength is available at younger ages, including in the teenage years, in some other UK cohort studies including UKHLS and the *Avon Longitudinal Study of Parents and Children* (ALSPAC) (Carney and Benzeval, 2018; Fraser et al., 2013). As ALSPAC study participants are currently in their early 30s and close to their peak physical capability levels, there is a unique opportunity to continue measuring grip strength in future waves. This could enable a better understanding of the associations between life course SEP and these measurements from the teenage years onwards. Additionally, the measurements of occupational activity used in this thesis may not fully capture all relevant aspects of the underlying construct. It would have been ideal to have more detailed measurements on occupational activity that captured intensity, frequency, and duration, as well as data on historical occupational activity levels that may not be reflected in the currently reported occupational activity levels, as individual's occupations evolve over time with changing roles and duties.

One of the challenges of measuring physical capability is that assessments differ in their operationalisation across population studies and standing balance performance is not an exception to this. The standing balance performance test used in the BCS70 study was most likely designed for an older population at risk of falls. Participants were required to complete eyes open test, followed by an eyes closed test. Only those who could successfully achieve 30 seconds on the eyes open test progressed to the eyes closed test. This created a ceiling effect, whereby not everyone progressed to the eyes closed test. As a result, an analytical decision to combine the outcomes of the eyes open and eyes closed tests led us to categorise the balance outcome. However, this resulted in a loss of variability in the standing balance performance outcome, as the continuous variable was reduced to only five groups. In future waves, the BCS70 study could benefit from including everyone in the cohort in the eyes-closed test, which may be appropriate until older age when balance-related challenges manifest.

7.3.1 *Generalisability*

Considering the importance of current socioeconomic inequalities on grip strength and standing balance, the generalisability of the findings in this thesis to more recently born cohorts is an important consideration. Specifically, the finding of associations between childhood SEP and grip strength and standing balance performance in the BCS70 highlights the socioeconomic inequalities experienced in the 1970s, which may not be reflective of the current nature and extent of socioeconomic inequalities. While some measures of inequality may have improved in the UK since the 1970s, for example improvements in equal pay by sex, other factors such as access to education, healthcare, and affordable housing may have worsened for some groups of the population (Boliver, 2013; Chowdry et al., 2013; Goddard and Smith, 2001; Hoolachan and McKee, 2019; M. Williams, 2013). Additionally, recent studies have shown that the austerity cuts in the early 2010s and the COVID-19 pandemic have disproportionately affected certain socioeconomic groups, highlighting ongoing and possibly increasing inequalities (Carmona, 2014; Islam et al., 2021; Marshall et al., 2019; Office for National Statistics, 2020; Stuckler et al., 2017). Given that current socioeconomic inequalities may be more severe than those in the past, the findings of associations between childhood SEP and grip strength and standing balance performance may be even more significant in more recently born cohorts.

Furthermore, it is important to note that the challenges and inequalities faced by older populations from minoritised ethnic groups may differ from those faced by younger generations. For instance, minoritised ethnic groups who migrated to the UK in the early to mid-20th century may have encountered different exposures and obstacles than those who were born in the UK. This is supported by a previous systematic review, which suggests that second-generation South Asians seem to be more physically active than first-generation South Asian participants but still less active than White British individuals (Bhatnagar et al., 2016). When examining ethnic differences in health outcomes, and particularly the generalisability of the findings in this thesis, it is important to consider the specific intergenerational differences that may exist.

As highlighted in Section 7.3, it is important to note that the participants in both the BCS70 and UKB may not be representative of the wider UK population. Therefore, it is necessary to exercise caution in interpreting the findings in the context of the UK population. Moreover, when considering the replication of the findings of this thesis, it is possible that they may not be similar to those of other countries due to potential social and political differences, which are important to SEP.

7.4 Implications of findings

7.4.1 Policy implications

7.4.1.1 Socioeconomic policies aimed at reducing inequalities across the life course

The results of this thesis may potentially aid in formulating policies and interventions that not only enhance socioeconomic conditions, but also improve outcomes related to strength and balance. The results on socioeconomic differences in grip strength among women in the BCS70 and UKB (Chapters 4 and 6), as well as the findings on standing balance performance among both men and women in the BCS70 (Chapter 5), highlight the importance of addressing socioeconomic adversity throughout life for both men and women.

There are currently no direct empirical studies that demonstrate the effectiveness of socioeconomic interventions on grip strength and standing balance. Nonetheless, given the strong and consistent associational evidence on the relationship between lower SEP and weaker grip strength (in women) and poorer standing balance performance (in both sexes) it is plausible that interventions targeting socioeconomic conditions could have positive effects on these outcomes (Agardh et al., 2011; Birnie et al., 2011a; Mackenbach et al., 2008; Manrique-Garcia et al., 2011; Stringhini et al., 2017). The suggestion that lifetime SEP - grip strength associations in women may be cumulative suggests that improving socioeconomic conditions from childhood through to adulthood may be beneficial. To improve childhood socioeconomic circumstances, it is crucial to address multiple sources of inequality. For example, initiatives that address inequalities, such as the successful and now-discontinued *Sure Start* program, can help reduce socioeconomic inequality in childhood (Cattan et al., 2022; K. Cooper and Stewart, 2017). This program has been shown to improve various outcomes for children, including health, social, emotional, physical, and behavioural aspects (K. Cooper and Stewart, 2017; Ginja et al., 2019; J. Hutchings et al., 2007; Mason et al., 2021; Sammons et al., 2015). These improvements may positively affect growth patterns and motor development, which are important for grip strength and standing balance performance (Blodgett et al., 2020; Kuh et al., 2019).

While socioeconomic adversity across the life course, including both childhood and adulthood SEP, has been found to be important for women's grip strength and standing balance performance in both sexes in this thesis, adulthood SEP is also crucial for men. Considering the strong evidence of associations between lower adult SEP and poorer overall health (Agardh et al., 2011; Mackenbach et al., 2008; Manrique-Garcia et al., 2011; Stringhini et al., 2017), implementing policies that address socioeconomic inequalities in adulthood are likely to be beneficial for many aspects of health, including grip strength and standing balance performance levels. Such policies may include increasing access to high-quality education, providing job training, and promoting government initiatives aimed at reducing income inequality (Marmot et al., 2020). Moreover, during the critical stage of early adulthood, when individuals transition from the family home and make choices that shape their future education and career paths, inequalities in health can emerge (Glendinning et al., 1992; Sweeting et al., 2016; West and Sweeting, 1996). Hence, future policies aimed at reducing socioeconomic disparities must focus on empowering individuals during this stage to make informed decisions that positively impact their prospects, health, and well-being (World Health Organization, 2014). Possible strategies, such as career guidance and mentorship, job training, access to affordable housing, and mental health support, could facilitate this goal (Evensen et al., 2017; Macintyre et al., 2020; Marmot et al., 2020).

7.4.1.2 Intersectionality-informed policymaking

A key feature of one of the chapters in this thesis was to examine the interactions between sex, age and ethnicity, in the associations between SEP and grip strength, leading to a number of novel findings. For instance, South Asian participants have been found to have the lowest grip strength levels and the highest rates of poor health outcomes in the UKB and in the wider literature (S. Jones et al., 2020; Leong et al., 2016; Leong et al., 2015; Ntuk et al., 2017). Typically, middle-aged men in manual occupations in the UKB have higher grip strength compared to men in the degree or higher category, which may be attributed to their occupational activities. However, this advantage is not observed among South Asian men. In contrast, Black men and women, who exhibit the highest grip strength, also experience some of the worst health and behavioural outcomes in the UKB and in the wider literature (S. Jones et al., 2020; Leong et al., 2016; Leong et al., 2015; Ntuk et al., 2017). Moreover, minoritised ethnic groups in the UK not only experience higher rates of poorer health but are also more likely to reside in areas with high poverty, unemployment, poorer housing, elevated crime rates, and air pollution than non-minoritised ethnic groups (Byrne, 2020; Davey Smith et al., 2000; Fecht et al., 2015; Marmot et al., 2020; Office for National Statistics, 2022; Sabater and Simpson, 2009; Stanner, 2001). Overlooking structural inequality and the unique challenges faced by different population groups during policymaking may hinder efforts to address socioeconomic inequalities that may be behind poor grip strength in minoritised ethnic groups. A tailored, collaborative approach involving policymakers, healthcare providers, community leaders, and individuals is vital for promoting equal opportunities, achieving health equity, and reducing health inequalities. Intersectional policymaking can be achieved by engaging diverse communities, analysing policy impacts comprehensively, developing targeted policies, establishing accountability measures, and consistently evaluating the policy's effects on various populations (Holman et al., 2022; Fagrell Trygg et al., 2022; Bambra; Carter et al., 2014; Hankivsky et al., 2014). By acknowledging the unique lived experiences of different populations and the impact of various forms of oppression, such as discrimination, marginalisation, and the interplay of sexism, racism, classism, ageism, and genderism on health outcomes, policymakers could address drivers of inequality in health (Bambra, 2022; Hankivsky et al., 2014; Holman et al., 2022) while enhancing overall health outcomes, including grip strength and standing balance performance.

7.4.2 Public health implications

7.4.2.1 Barriers to meeting recommended strength and balance guidelines

Interventions targeting strength and balance have been shown to be effective, with compelling evidence suggesting that resistance exercise and balance and coordination interventions can have a positive impact on strength and balance abilities for both men and women across all ages (Grgic et al., 2020; Lacroix et al., 2017; Lesinski et al., 2015; Pahor et al., 2006; Pahor et al., 2014; Ransdell et al., 2021). Strength and balance recommendations were included in the inaugural UK Chief Medical Officers' physical activity guidelines in 2011 (Bull et al., 2011). In the 2019 guidelines, recommendations for these two components of physical activity were given a more prominent position, reflecting their importance for overall health (C. Foster et al., 2019). However, despite the Chief Medical Officers' recommendations, the proportion of the population engaging in the current recommended levels of strengthening and balance activities is low according to physical activity surveillance studies in the UK (Bennie et al., 2020; Sandercock et al., 2022; Strain et al., 2016). For instance, data from the *Active Lives Survey* suggest that, in the period of 2015 and 2017, 67% of adults achieved the recommended levels of overall physical activity as per the Chief Medical Officers' guidelines, equivalent to at least 150 minutes per week of moderate to vigorous physical activity, while only 23% of the sample met the recommended guideline of engaging in strength activities twice a week (Sandercock et al., 2022). Similarly, in the *Scottish Health Survey* (2012–2014), 64% of the adult population met the recommended physical activity levels as per the 2011 guidelines, but only 27% met the muscle-strengthening component of this guidance, and just 15% met the balance and coordination guidelines (Strain et al., 2016). For strength-related activities, individuals who were female, older, living with disability, or of lower SEP were less likely to engage in these activities than their male, younger, non-disabled, and higher SEP counterparts (Bennie et al., 2020; Sandercock et al., 2022; Strain et al., 2016). The same was found for balance training activities, with differences in participation observed across age groups, with older adults being less likely to engage in balance training (Strain et al., 2016). Although not identified in UK surveillance studies on adherence to the strength and balance guidelines, people from minoritised ethnic groups including people of South Asian, African, and Caribbean origin have some of the lowest levels of overall physical activity in the UK, and, as a result, are less likely to participate in strength and balance-based exercises (Bhatnagar et al., 2016; Fischbacher et al., 2004; Higgins and Dale, 2010; Sport England, 2022; E. Williams et al., 2011). This presents a significant challenge as not only is a substantial portion of the population failing to meet the strength and balance components of the *UK Chief Medical Officers'* physical activity guidelines, but also the individuals most susceptible to muscle weakness and balance-related issues are also the least likely to achieve these recommendations.

There are several barriers that prevent certain populations from meeting the strength and balance recommendations (Cavill et al., 2022; Cavill and Foster, 2018; Gluchowski et al., 2022; Higgerson et al., 2018; Richardson et al., 2017; Vasudevan and Ford, 2022). For example, in strength training for older people, not only is there a lack of awareness of the strength components of the 2019 physical activity guidelines, but there is also a lack of understanding of the benefits of strength training (Gluchowski et al., 2022). Furthermore, there is a misconception of what constitutes strength training, with some considering leisurely walking as a form of strength training (Gluchowski et al., 2022). Similar findings were also observed in middle-aged Black men, who had little awareness of the strength and balance guidelines and their importance for overall health (Cavill et al., 2022). They only associated the need for balance activities with experiencing balance problems (Cavill et al., 2022). In a study focusing on women, it has been found that there may be additional barriers to strength training. These can include psychological de-motivators related to perceptions of sex-based stigma, where strength training is viewed as a man's activity that could make women appear bulkier and less feminine (Vasudevan and Ford, 2022). Women may also experience external discouragement from other members of society, particularly in the form of comments about their bodies and involvement in strength training (Vasudevan and Ford, 2022). In addition, access to gym and fitness facilities may be prohibitive in engaging with strength and balance recommendations for those of lower SEP and those living with disability due to issues such as lack of accessibility and high costs (Higgerson et al., 2018; Richardson et al., 2017). Addressing these barriers could promote strength and balance training and increase participation levels in these activities. Potential facilitators to achieving these goals include providing education and resources to promote the benefits of strength training and to dispel misconceptions. In doing so, an emphasis can be placed on the importance of doing strength and balance exercises for living a healthy and independent life, and more importantly, as individuals age. Moreover, providing easy access to gyms and facilities with accessible equipment, as well as offering vouchers for gyms and fitness centres and increasing the availability of outdoor gyms and fitness spaces, such as those in parks, could help overcome the inaccessibility and financial challenges associated with participating in strength and balance activities (Higgerson et al., 2018; J. Lee et al., 2018; Richardson et al., 2017).

In addition to the need to address the barriers that impede the participation of certain populations in strength and balance training, studies have shown that physical activity guidelines in the UK have limited reach and pose barriers for certain groups, with some members of the public, particularly those from disadvantaged population groups, being uninformed about them (Cavill et al., 2022; Gluchowski et al., 2022; Hunter et al., 2014). To improve their effectiveness, it has been suggested that accessible and culturally sensitive guidelines that use non-technical language and multimedia campaigns should be developed and implemented, considering the preferences of under-served populations (Budzynski-Seymour et al., 2021; R. Gordon et al., 2006; Latimer et al., 2010; Milton et al., 2020; Nobles et al., 2020; Wakefield et al., 2010).

7.4.2.2 Tailored interventions

Although there is a strong evidence base for promoting strength training activities in certain groups such as women, older adults, those of low SEP, and people from minoritised ethnic groups, including in particular of South Asian origin, in this thesis and the wider literature, this thesis has presented novel insights regarding middle-aged men with grip strength advantage related to manual work (Arokiasamy and Selvamani, 2018; Birnie et al., 2011a; Cheval et al., 2018; Cheval et al., 2019; R. Cooper et al., 2011a; Dodds et al., 2014; Dodds et al., 2016; Hurst et al., 2013; Leong et al., 2015; Lindle et al., 1997; Ntuk et al., 2017; Petersen et al., 2018; Samson et al., 2000; N. Smith et al., 2019; Spruit et al., 2013; Starr and Deary, 2011; Strand et al., 2011a; Weinstein, 2016). Evidence from the BCS70 and UKB studies provides compelling evidence on the role of manual-based occupational activity on grip strength in middle-aged men, with grip strength advantage diminishing with age as these men approach retirement, as demonstrated in the UKB. Previous findings from the Health Survey for England support the importance of manual labour for achieving physical activity levels, showing that men of working age in manual occupations are more likely to meet the UK Chief Medical Officers' physical activity recommendations than those in sedentary jobs (Allender et al., 2008). However, this advantage disappears when occupational activity is excluded, and physical activity levels tend to decline during retirement, particularly among those who had occupationally active jobs (Allender et al., 2008; Chung et al., 2009). The public health implications of these findings are significant, as retirement represents a vulnerable period for working-class men. Compared with men of higher SEP, evidence from large population-based studies consistently shows that men of lower SEP are more likely to engage in unhealthy behaviours, including lower leisure-time physical activity, higher sedentary time, smoking, poorer diet quality, and poorer health-seeking behaviour, such as neglecting to get regular health check-ups (Beenackers et al., 2012; Galdas et al., 2005; Irala-Estevez et al., 2000; I. Lee et al., 2012; Mackenbach et al., 2008; Ng et al., 2014; O'Donoghue et al., 2016; Stringhini et al., 2018; Stringhini et al., 2017; Stringhini et al., 2014; Stringhini et al., 2010). The combination of losing their occupational activity advantage, and exposure to a number of other unhealthy behaviours may put men of lower SEP at a higher risk of poor musculoskeletal health and function, as well as a range of other chronic health conditions and outcomes post-retirement.

To support middle-aged men of lower SEP in maintaining their strength, tailored public health interventions need to be implemented, especially in the years leading up to retirement. Behavioural change interventions aimed at increasing men's physical activity levels and participation have been shown to be effective, with interventions lasting 12 weeks or less leading to a mean increase of 97 minutes of physical activity per week, with long-lasting effects of a year or more (Sharp et al., 2020). Positive outcomes have also been observed in weight loss and weight loss maintenance interventions specifically designed for men (M. Young et al., 2012). The UK's Football Fans in Training program is an example of a successful tailored intervention to improve men's physical and mental health, targeting men aged 35 to 65 and leveraging positive football culture, social support, and camaraderie to encourage healthy behaviours over a 12-week period (Hunt et al., 2020; Hunt et al., 2014; Wyke et al., 2015). These interventions have been shown to help middle-aged men of lower SEP develop the education and skills needed to build healthy behaviours and manage the effects of retirement, while also gaining social support, accountability, and a sense of community, by promoting physical activity, healthy eating, and routine health check-ups in a group setting.

7.4.3 *Implications for future research*

In this thesis, several gaps and areas for future research have been identified. As discussed in the section above, using data from cohort studies that have grip strength measurements from adolescence and early adulthood, further work could be done to investigate the role of childhood and adolescent SEP on these two markers, given that the development of strength and balance begins early, and the impacts of socioeconomic inequalities can also manifest early in life (Birnie et al., 2011a; Blodgett et al., 2022a; Sayer et al., 2004; Shaw et al., 2017; Strand et al., 2011a). Understanding when the effect of childhood socioeconomic position on strength and balance first manifests could provide valuable information for timely interventions. Moreover, given the scarcity of evidence examining the association between childhood SEP and the wide range of physical capability measures at earlier ages, it would be useful to investigate the emergence of socioeconomic inequalities in these measures.

Chapters 4, 5 and 6 have provided important new insights into the potentially protective aspect of physical activity levels related to occupation. This highlights the need for future research on the type, timing, and frequency of occupational activity required to mitigate socioeconomic inequalities. Additionally, research on potential interventions required for these middle-aged men involved in manual occupations as they transition to retirement should also be considered. This direction of research is timely, given that these findings demonstrate that lower SEP is not necessarily always bad for all aspects of health at all life stages. Therefore, future research areas could also focus on identifying potential interventions for middle-aged men with higher physical activity levels related to their occupation. This would ensure that they receive appropriate strength and balance interventions during retirement when their occupational activity levels decline, while also avoiding the negative effects associated with poor health behaviours related to lower SEP.

Another major area of research focus in understanding life course socioeconomic inequalities in strength and balance is to consider how ethnicity plays a role in these associations. For instance, when examining the relationship between childhood SEP and grip strength, it would be worthwhile to explore how the associations of lower SEP and weaker grip strength, observed for women in the BCS70, would vary for women of different ethnic groups. This would offer useful insights and perspectives for timely interventions targeting socioeconomic and ethnic inequalities.

Further research could also investigate ethnic-specific variations in grip strength. Currently, there has only been one systematic review conducted on this topic. However, the review focuses on global variation and does not address ethnicity-specific variation, despite the fact that populations are diverse and include different ethnic groups, such as those in the UK (Dodds et al., 2016). Additionally, a large number of population-based studies examining ethnic variations in grip strength have emerged since the publication of this review. Therefore, such a review could provide useful insights that are relevant to the ethnicity-specific definitions of muscle weakness for sarcopenia.

7.5 Concluding remarks

Using a life course epidemiological perspective, this thesis has provided important insights into the relationships between lifetime SEP and grip strength and standing balance in the BCS70, as well as adulthood SEP and grip strength in the UKB. It has also identified some of the pathways through which these associations may operate. The analysis of data from the BCS70 showed that lower childhood and adulthood SEP were associated with weaker grip strength among women. Additionally, lower adulthood SEP was also found to be associated with weaker grip strength in the UKB for women. For men, the BCS70 data showed no associations between indicators of childhood SEP and grip strength. However, in both the BCS70 and UKB datasets, lower adulthood SEP was associated with stronger grip strength, possibly due to higher levels of occupational activity related to manual occupations among middle-aged men. Notably, the associations between adulthood SEP and grip strength varied by age and ethnicity among men. Men of South Asian heritage did not experience the same occupational activity advantage as men of other ethnic groups. Furthermore, in the UKB, South Asian participants generally had weaker grip strength than White men, while Black participants were stronger than White men and women, even after accounting for height, adiposity, and health and behavioural factors. Lastly, there was evidence that lower childhood SEP was associated with poorer standing balance performance, which was primarily explained by adulthood SEP. Lower adulthood SEP was associated with poorer standing balance performance, and a significant portion of the association was not explained by the potential mediators examined.

These findings have addressed a gap in the existing literature by examining associations at younger ages than previously done, as well as exploring interactions between sex, age, and ethnicity in relation to SEP where possible. Moreover, this thesis has identified additional areas of research, including investigating socioeconomic inequalities in strength and balance at earlier ages, and the need to build evidence around potential interventions required for middle-aged men of high physical activity related to their manual occupations once they retire.

The overall findings in this thesis have implications for policy and public health. Priorities include addressing socioeconomic inequalities across the life course and implementing targeted interventions to improve strength levels and balance abilities, especially among specific groups such as middle-aged men in manual occupations and South Asian participants of lower SEP. This thesis advocates for the importance of promoting healthy ageing and reducing socioeconomic inequalities in musculoskeletal health and function. It provides valuable insights that can inform, and shape policies aimed at enabling individuals to live longer with good health, independence, and vitality, while also contributing to the creation of a more equitable and healthy society.

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Appendices

APPENDIX A1

Literature review

A.1 Literature search strategy and results table

Table A.1.1: Search strategy and results for literature review search conducted on 15/11/2022 in PubMed

#	Search term	Number of studies
1	childh*	
2	early-life OR early life	
3	lifecourse OR life course	
4	lifelong	
5	OR/ search #1 to #4	604,587
6		
7	socioeconomic	
8	socio-economic	
9	social OR economic	
10	OR/ search #7 to #9	2,480,461
11		
12	class OR conditions OR factor*	
13	position OR status	
14	adversity OR circumstances	
15	OR/ search #12 to #14	13,095,936
16		
17	’physical capability’	
18	’physical performance’	
19	’physical function’	
20	balance OR grip OR walk*	
21	’chair rise’	
22	’gait speed’	
23	’hand strength’	
24	’muscle strength’	
25	’postural control’	
26	OR/ search #17 to #25	715,380
27		
28	#10 AND #15	1,202,480
29	#5 AND #28	83,116
30	#29 AND #26	2,852

A.2 Literature review table

Table A.2.1: Summary of the studies that examined the associations between childhood SEP and physical capability

Study/sample details	Exposure and outcome	Covariates	Associations
(Birnie et al., 2011) Study: Systematic review Date: Inception to 2010 Sample size: Grip strength: 1,061,855 Walking speed: 20,770 Chair rise: 17,215 Standing balance: 22,156) Age: 18-79 years	Childhood SEP: 1) Father's occupation 2) Father's education 3) Mother's education 4) Childhood economic environment 9/11 studies had retrospective ascertained Physical capability: Grip strength Walking speed Chair rise speed Standing balance	Confounders 1) Age 2) Adult SEP 3) Body size	Model 1 (Confounder: 1) ↓ childhood SEP = ↓ grip strength ↓ childhood SEP = ↓ walking speed ↓ childhood SEP = ↓chair rise speed ↓ childhood SEP = ↓ balance time Model 2 (Confounder: 1-2) ↓ childhood SEP = NA with grip strength ↓ childhood SEP = ↓ walking speed ↓ childhood SEP = ↓ chair rise speed ↓ childhood SEP = NA with standing balance Model 3 (Confounder: 1-3) ↓ childhood SEP = NA with grip strength ↓ childhood SEP = NA with walking speed ↓ childhood SEP = ↓ chair rise speed ↓ childhood SEP = NA standing balance

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Strand et al., 2011) Study: MRC NSHD Design: Birth cohort Setting: Britain Period: 1946-ongoing Sample size: n = 2,988 Age: 53	Childhood SEP: Mothers education (P) - ME Fathers occupation (P) - FO Physical capability: Chair rise speed Grip strength Standing balance	- Birth weight - Height and weight - Childhood growth - Material home conditions, 4 yrs - Age at first walking - Cognitive ability, 8 yrs - Motor coordination, 15 yrs - Physical activity - Height and weight - Smoking - Cognitive function - Lung function (FEV1) - Health status	Model 0 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance time ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = ↓ standing balance time Model 1 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = ↓ standing balance time Model 2 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = NA standing balance time

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
-	-	-	Model 3 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = NA with standing balance time Model 4 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance time ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = NA with standing balance time

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
-	-	-	Model 5 ↓ ME = NAwith grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance time ↓ FO = NA with grip strength ↓ FO = ↓ chair rise speed ↓ FO = NA with standing balance time Model 6 ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance time ↓ FO = NA with grip strength ↓ FO = Reduced chair rise speed ↓ FO = NA with standing balance time
-	-	-	Model 7 (Fully adjusted) ↓ ME = NA with grip strength ↓ ME = NA with chair rise speed ↓ ME = ↓ standing balance time ↓ FO = NA with grip strength ↓ FO = NA with grip strength ↓ FO = NA with standing balance time

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Starr and Deary, 2011) Study: Lothian birth cohort Design: cohort study Setting: Scotland Period: 1921 - Sample size: n = 559 Age: 79 - 87 years	Childhood SEP: Participant’s education (P) Father’s education (P) Mother’s education (P) Participant’s social class (P) Physical capability: Grip strength	Wave Vital status Sex Height Weight Participant’s adult SEP	↓ childhood SEP = ↓ grip strength
(Hurst et al., 2013) Study: MRC NSHD Design: Birth cohort Setting: Britain Period: 1946-ongoing Sample size: n = 2,229 Age: 60 -64 years	Childhood SEP: Fathers occupation (P) - FO Physical capability: Chair rise speed Grip strength Standing balance Walking speed	Adult height childhood cognition BMI Lifetime smoking status Adult occupation Adult education	Adjust all for gender Model 1: ↓ childhood SEP = ↓ grip strength ↓ childhood SEP= ↓ chair rise speed ↓ childhood SEP= ↓ standing balance time ↓ childhood SEP = ↓ walking speed Model 2: Adjusted ↓ childhood SEP = ↓grip strength ↓ childhood SEP = ↓ chair rise speed ↓ childhood SEP = ↓ standing balance time ↓ childhood SEP = ↓ walking speed

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Murray et al., 2013) Study: MRC NSHD Design: Birth cohort Setting:Britain Period: 1946-ongoing Sample size: 2,566 Age: 53	Childhood SEP Childhood Area deprivation (CAD) Physical capability: Chair rise speed Grip strength Standing balance	Adult SEP Childhood SEP	↓ childhood SEP = ↓ standing balance ↓ childhood SEP = NA with chair rise speed ↓ childhood SEP = NA with grip strength
(Sousa et al, 2014) Study: IMIAS Design: cohort study sample size: 1,995 Age: 66-72 years	Childhood SEP: Family SEP (R) Having been hungry (R) Parental unemployment (R) Physical capability: Short Physical Performance Battery test (SPBI) - Balance Gait speed Chair stand	Site Age Sex	↓childhood SEP (men) = ↓ SPBI ↓ childhood SEP (Women) = ↓ SPBI

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Henretta & McCrory, 2015) Study: TILDA Design: cohort study Setting: Ireland Sample size: 2,233 Age: 50-59 years	Childhood SEP: Fathers education (R) Physical capability: Walking speed	Confounders: 1) Age 2) Sex 3) Height 4) Prescriptions that lead to physical slowing Mediators: 1) Childhood health 2) Rural childhood 3) Own education 4) Marital status 5) Smoking history 6) BMI 7) Current adult health conditions 8) Cognition	All models adjusted for confounders 1 – 4. Model 1 (Mediators 1-2) ↓ childhood SEP = ↓ walking speed Model 2 (P Mediators 1-3) ↓ childhood SEP= ↓ walking speed Model 3 (Mediators 1-6) ↓ childhood SEP = ↓ walking speed Model 4 (Mediators 1-7) ↓ childhood SEP = ↓ walking speed Model 5 (Mediators 1-8) ↓ childhood SEP= ↓ walking speed

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Weinstein, 2016) Study: SHARE Design: cohort study Setting: Israel Sample size: : 2,332 Age: 57-78 years	Childhood SEP: Childhood financial status - CFS (R) Number of books - NBC (R) Physical capability: Grip strength Chair rise speed	1) Age 2) Sex 3) Language 4) Income 5) Height 6) Weight 7) Current health status 8) Chronic disease 9) Education level 8) Physical activity 9) Alcohol	Model 1 (adj 1-5) ↓ CFS = ↓ chair-rise ↓ CFS = ↓ grip strength ↓ NBC = ↓ chair-rise speed ↓ NBC = ↓ grip strength Model 2 (adj 1-8) ↓ CFS = ↓ chair-rise ↓ CFS = ↓ grip strength ↓ NBC = ↓ chair-rise speed ↓ NBC = ↓ grip strength

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Caleyachetty et al., 2017) Study: NSHD Design: cohort study Setting: Britain Sample size: : 2,856 Age: 60-64 years	Childhood SEP: Maternal education (P) Fathers social class (P) House ownership (P) Poor household amenities (P) Overcrowding (P) Poorly repaired house (P) Unclean child (P) Poorly cleaned house (P) State of child cloths (P) Physical capability: Chair rise speed Grip strength Standing balance time Walking speed	1) 1) Sex 2) Childhood social risk 2a) Maltreatment 2b) Low concern for child's education 2c) Parental psychiatric history 2d) Parental divorce 2e) Father affectionless control 2f) Parent death 2g) Paternal separation	Model 1 (adj 1) ↓ CSEP = ↓ physical capability Model 2 (adj 2) ↓ CSEP = ↓ physical capability

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(N. Smith et al., 2019) Study: HRS Design: cohort study Setting: USA Sample size: 13,921 Age:52 – 99 years	Childhood SEP: Composite of.. 1) Paternal education (R) 2) Maternal education (R) 3) Father moved due to financial hardship (R) 4) Paternal occupation (R) 5) Perception of family SES before 16 (R) Physical capability: Grip strength	1) Adult SEP 2) Adult psychosocial factors 3) Physical activity 4) Smoking status 5) Body mass index 6) Comorbidity 7) Occupation 8) Smoking	Time 1 (2006- 2008) Model 2: Women ↓ childhood SEP = NA with grip strength Men ↓ childhood SEP = ↓ grip strength Model 3 (adj 1-8) Women ↓ childhood SEP = ↓ grip strength Men ↓ childhood SEP = NA with grip strength
-	-	-	Time 2 (2010- 2012) Model 2: Women ↓ childhood SEP = NA with grip strength Men↓ childhood SEP = ↓ grip strength Model 3 (adj 1-8) Women ↓ childhood SEP = NA with grip strength Men ↓ childhood SEP = NA with grip strength

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Anderson et al., 2017) Study: ALSPAC Design: cohort study Setting: Bristol, England Period: 1990 – ongoing Sample size: 2,221 Age:48 – 54 years	Childhood SEP: Mother's occupation (R) Father's occupation (R) Physical capability: Score of: Chair rise speed Grip strength Standing balance Walk speed low score = poorer outcome	Age Adult SEP Ethnicity Psychosocial adversity	Model 1 (unadj) ↓childhood SEP = ↓ score Model 2 (adj: age) ↓childhood SEP = ↓ score Model 3 (adj: age, adult SEP) ↓childhood SEP = ↓ score Model 4 (adj: age, adult SEP, body size) ↓childhood SEP = ↓ score
(Hwang et al., 2017) Study: IMIAS Design: cohort study Setting sample size: Kingston (N = 398) St. Hyacinthe (N = 401) Tirana, Albania (N = 394) Natal, Brazil (N = 407) Manizales, Colombia (N = 402) Age: 67-78 years	Childhood SEP: Family SEP (R) Having been hungry (R) Parental unemployment (R) Physical capability: SPBI test: Balance Gait speed Chair stand speed	Education Age Sex	Men ↓childhood SEP = NA with SPBI Women ↓childhood SEP = ↓ SPBI

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Petersen et al., 2018) Study: CAMB Design: cohort study Setting: Denmark Sample size: 4,204 Age: 48-58 years	Childhood SEP: Fathers occupational class (FOC) (P) Parental Social class (PSC) (R) Physical capability: Balance Flexibility Jump height Lower back force Abdominal force Grip strength Chair rise	Adult SEP	Metropolit Cohort: ↓ FOC = ↓ jump height ↓ FOC = ↓poor chair rise time ↓ FOC = NA with balance time ↓ FOC = NA with flexibility distance ↓ FOC = NA with lower back force ↓ FOC = NA with abdominal force ↓ FOC = NA with grip strength Copenhagen Perinatal Cohort: ↓ PSC = ↓ chair rise time ↓ PSC = ↓ jump height ↓ PSC = ↓ grip strength ↓ PSC = NA with balance time ↓ PSC = NA with flexibility distance ↓ PSC = NA with lower back force ↓ PSC = NA with abdominal force

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Cheval et al., 2018) Study: SHARE) Design: cohort study Setting: Europe Sample size: 24,179 Age: 50-96 years	Childhood SEP: 1) Occupation of main breadwinner (R) 2) Number of books at home (R) 3) Measure of overcrowding (R) 4) Housing quality (R) Physical capability: Grip strength	Confounders: 1) Birth cohort 2) Welfare regime 3) Living with biological parents 4) Participant attrition Mediators 1) Adult SEP i) education ii) occupation iii) satisfaction with household income 2) Unhealthy behaviours (Physical inactivity, poor diet, smoking, alcohol)	All models adjusted for confounders 1 – 4. Model 1: Women ↓childhood SEP = ↓ grip strength Men ↓childhood SEP = ↓ grip strength Model 2 (Mediators: 1i): Women ↓ childhood SEP = ↓ grip strength Men ↓ childhood SEP = ↓ grip strength

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
-	-	-	Model 3 (Mediators: 1i-ii): Women ↓ childhood SEP = ↓ grip strength Men ↓ childhood SEP = ↓ grip strength Model 4 (Mediators: 1i-iii): Women ↓ childhood SEP = ↓ grip strength Men: ↓ childhood SEP = ↓ grip strength Model 5 (Mediators: 1i-iii, 2) Women ↓ childhood SEP = ↓ grip strength Men ↓ childhood SEP= ↓ grip strength

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Noppert et al., 2018) Study: PALS Design: Cohort study Setting: USA Period: 1921 - Sample size: 859 Age: 30 – 90+	Childhood SEP: Parental education - PE (R) Subjective CSEP - SCSEP (R) Physical capability: Walking speed test Walking endurance test Lower body strength	1) Age 2) Race/ethnicity 3) Sex 4) Marital status 5) Employment status	Model 1 ↓ PE = ↓ walk speed ↓ PE = NA with endurance ↓ PE = NA with chair rise speed ↓ SCSEP = NA with walk speed ↓ SCSEP = NA with endurance ↓ SCSEP = NA with chair rise speed Model 4 (adj 1-4) ↓ PE = NA with walk speed ↓ PE = NA with endurance ↓ PE = NA with chair rise speed ↓ SCSEP = NA with walk speed ↓ SCSEP = NA with endurance ↓ SCSEP = NA with chair rise speed
(Cheval et al., 2019) Study: SHARE Design: cohort study Setting:Europe Sample size: 23,444 Age: 50-96 years	Childhood SEP: 1) OccupationAL CLASS (R) - OBM 2) Number of books at home (R) - NBM 3) overcrowding (R) – MO 4) Housing quality (R) -HQ Physical capability: Grip strength	1) Adult SEP 2) Childhood health problems 3) Age at baseline 4) Birth cohort 5) Attrition 6) Country of residence 7) Height	Model 1 (adj 1-7) ↓ OBM (men) = ↓ grip strength ↓ NBM (Women) =↓ grip strength ↓ MO (men) = ↓ grip strength ↓ HQ (Women) =↓ grip strength

Table A.2.1 continued from previous page

Study/sample details	Exposure and outcome	Covariates	Associations
(Kuh et al., 2019) Study: MRC NSHD Design: Birth cohort study Setting: Great Britain Period: 1946-2015 Sample size: 3,058 Ages: 53, 60–64 or 69	Childhood SEP: Fathers occupation (FO) Physical capability: Grip strength	Age	Model 1 ↓ FO (men) = NA with grip strength ↓ FO (Women) = NA with grip strength Model 2 (Age interaction) ↓ FO (men) = NA with grip strength ↓ FO (Women) = ↓ grip strength
(Blodgett et al., 2020) Study: MRC NSHD Design: Birth Cohort Setting: Great Britain Period: 1946 - 2015 Age and sample size: Age 53 (n=2,988) Age 60-64 (n=2,229) Age 69 (n=2,149)	Childhood SEP: 1) Paternal occupational class (P) 2) Maternal education (P) Physical capability: Standing balance	Age	Model 1 ↓ FO (men) = no association with grip strength ↓ Paternal occupational class = poorer balance ↓ Maternal education = poorer balance *Association attenuates with age
(Carney & Benzeval, 2018) Study: UKHLS Design: Cohort study Setting: United Kingdom Period: 1911 - 2011 Age and sample size: Age 19-99 (N=19,292)	Childhood SEP: Maternal education (R) Physical capability: Grip strength	None	Men ↓ Maternal education = ↓ grip strength *Association attenuates with age Women ↓ Maternal education = ↓ grip strength * **Association strengthens with age

NA = No association; R=Retrospectively ascertained, P = Prospectively ascertained; NSHD = National Survey of Health and Development; SHARE = Survey of Health Ageing and Retirement in Europe; TILDA = The Irish Longitudinal Study of Aging; HRS = Health and Retirement Study; CAMB = Copenhagen aging and midlife biobank; IMIAS = International Mobility in Aging Study; ALSPAC = Avon Longitudinal Study of Parents and Children; PALS = Physical Performance Across the LifeSpan.

APPENDIX B

BCS70 supplementary materials

B.1 Published work

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BMC Public Health

RESEARCH Open Access

Associations between childhood and adulthood socioeconomic position and grip strength at age 46 years: findings from the 1970 British Cohort Study

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Abstract

Background: Muscle weakness is a key criterion for important age-related conditions, including sarcopenia and frailty. Research suggests lower childhood socioeconomic position (SEP) may be associated with muscle weakness in later life but there is little evidence on associations in younger adults closer to peak muscle strength. We aimed to examine relationships between indicators of SEP in childhood and adulthood and grip strength at age 46y.

Methods: We examined 7,617 participants from the 1970 British Cohort Study with grip strength measurements at 46y. We used sex-specific linear regression models to test associations between five different indicators of SEP in childhood and adulthood (paternal occupational class and parental education levels at age 5 and own occupational class and education level at age 46) and maximum grip strength. Models were adjusted for birth weight, BMI in childhood and adulthood, adult height, disability in childhood, leisure-time physical activity in childhood and adulthood, sedentary behaviour in childhood and adulthood, occupational activity and smoking at age 46.

Results: Among women, lower SEP in childhood and adulthood was associated with weaker grip strength even after adjustments for covariates. For example, in fully-adjusted models, women whose mothers had no qualifications at age five had mean grip strength 0.99 kg (95% CI: -1.65, -0.33) lower than women whose mothers were educated to degree and higher. Among men, lower levels of father's education and both adult SEP indicators were associated with stronger grip. The association between own occupational class and grip strength deviated from linearity; men in skilled-manual occupations (i.e. the middle occupational group) had stronger grip than men in the highest occupational group (Difference in means: 1.33 kg (0.60, 2.06)) whereas there was no difference in grip strength between the highest and lowest occupational groups. Adjustment for occupational activity largely attenuated these associations.

Conclusion: Findings highlight the need to identify age and sex-specific interventions across life to tackle inequalities in important age-related conditions related to weakness.

Keywords: Grip strength, Muscle weakness, Socioeconomic position, Life course, Birth cohorts

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Research summary

What is already known on this subject?

- Muscle weakness (often indicated by low grip strength) is a key criterion for important age-related conditions including sarcopenia and frailty. It is

highly prevalent in later life and can result from poor muscle development in earlier life and/or faster rates of age-related decline in strength from midlife.
• A growing body of evidence has shown that weak grip strength in later life may originate in early life and be influenced by factors including childhood and adulthood socioeconomic position (SEP).
• Most studies that have examined the association between early life SEP and grip strength have focused on older adults, and in the few studies that have examined younger adults findings are inconsistent.

What this study adds?

• In a relatively large, nationally representative population of middle-aged adults in Great Britain we found sex differences in the associations between SEP and grip strength.
• In women, lower SEP in childhood and adulthood was consistently associated with weaker grip strength at age 46y.
• In men, there were no evidence of an association between two indicators of childhood SEP (father's occupational class and mother's education) and grip strength at age 46y. However, lower father's educational attainment and lower adult SEP were associated with stronger grip, largely explained by higher levels of occupational activity in the skilled manual occupational group.

Background

Muscle weakness, commonly indicated by low grip strength, is associated with mobility disability, loss of independence, premature mortality and many other adverse health outcomes [1–6]. It is also a key criterion for important age-related conditions including sarcopenia and frailty [7, 8]. These age-related conditions which are highly prevalent [9, 10] have profound implications for individuals, their families and society. In addition, estimates of the annual healthcare costs associated with muscle weakness and sarcopenia in a range of different countries around the world are substantial [11] and likely to increase with time as the global population ages. To address the public health challenge that muscle weakness represents we need to identify strategies that improve people's chances of developing optimal strength in early life, maintaining strength through midlife and minimising decline in later life. This requires a better understanding of the risk factors across life that are associated with grip strength at different life stages.

Over the last two decades, a growing body of evidence has shown that differences in levels of grip strength in later life may originate in early life [12, 13]. This has resulted in investigations into the associations of various childhood factors with grip strength in adulthood, including indicators of socioeconomic position (SEP) [14, 15]. However, despite a systematic review published in 2011 that synthesised data from 12 studies on the association between childhood SEP and adult grip strength [14], and several subsequent investigations [15–23], evidence of an association between lower childhood SEP and weaker grip strength in adulthood remains equivocal. The authors of the systematic review reported considerable heterogeneity between studies [14]. This may be due to variations in the scale and direction of associations between childhood SEP and grip strength by age, sex, birth cohort, and/or place.

As most existing studies of childhood SEP and grip strength have focused on adults aged 60 and over [14, 16–19, 21–23], it is difficult to establish how associations vary across adulthood. In addition, even where existing studies have examined populations spanning a wide age range, including younger adults [18–22], interactions between age and SEP have rarely been formally tested [24]. Where associations have been observed between low childhood SEP and weak grip strength, it has not been possible to establish whether these are explained by the influences of SEP in early life on the attainment of peak grip strength or its subsequent decline. More studies of younger adults closer to peak grip strength are required to establish this. This is especially as the only study on younger adults, included in the systematic review [14], found lower childhood SEP was associated with stronger grip in Swedish males at age 18. This is in the opposite direction to the association reported in some studies of older adults highlighting that childhood SEP may have different patterns of association with grip strength at different life stages.

Also limiting our understanding of childhood SEP and grip strength associations is the fact that most studies only include adults born before 1950 [15–23]. Whether similar associations are also found in more recently born generations exposed to different social, political, economic and work environments across life also remains to be established.

To address the need for studies of the association between SEP and grip strength in younger adults from more recently born cohorts, we aimed to explore the relationships between indicators of SEP in childhood and adulthood with grip strength at age 46y in the 1970 British Cohort Study. We examined: (a) whether indicators of SEP prospectively ascertained in childhood and adulthood were associated with grip strength; (b) whether these associations varied by sex and were explained by several important covariates.

Methods

Study design and population

We conducted secondary analysis using data from the 1970 British Cohort Study (BCS70), an ongoing prospective study of males and females born in England, Scotland and Wales within a single week in March 1970, with immigrants added into the sample during the first three waves [25]. A total of 18,037 males and females were recruited and assessed on at least one occasion (at birth, and ages 5, 10, 16, 26, 30, 34, 38, 42 and 46) [26]. At age 46, a home visit was conducted, during which a 50-min interview and a nurse-led biomedical assessment, including grip strength measurement, was undertaken. A total of 8,581 participants completed at least one component of the data collection at age 46 (Fig. 1). Of these, 7,685 completed a nurse biomedical assessment, and 7,547 had valid grip strength measures. Participants provided informed consent and the assessment at age 46y received full ethical approval from NRES Committee South East Coast—Brighton & Sussex (Ref 15/LO/1446).

Assessment of grip strength

During the biomedical assessment at age 46y, grip strength was measured in kilograms using a Smedley hand-held dynamometer by trained nurses following standardised protocols. The maximum measurement of six attempts (three in each hand) was used in analyses. Participants were excluded from the grip strength assessment if they had had hand surgery in the past six months or had swelling, inflammation, severe pain, or a recent injury to their hands. If participants were unable or unwilling to complete the grip strength tests, the reason for this was recorded. Participants unable to complete the grip strength assessment for health reasons ($n=70$) were allocated a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution [17] on the assumption that these participants were likely to have had low grip strength whereby their exclusion may bias results [27].

Socioeconomic position

We chose a priori to use indicators of SEP ascertained at ages five and 46y. At age five, we used father's occupational class (or at birth if missing ($n=1,176$)) and mother's and father's educational levels. Using the Registrar General's Social Classification (RGSC), occupational class was categorised into four groups: I professional/II intermediate, III skilled non-manual, III skilled manual and IV partly skilled/V unskilled. Both mother's and father's educational levels were based on the highest qualification achieved categorised into four groups: Higher vocational/degree and higher, A-level/equivalent (advanced secondary education), Vocational/O-level/equivalent (ordinary secondary education) and No qualification. At age 46, we selected to use own occupational class, back-coded from National Statistics Socio-Economic Classification of occupations to RGSC, and then similarly categorised as father's occupational class. Own highest qualification at age 46 was also used, categorised into four groups: Degree and higher, A-level and vocational qualification (advanced secondary education), GCSEs (ordinary secondary education) and no qualifications.

Covariates

Covariates were selected a priori based on previous literature [28, 29] and considered within the framework outlined in supplementary Figure S1. As height is strongly associated with grip strength [28], and in many cases, relative grip strength (i.e., grip strength adjusted for height) is presented as a primary outcome measure [30], analyses were initially adjusted for adult *height* (nurse-measured at age 46). Childhood factors included: birth weight (kg) (ascertained from birth records) and the following variables assessed at age ten: body mass index (BMI) (calculated as kg/m^2 from nurse-measured height and weight); leisure-time physical activity (maternal report of how often the participant played sports in their spare time); sedentary behaviour (maternal report of how often the participant watched television in their spare time); disability (parental report of whether they considered the participant to have a physical or mental disability or handicap, or any other disabling condition which interfered with everyday life, or which might be a problem at school).

Adulthood covariates were BMI at age 46 (derived from nurse-measured height and weight); self-reported smoking status at age 42; sedentary behaviour at age 42 (self-reported length of time spent watching television on a typical weekday); leisure-time physical activity at age 42 (self-reported number of days spent doing 30 min or more of exercise in a typical week); occupational activity at age 46 (self-report of the types of physical activity involved in the participant's work). The categorisation of all covariates are presented in Table 1.

Statistical analyses

T-tests and chi-squared tests were used to examine sex differences in continuous and categorical variables, respectively. We tested the associations between each SEP indicator and maximum grip strength at 46y using linear regression models. We first ran formal tests of interaction between sex and each SEP indicator and where there was evidence of sex interaction (based on

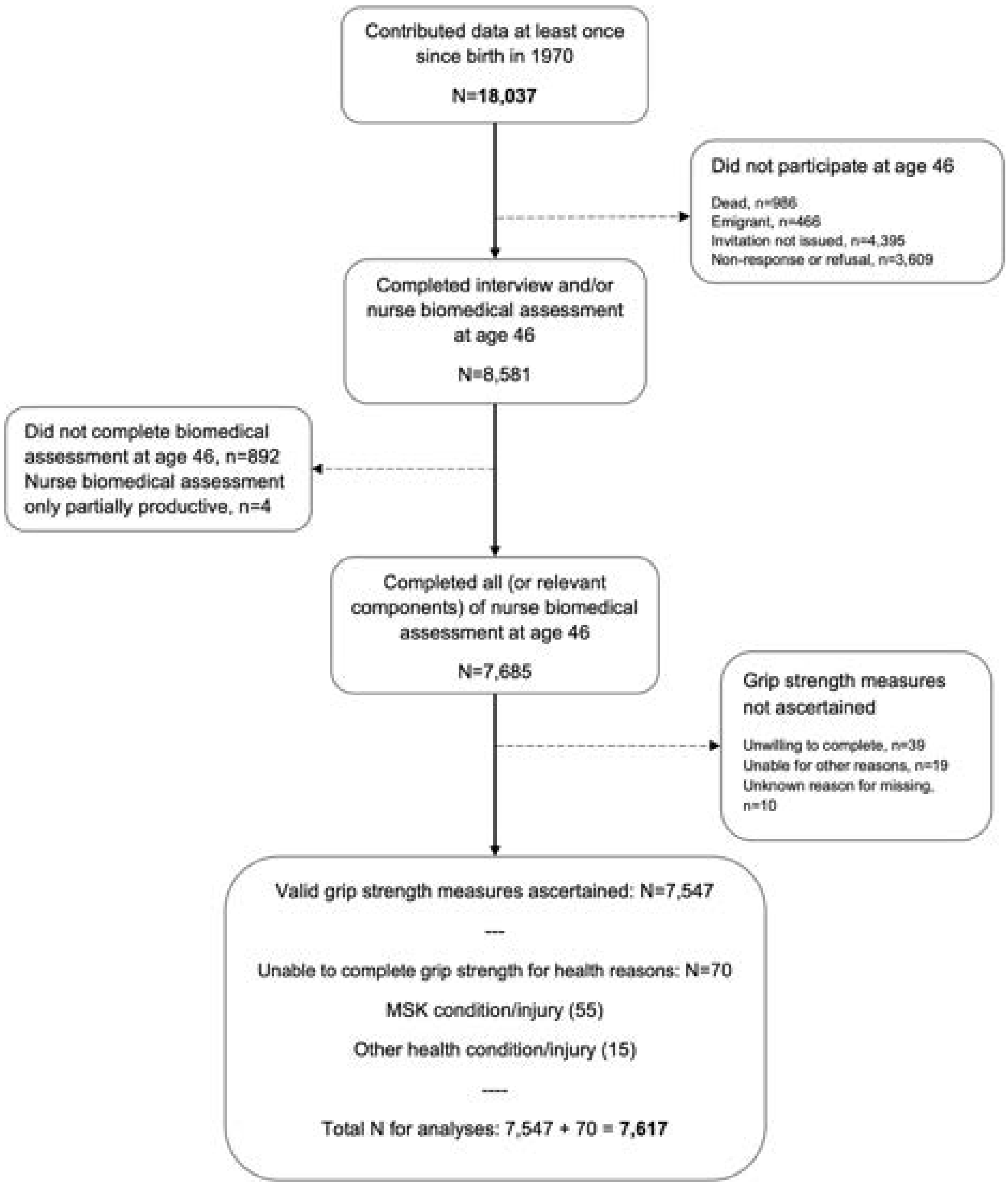

Fig. 1 Flow diagram of participation in the BCS70

$p < 0.1$) subsequent models were stratified by sex. Linear trends were assessed using likelihood ratios tests. Covariates were added to the models sequentially. Initially, adult height was included, then childhood factors, and then adulthood factors. As well as running models with factors grouped (as presented) we also

Table 1 Characteristics of the BCS70 participants included in analyses (maximum $N = 7{,}617$*)

Characteristics	Overall N [a]	Mean (SD) or N (%) [a]		p-value [b]
		Female (N = 3,922)	Male (N = 3,695)	
Outcome				
Max grip strength (kg) at age 46y [c]	7,617	29.51 (5.83)	48.03 (9.01)	< 0.001
Socioeconomic indicators				
Father's occupational class at age 5y	7,198			0.07
I Professional/II Intermediate		1,059 (28.4)	1,039 (29.9)	
III Skilled non-manual		399 (10.7)	390 (11.3)	
III Skilled manual		1,584 (42.5)	1,479 (42.6)	
IV Partly skilled/V Unskilled		686 (18.4)	562 (16.2)	
Mother's highest qualification at age 5y	5,931			0.96
Higher vocational/degree and higher		289 (9.4)	276 (9.7)	
A-level/equivalent		138 (4.5)	134 (4.7)	
Vocational/O-level/equivalent		1,095 (35.5)	1,010 (35.4)	
No qualification		1,557 (50.6)	1,432 (50.2)	
Father's highest qualification at age 5y	5,565			0.74
Higher vocational/degree and higher		520 (18.1)	512 (19.0)	
A-level/equivalent		253 (8.8)	221 (8.2)	
Vocational/O-level/equivalent		845 (29.5)	789 (29.2)	
No qualification		1,252 (43.6)	1,173 (43.5)	
Own occupational class at age 46y	6,404			< 0.001
I Professional/II Intermediate		1,410 (45.4)	1,614 (48.9)	
III Skilled non-manual		997 (32.1)	469 (14.2)	
III Skilled manual		326 (10.5)	959 (29.1)	
IV Partly skilled/V Unskilled		372 (12.0)	257 (7.8)	
Own highest qualification at age 46y	7,512			< 0.001
Degree and higher		1,055 (27.2)	923 (25.4)	
A-level and vocational qualification		608 (15.7)	467 (12.9)	
GCSEs		1,243 (32.1)	1,119 (30.8)	
No qualification		973 (125.)	1,124 (31.0)	
Covariates				
Birth weight (kg) (Mean (SD))	7,046	3.26 (0.50)	3.37 (0.53)	< 0.001
BMI (kg/m^2) at age 10y (Mean (SD))	6,016	16.93 (2.20)	16.73 (1.90)	0.025
Leisure-time physical activity at age 10y	6,607			< 0.001
Never or hardly ever		365 (10.7)	158 (4.9)	
Sometimes		1,643 (48.3)	920 (28.7)	
Often		1,392 (40.9)	2,129 (66.4)	
Sedentary behaviour (TV watching) at age 10y	6,626			< 0.001
Never or hardly ever		49 (1.4)	26 (0.8)	
Sometimes		810 (23.7)	512 (15.9)	
Often		2,559 (74.8)	2,670 (83.3)	
Disability at age 10y	6,606			0.057
No		3,203 (93.7)	2,943 (92.3)	
Yes, slight		195 (5.7)	228 (7.1)	
Yes, severe		19 (0.6)	18 (0.6)	
Height (m) at age 46y (Mean (SD))	7,553	1.64 (0.06)	1.77 (0.07)	< 0.001
BMI (kg/m^2) at age 46y (Mean (SD))	7,387	28.22 (6.17)	28.64 (4.63)	< 0.001
Smoking status at age 42y	7,111			0.003
Never smoker		1,776 (48.0)	1,590 (46.6)	
Ex-smoker		1,111 (30.0)	966 (28.3)	

Table 1 (continued)

Characteristics	Overall N [a]	Mean (SD) or N (%) [a]		*p*-value [b]
		Female (*N* = 3,922)	Male (*N* = 3,695)	
Current smoker (less than daily)		210 (5.7)	183 (5.4)	
Current smoker (daily)		604 (16.3)	671 (19.7)	
Sedentary behaviour (TV watching) at age 42y	6,368			< 0.001
0 to < 1 h		624 (18.4)	447 (15.0)	
1 to < 3 h		1,976 (58.4)	1,790 (60.0)	
3 to < 5 h		621 (18.4)	555 (18.6)	
5 + hours		162 (4.8)	193 (6.5)	
Leisure-time physical activity (days/week) at age 42y	7,008			< 0.001
0 days		1,135 (31.1)	809 (24.0)	
1 day per a week		438 (12.0)	390 (11.6)	
2 days per a week		560 (15.4)	482 (14.3)	
3 days per a week		534 (14.6)	506 (15.1)	
4/5 days per a week		549 (15.1)	661 (19.7)	
6/7 days per a week		430 (11.8)	514 (15.3)	
Occupational activity at age 46y	6,291			< 0.001
Sitting occupation		1,756 (55.7)	1,682 (53.6)	
Standing occupation		635 (20.1)	337 (10.7)	
Physical work		733 (23.3)	850 (27.1)	
Heavy manual work		28 (0.9)	270 (8.6)	

[*] Sample restricted to those with valid measures of grip strength at age 46y. Including those who were unable to complete the grip strength for health reasons whose values have been imputed a value of grip strength equivalent to the mean of the bottom sex-specific fifth of the grip strength distribution (*N* = 70)

N = Total number

[a] Ns presented in table vary due to missing data

[b] Statistical tests of sex difference: chi-square of independence; t-test

[c] Including those 70 people with imputed grip strength values. Observed mean max grip strength (*N* = 7,547): Females 29.60 kg (SD 5.81 kg); Males 48.09 kg (SD 8.99 kg)

examined associations with adjustment for each adulthood covariate added in turn. To take account of the continuity of SEP from childhood to adulthood, associations between childhood SEP indicators and grip strength were also adjusted for adulthood SEP.

To reduce selection bias, we used sex-stratified multiple imputation, which assumes that the data were missing at random, with chained equations to impute missing values in the explanatory factors and covariates (missing data ranged from 0.8% (height at 46y) to 26.9% (father's education) – see Table S1 and S2 in Additional file 1) in the sample with valid data on grip strength (including those 70 individuals unable for health reasons with imputed values) (*N* = 7,617) (Fig. 1) [31]. As a larger number of imputations have been suggested in settings where high statistical power is needed, we utilised 50 imputations [32]. Analyses were run on the 50 imputed data sets created, and estimates were combined using Rubin's rules [33]. All analyses were conducted using R (R Foundation for Statistical Computing, v4.0.3, Vienna, Austria).

Sensitivity analyses

Sensitivity analyses were conducted to check that the results were not influenced by: 1) inclusion of participants who completed the grip strength assessment sat down or with their arm supported (*N* = 727); 2) inclusion of participants who were unable to complete their grip strength assessment due to health reasons (*N* = 70); 3) inclusion of participants who reported disability at age 46 according to the European Statistics of Income and Living Conditions classification (severely hampered (*n* = 452) or missing information disability (*N* = 3)).

Results

Table 1 shows the distributions of childhood and adulthood characteristics by sex in the analytic sample. Men had higher mean grip strength at age 46 than women (48.0 kg vs 29.5 kg; $p < 0.001$). Participants were most often born to fathers with occupational class III manual and parents with no formal qualifications.

Figures 2 and 3, and Tables S3 and S4 in Additional file 1, show the sex-stratified associations between childhood and adulthood SEP indicators and grip strength. All

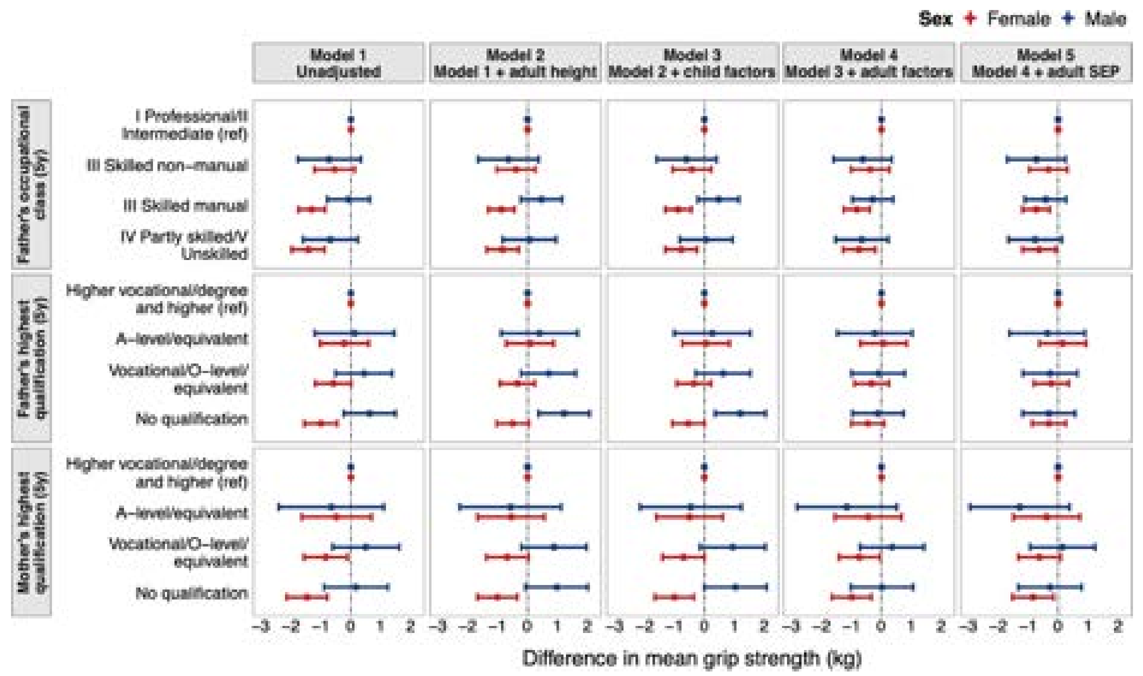

Fig. 2 Associations between indicators of childhood socioeconomic position and grip strength at age 46 years in the BCS70 (linear regression models stratified by sex with sample restricted to those with valid measures of grip strength at age 46 years (maximum $N = 7{,}617$* (3,922 females and 3,695 males))) results are combined from analyses run across 50 imputed datasets. *70 participants unable to complete the grip strength tests for health reasons were included by allocating them grip strength values equivalent to the mean of the bottom sex-specific fifth. Model 1: unadjusted (p-values from formal tests of sex interaction, $p = 0.015$ for Father's occupation at age 5y, $p = 0.025$ for Mother's highest qualification at age 5y and $p = 0.016$ for Father's highest qualification at age 5y); Model 2: adjusted for height at age 46y; Model 3: adjusted for Model 2 + birth weight (kg), BMI at age 10y (kg/m^2), leisure-time physical activity at age 10y, sedentary behaviour (TV watching) at age 10y and disability at age 10y; Model 4: adjusted for Model 3 + BMI at age 46y (kg/m^2) + smoking status at age 42y, sedentary behaviour (TV watching) at age 42y, leisure-time physical activity (days/week) at age 42y and occupational activity at age 46y

associations between childhood and adulthood SEP indicators and grip strength varied by sex ($p_{\text{interaction}} < 0.05$) (Tables S3 and S4 in Additional file 1). Among women, in unadjusted analyses, lower SEP was linearly associated with weaker grip strength ($p < 0.001$) (Figs. 2 and 3, Tables S3 and S4); this was observed for all five SEP indicators. When models of the associations between the three indicators of childhood SEP and grip strength were adjusted for covariates, associations of lower father's occupational class and lower mother's education with weaker grip strength were partly attenuated but even after adjustment for adult SEP, modest associations remained (Fig. 2). For example, in the unadjusted model, women whose mothers had no qualifications had mean grip strength 1.46 kg (95% CI: -2.14, -0.78) lower than women whose mothers were educated to vocational/degree or higher, and in the fully adjusted model, this difference was 0.99 kg (-1.65, -0.33). However, associations between lower father's education and weaker grip strength were fully attenuated after adjustment for adult height. In adulthood, the association of lower educational attainment and weaker grip strength was partially attenuated after adjustments, but an association remained in the final model (Fig. 3, Table S4). In contrast, the association between lower own occupational class and weaker grip strength was fully attenuated after adjustment for adult height (Fig. 3).

In men, there was no evidence of association between father's occupational class or mother's education and grip strength (Fig. 2, Table S3). However, in height-adjusted models, there was evidence that lower father's education was associated with stronger grip. This association was maintained after adjustment for childhood factors but fully attenuated after adjustment for adulthood factors (Fig. 2). Lower SEP in adulthood was also associated with stronger grip at age 46 (Fig. 3, Table S4). The association between lower own education and stronger grip was strengthened after adjustment for height and childhood covariates and only partially attenuated after adjustment for adulthood covariates.

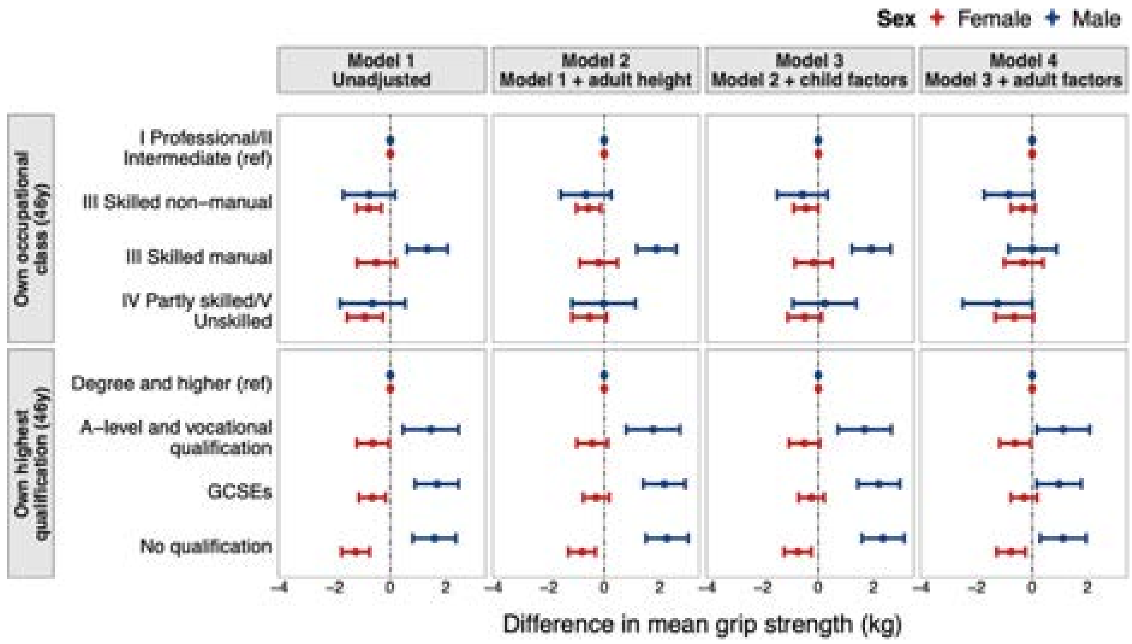

Fig. 3 Associations between indicators of adulthood socioeconomic position and grip strength at age 46 years in the BCS70 (linear regression models stratified by sex with sample restricted to those with valid measures of grip strength at age 46 years (maximum $N = 7{,}617$* (3,922 females and 3,695 males))) results are combined from analyses run across 50 imputed datasets. *70 participants unable to complete the grip strength tests for health reasons were included by allocating them grip strength values equivalent to the mean of the bottom sex-specific fifth. Model 1: unadjusted (p-values from formal tests of sex interaction, $p = 0.015$ for Fathers occupation at age 5y, $p = 0.025$ for Mother's highest qualification at age 5y and $p = 0.016$ for Father's highest qualification at age 5y); Model 2: adjusted for height at age 46y; Model 3: adjusted for Model 2 + birth weight (kg), BMI at age 10y (kg/m^2), leisure-time physical activity at age 10y, sedentary behaviour (TV watching) at age 10y and disability at age 10y; Model 4: adjusted for Model 3 + BMI at age 46y (kg/m^2) + smoking status at age 42y, sedentary behaviour (TV watching) at age 42y, leisure-time physical activity (days/week) at age 42y and occupational activity at age 46y

The association between own occupational class and grip strength in men deviated from linearity (Fig. 3, Table S4); men in skilled manual occupations had a stronger grip than men in professional/intermediate occupations (unadjusted regression coefficient: 1.33 kg (0.60, 2.06)) whereas there was no difference in grip strength between the highest and lowest occupational groups. This association strengthened after adjustment for height and childhood factors, but inclusion of adulthood factors fully attenuated the association (0.01 kg (-0.85, 0.88)). The attenuation of associations in men after adjustment for adult factors was found to be largely driven by occupational activity (Table S5).

Results from models run on complete cases were similar to those run across imputed datasets (Table S6). Results from sensitivity analyses were similar to those described above, suggesting that our analyses are unlikely to be impacted by the: 1) inclusion of participants who completed grip strength assessment sat down or with the arm supported (Table S7); 2) inclusion of participants who were unable to complete their grip strength assessment due to health reasons (Table S8); 3) the inclusion of participants who were severely hampered or had missing information on disability (Table S9).

Discussion

Main findings

In a cohort of men and women followed from birth in 1970 until midlife, we found sex-specific associations between SEP in childhood and adulthood and grip strength at age 46y. In women, there was evidence of associations between all five indicators of SEP and weaker grip strength, and many of these, including associations of father's occupational class and mother's education with grip strength, were robust to adjustments for body size and childhood and adulthood factors. Notably, associations between childhood SEP and grip strength were not fully explained by the continuity of SEP between childhood and adulthood. In men, there was no evidence of an association between two of the three childhood indicators of SEP and grip strength. However, lower father's education (once height-adjusted) and lower adulthood SEP were associated with stronger grip. The non-linear association for own occupational class was explained by higher levels of occupational activity among men in skilled manual occupations.

Comparison with previous studies

Our work adds to existing literature on associations between childhood and adulthood SEP and grip strength. We found evidence of associations between childhood and adulthood SEP and weaker grip strength in women. In previous studies, where associations have been observed, lower SEP was typically associated with weaker grip strength and so our findings in women are consistent [16, 18–22]. However, our study is the first to show robust associations between prospectively ascertained childhood and adulthood SEP and grip strength in middle-aged women. Our findings of associations between lower adulthood SEP and stronger grip in men contrast with what has been reported in many previous studies in older adults [14, 16–23]. It is also not fully consistent with analyses of the UK Household Longitudinal Study (UKHLS) which reported that in men there was no overall association between educational attainment and grip strength and associations between lower maternal education, lower income and weaker grip [24]. However, in UKHLS, participants were aged 16 to 99y, and so the authors were able to test variation by age. When they did this there was some evidence of an association between lower SEP and stronger grip in earlier adulthood. This is consistent with our findings and another study of younger men—an association between lower SEP and stronger grip was reported in a study of Swedish male military personnel aged 18y [34]. Our findings thus add further weight to the suggestion that in men, associations between SEP and grip strength may change direction with age.

Explanation of findings

In considering potential explanations of the consistent associations between lower childhood and adulthood SEP and weaker grip in women, it is necessary to consider the different factors that could be acting on pathways between SEP across life and grip strength in midlife. This is because SEP indicators are distal factors, and therefore associations would be expected to be mediated by more proximal factors that are socioeconomically patterned and relate to subsequent grip strength. In identifying these factors, it is important to consider the complex biological and social pathways that have been proposed to explain socioeconomic differences in health outcomes [35]. In the case of grip strength, there are likely to be a range of factors and pathways implicated including those related to growth and development (both in utero and across childhood and adolescence), and the factors that drive this (i.e. nutrition and exposure to hormones), attainment of adult body size and composition, health behaviours (most importantly physical activity) and health status [29]. Although we were able to adjust for some of these factors in our analyses, there are others that we were not able to, such as differences in sex hormones and diet across life.

While similar pathways are likely to operate in men, our findings suggest that occupational activity (specifically physical and heavy manual work) is countering some of the potentially adverse effects of low SEP on grip strength in midlife. As occupational activity was the factor in adulthood that caused the greatest attenuation in the scale of the associations between father's education and both indicators of adult SEP and grip strength, this would suggest that occupational activity may be responsible for the associations we observe in men. This is consistent with findings from a study of Danish men with a mean age of 59y which reported an association between higher levels of specific types of occupational activity and stronger grip [36]. Occupational activity has historically been linked with premature mortality [37]; however, a recent nationwide prospective cohort study in Norway found a positive dose–response relationship between occupational activity and longevity in men that was explained by a range of covariates including body mass index, lifestyle factors, cardiovascular diseases, and childhood SEP [38], and an umbrella review prepared for the *2020 WHO Physical Activity Guideline Development Group* found occupational activity to protect against most health-related outcomes, including cancers, heart disease, and type 2 diabetes [39]. Our results are consistent with these studies suggesting potentially protective effects of occupational activity in middle-aged men.

Methodological considerations

Our study addresses an important research gap by examining the associations between childhood and adulthood SEP and grip strength in younger adults from a more recently born cohort than previous studies. Another benefit of studying a younger cohort is that they are still relatively healthy and so the potential confounding effects of age-related health conditions which may explain associations in older populations are minimised. We formally tested sex differences in our associations which is important as it has previously been suggested that sex differences might be a potential source of variation between studies of the association between childhood SEP and grip strength [14].

Another key strength of our study is that we used a large, population-based sample that was nationally representative at birth with prospectively ascertained SEP indicators and several potentially important covariates from multiple time points. Nonetheless, as in all longitudinal studies, the BCS70 has experienced attrition, which may have introduced bias. BCS70 participants who contributed data at age 46y were more likely to be women, be taller, less likely to be current smokers and have a higher childhood and adulthood SEP than those lost to follow-up [26]. However, we maximised our analytic sample and minimised potential bias due to missing data by using multiple imputation. Here, we used sex-stratified multiple imputation to account for the sex-interactions in our associations [31]. By using multiple imputation, we were making the assumption that data were missing at random but, we have to acknowledge that this may not have been the case. However, we did use a range of auxiliary variables that are predictive of missingness within the BCS70 in our multiple imputation [40, 41]. Other limitations include the inability to examine associations between SEP and grip strength by ethnicity, as much of the BCS70 is white-British. This makes it difficult to fully generalise our findings to today's population in Great Britain, although the BCS70 cohort does provide important new insights on the associations between childhood and adulthood SEP and grip strength that complement findings from older cohorts because of their exposure to more contemporaneous social and political factors.

Another potential limitation is that our study utilised a single question to measure occupational activity; future research would benefit from more detailed measurements of occupational activity including data on intensity, duration, and frequency of activity. We also acknowledge that there may be residual confounding. However, in our analyses we adjusted for a wide range of covariates.

Policy implications

As low grip strength is associated with higher subsequent risk of disability [2], and reduces one's chances of living a healthy, independent life, the findings reported in this study are meaningful in the context of the UK government's ambitious goal of *'ensuring that people can enjoy at least five extra healthy, independent years of life by 2035, while narrowing the gap between the experience of the richest and poorest'* [42]. They highlight the complexity of the associations between SEP and grip strength and the need to identify age and sex-specific interventions to tackle the stark health inequalities in important age-related conditions related to muscle weakness.

In women, as lower SEP in childhood and adulthood was associated with weaker grip strength, strategies to reduce their exposure to socioeconomic adversity across life are likely to benefit their grip strength at midlife. For men, lower SEP in adulthood was associated with stronger grip at age 46y, which was mostly attenuated by higher levels of occupational activity. Evidence from the oldest British birth cohort, born in 1946, suggests that an association between lower lifetime SEP and weaker grip emerges as the cohort age (there is limited evidence of association at age 53 but an association is seen at 60–64 and 69) [15, 17, 23]. This suggests that the association in BCS70 may change with age, especially as there is evidence that the protective effects of occupational activity may recede by the time of retirement [43, 44]. As this could relate to either reductions in levels of beneficial activity and/or the accumulation of wear and tear related to heavy manual work, further research is needed to identify the types of interventions that may be most effective in ensuring that men of lower SEP maintain any midlife strength advantage into later life.

Conclusions

We have identified sex differences in the associations between childhood and adulthood SEP and grip strength in middle-aged British adults. Our findings highlight the need to identify age and sex-specific interventions to tackle inequalities across life in important age-related conditions related to weakness.

Abbreviations

BCS70: 1970 British Cohort Study; BMI: Body Mass Index; RGSC: Registrar General's Social Classification; SEP: Socioeconomic position; UKHLS: UK Household Longitudinal Study.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-022-13804-7.

Additional file 1: Figure S1. Pathway diagram detailing the illustrates the proposed pathways of association. **Table S1.** Variables used in multiple imputation**Table S2.** A comparison of the distributions of variables included in the multiple imputation models by completeness of data. **Table S3.** Associations between indicators of childhood socioeconomic position and grip strength at age 46 years in the BCS70 (linear regression models in A) Females (*n*=3,922) and B) Males (*n*=3,695)). **Table S4.** Associations between indicators of adulthood socioeconomic position and grip strength at age 46 years in the BCS70 (linear regression models in A) Females (*n*=3,922) and B) Males (*n*=3,695)). **Table S5.** Associations between adulthood socioeconomic position and grip strength at age 46 years in the BCS70 with individual adjustments for each adult covariate (linear regression models in Males (*n*=3,695)). **Table S6.** Unadjusted associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 years in the BCS70 on observed data (linear regression models in A) Females (*n*=3,922) and B) Males (*n*=3,695)). **Table S7.** Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 years in the BCS70 on the sample who completed the grip strength assessment standing unsupported (linear regression models in A) Females (*n*=3,498) and B) Males (*n*=3,392)) [Sensitivity analysis]. **Table S8.** Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those participants unable to complete the grip strength assessments for health reasons(linear regression models in A) Females (*n*=3,872) and B) Males (*n*=3,675)) [Sensitivity analysis]. **Table S9.**

Associations between indicators childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those participants classified as severely hampered according to the European Statistics of Income and Living Conditions (EU-SILC) classification disability definition or with missing disability data (linear regression models in A) Females (*n*=3,638) and B) Males (*n*=3,394)) [Sensitivity analysis].

Additional file 2:

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Authors' contributions
All authors contributed to design of the research; MY and RC developed the research objectives; MY performed statistical analyses with input from RC; MY wrote the paper with input from RC; MY had primary responsibility for final content. All authors provided critical revisions to an earlier draft, and read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
Participants provided informed consent and the assessment at age 46y received full ethical approval from NRES Committee South East Coast—Brighton & Sussex (Ref 15/LO/1446). Administrative permissions were required to access the raw data from the UK Data Service. This was approved by the Centre for Longitudinal Studies (CLS) Data Access Committee team. All methods were carried out following relevant guidelines and regulations.

Consent for publication
Not applicable.

Conflict of interest
The authors declare that there is no conflict of interest or relationships to disclose.

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Publisher's Note

B.2 Exploration of SEP indicators in the BCS70

Table B.2.1: Available SEP indicators at each wave of the BCS70 that were explored for use in analyses.

Wave	SEP Variable label	SEP Variable name
1970: Birth	Mother's age at completion of education	A0009
	Father's age at completion of education	A0010
	Employment Status of Mother	A0019
	Employment Status of the Father	A0015
	Mothers Social Class in 1970	A0018
	Fathers Social Class in 1970	A0014
	Fathers occupation class (or mothers if missing)	BD1PSOC
	Mothers Socio Economic Group (RG 1966)	A0017
	Father Socio Economic Group (RG 1966)	A0013
1975: 5y	Mothers Highest Education Qualification	E189A
	Fathers Highest Education Qualification	E189B
	Parents Highest Education Qualification	E190
	Age mother left school	E191
	Age father left school	E192
	Years of post-school education: mother	E193
	Years of post-school education: father	E194
	Years of full-time education after the age of 15 mother	E195
	Years of full-time education after the age of 15 father	E196
	Classification of mother's occupation	E206
	Classification of father's occupation	E197
	Fathers occupation class (or mothers if missing)	BD2SOC
	Mothers current occupation	E205
	Tenure of accommodation	E220
1980: 10y	Social class from father's occupation (mothers if missing)	BD3PSOC
	Received state benefit last 12 months?	BD3BEN
	Gross weekly family income	BD3INC
1986: 16y	Social class from father's occupation (mothers if missing)	BD4PSOC
	Employment status of mother	T12_2
	Employment status of father	T12_1
	Mother's occupation unit group (1980 Operational Code)	T11_8
	Father's occupation unit group (1980 Operational Code).	T11_1
	Mother's social class (OPCS 1980)	T11_9
	Father's social class (OPCS 1980)	T11_2

Table B.2.1: Available SEP indicators at each wave of the BCS70 that were explored for use in analyses.

Wave	SEP Variable label	SEP variable name
	Combined income of parents per wk/mth	OE2
1996: 26y	Age leaving full-time education (including 6th form)	B960129
	Net Pay	B960312
	Tenure of current address	B960421
	Activity employment status	JEMPST
	Standard Occupational Classification 1990	J90SOC
	Socio-economic Groups (SEG) 1991	J91SEG
	Social class 1991	J91SC
	Cambridge Sub-group and title Identification	JCAMGP
	Cambridge Scale Score - Males	JCAMSM
	Cambridge Scale Score - Females	JCAMSF
	ISCO ’88-Int Stan Class of Occupations	J88ISC
	Key Occupation Statistics (KOS)	JKOS
	CODOT - 3 digit classification	JCODOT
	OPCS 1980 - Operational Code	JOP80C
	OPCS 1980 - Occupation Unit Group	JOP80G
	Socio-Economic Group 1981	J81SEG
	Social Class RG”s 1981	J81RGS
	OPCS 1970 - Occupation Unit Group	JOP70G
	Socio-Economic Group 1971	J71SEG
	Social Class RG”s 1971	J71RGS
	Socio-Economic Group 1966	J66SEG
	Social Class RG”s 1966	J66RGS
	Socio-Economic Group 1961	J61SEG
	Goldthorpe Social Class 1990	J90GSC
	Goldthorpe Social Class 1980	J80GSC
	Goldthorpe Social Class 1970	JOP70G
	Hope-Goldthorpe Collapsed Group	JHGCG
	Hope-Goldthorpe Scale Score	JHGSS
	Tenure of current address	B960421
	Registrar General’s Social. Class 1991	rgsc91
2000: 30y	Highest Academic level at 2000 sweep	HIACA00
	Highest NVQ level (academic or vocational) at 2000	HINVQ00
	Activity employment status	JEMPST
	Standard Occupational Classification 1990	J90SOC
	Socio-economic Groups (SEG) 1991	J91SEG

Table B.2.1: Available SEP indicators at each wave of the BCS70 that were explored for use in analyses.

Wave	SEP Variable label	SEP variable name
	Social class 1991	J91SC
	Standard Industrial Classification (SIC)	JSIC
	Type of organisation CM works for (s6&s7)	JTORG
	Registrar General's Social. Class 1991	sc
2004: 34y	Highest Academic level up to 2004	BD7HACHQ
	Highest NVQ level (academic or vocational) up to 2004	BD7HNVQ
	Type of accommodation	B7ACCOM
	Home ownership / tenure status	B7TEN2
	Main economic activity	BD7ECACT
	Total take-home pay (pounds)	B7CNETPY
	Socio-economic classification (NS-SEC)	B7NSSEC
	Socio-economic classification (NS-SEC 8)	BD7NS8
	Socioeconomic group (SEG – old scheme)	B7SEG
	Social Class	B7SC
	Activity employment status	JEMPST
	Standard Occupational Classification 1990	J90SOC
	Socio-economic Groups (SEG) 1991	J91SEG
	Social class 1991	J91SC
	Standard Occupational Classification 2000	J2KSOC
	NS-SEC (long version)	JNSSEC
	NS-SEC8 (analytic version)	J8NSSEC
	Standard Industrial Classification (SIC) 1992	J92SIC
	Type of organisation CM works for (s6&s7)	JTORG
2008: 38y	Highest Academic level up to 2008	B8ACCOM
	Home ownership / tenure status	B8TEN2
	Main economic activity	BD8ECACT
	CM partner's current economic activity	BD8POTHA
	Weekly amount of take-home pay	B8CNETWK
	Activity employment status	JEMPST
	Standard Occupational Classification 1990	J90SOC
	Socio-economic Groups (SEG) 1991	J91SEG
	Social class 1991	J91SC
	Standard Occupational Classification 2000	J2KSOC
	NS-SEC (long version)	JNSSEC
	NS-SEC8 (analytic version)	J8NSSEC
	Standard Industrial Classification (SIC) 1992	J92SIC

Table B.2.1: Available SEP indicators at each wave of the BCS70 that were explored for use in analyses.

Wave	SEP Variable label	SEP variable name
2012: 42y	Highest NVQ Level from an Academic or Voc (up to 2012)	BD9HNVQ
	Type of accommodation	B9RESINC
	Home ownership / tenure status	B9TEN
	Main economic activity	BD9ECACT
	Social Class - NS-SEC Analytic Categories (current job)	B9CNS8
	Partner’s social class - NS-SEC Analytic (partners job)	B9PNS8
	Total income (banded) - Cohort members with a partner	B9TOTNCP
	Activity employment status	JEMPST
	Standard Occupational Classification 1990	J90SOC
	Socio-economic Groups (SEG) 1991	J91SEG
	Social class 1991	J91SC
	Standard Occupational Classification 2000	J2KSOC
	NS-SEC (long version)	JNSSEC
	NS-SEC8 (analytic version)	J8NSSEC
	Standard Industrial Classification (SIC) 1992	J92SIC
2016: 46y	Highest Academic Qualification up to 2016-18	BD10HACHQ
	Highest NVQ level from an academic qual 2016-18	BD10HANVQ
	Highest NVQ Level from an academic qual 2016-18 RG	BD10HNVQ
	Housing Tenure	BD10TENURE
	Current economic activity status	BD10ECACT
	Partner’s current economic activity status	BD10PEACT
	NS-SEC Full Operational Categories (current job)	BD10CNSSEC
	NS-SEC Combined Operational Categories (current job)	BD10CNSSCC
	NS-SEC Analytic Categories (current job)	BD10CNS8

B.3 Validation of method to back-code NS-SEC to RGSC at age 46.

To validate the back-coding of occupational class from NS-SEC to RGSC at age 46, the coding approach was tested for validity using the original RGSC and NS-SEC coding known at age 42. The back-coded RGSC variable was created using the NS-SEC to RGSC back-code (refer to Table B.3.1). The validity of this approach was evaluated by comparing the original RGSC variable with the newly created RGSC variable using a two-by-two table (refer to Table B.3.2). The results show that the back-coded RGSC variable and the original RGSC variable match well, especially in the top four categories, indicating that the back-coding of NS-SEC to RGSC is valid.

Table B.3.1: The coding used to back-code NS-SEC to RGSC at age 46.

RGCSC category	NS-SEC level
I Professional	3.1, 3.3
II Intermediate	1, 2, 3.2, 4.1, 4.3, 5.0, 7.3, 8.1, 8.2, 9.2
III Skilled non-manual	4.2, 4.4, 6.0, 7.1, 7.2, 12.1, 12.6
III Skilled manual	7.4, 9.1, 10.0, 11.1
IV Partly skilled	11.2, 12.2, 12.4, 12.5, 12.7, 13.1, 13.2, 13.5
V Unskilled	13.4

Table B.3.2: Comparison of RGSC coding at age 42 (non-derived variable vs back-coded variable from NS-SEC at age 42).

	RGSC (back-coded from NS-SEC at age 42)						
	I[1]	II[2]	III NM[3]	III M[4]	IV[5]	V[6]	Total
RGSC at age 42)							
I[1]	247 (95%)	13 (5.0%)	0 (0%)	(0%)	(0%)	(0%)	1,928 (100%)
II[2]	5 (0.2%)	1,814 (89%)	60 (2.9%)	146 (7.2%)	9 (0.4%)	0 (0%)	2,034 (100%)
III NM[3]	0 (0%)	47 (4.7%)	847 (85%)	103 (10%)	2 (0.2%)	0 (0%)	999 (100%)
III M[4]	0 (0%)	20 (2.2%)	59 (6.5%)	758 (84%)	66 (7.3%)	0 (0%)	903 (100%)
IV[5]	60 (0%)	18 (2.1%)	14 (1.7%)	118 (14%)	629 (75%)	61 (7.3%)	840 (100%)
V[6]	0 (0%)	0 (0%)	0 (0%)	40 (21%)	12 (6.3%)	137 (72%)	189 (100%)
Total	252 (4.8%)	1,912 (37%)	980 (19%)	1,165 (22%)	718 (14%)	198 (3.8%)	5,225 (100%)

[1] I Professional/II Intermediate; [2] II Intermediate; [3] III Skilled non-manual; [4] III Skilled manual; [5] IV Partly skilled; [6] V Unskilled; Pearson's P-value for Chi-squared test: <0.001.

B.4 Missing data and variables for multiple imputation

Table B.4.1: Variables used in multiple imputation by chained equations for grip strength analyses (N=7,617).

Variable	Type of variable	Method used to predict missing data	N (%)* with data on this variable
Exposure variable			
Father's occupational class (5y)	Ordinal	Ordered logistic regression	7,198 (94.5)
Mother's highest qualification (5y)	Ordinal	Ordered logistic regression	5,931 (77.9)
Father's highest qualification (5y)	Ordinal	Ordered logistic regression	5,565 (73.1)
Father's occupational class (16y)	Ordinal	Ordered logistic regression	6,798 (89.2)
Own occupational class (30y)	Ordinal	Ordered logistic regression	6,253 (82.1)
Own occupational class (46y)	Ordinal	Ordered logistic regression	6,404 (84.1)
Own highest qualification (46y)	Ordinal	Ordered logistic regression	7,512 (98.6)
Covariates			
Birth weight	Continuous	Predictive mean matching	7,046 (92.5)
Body Mass Index (10y)	Continuous	Predictive mean matching	6,016 (79.0)
Disability (10y)	Ordinal	Ordered logistic regression	6,606 (86.7)
Sedentariness (10y)	Ordinal	Ordered logistic regression	6,626 (87.0)
Leisure-time physical activity (10y)	Ordinal	Ordered logistic regression	6,607 (86.7)
Height (46y)	Continuous	Predictive mean matching	7,553 (99.2)
Body Mass Index (46y)	Continuous	Predictive mean matching	7,387 (97.0)
Smoking (42y)	Ordinal	Ordered logistic regression	7,111 (93.4)
Sedentariness (42y)	Ordinal	Ordered logistic regression	6,368 (83.6)
Leisure-time physical activity (42y)	Ordinal	Ordered logistic regression	7,008 (92.0)
Occupational activity (46y)	Ordinal	Ordered logistic regression	6,291 (82.6)
Auxiliary variables			
Sex at birth	Binary	-	7,617 (100)
Father's age at completion of education	Continuous	Predictive mean matching	6,781 (89.0)
Mother's age at completion of education	Continuous	Predictive mean matching	7,007 (92.0)
Mother's age at deliver	Continuous	Predictive mean matching	7,012 (92.1)
Mother's marital status at birth	Ordinal	Ordered logistic regression	7,045 (92.5)
Number of older siblings at the birth	Continuous	Predictive mean matching	7,052 (92.6)

* For the percentage reported, the numerator is the observed data divided by the denominator (total analytic sample size: n=7,617)

Table B.4.2: Variables used in multiple imputation by chained equations for standing balance analyses (N=7,519).

Variable	Type of variable	Method used to predict missing data	N (%)* with data on this variable
Exposure variable			
Father's occupational class (5y)	Ordinal	Ordered logistic regression	7,104 (94.5)
Mother's highest qualification (5y)	Ordinal	Ordered logistic regression	5,837 (77.8)
Father's highest qualification (5y)	Ordinal	Ordered logistic regression	5,471 (73.0)
Housing tenure at age (5y)	Ordinal	Ordered logistic regression	6,137 (81.8)
Own occupational class (46y)	Ordinal	Ordered logistic regression	6,314 (84.1)
Own highest qualification (46y)	Ordinal	Ordered logistic regression	7,416 (98.6)
Housing tenure at age (46y)	Ordinal	Ordered logistic regression	7,467 (99.3)
Weekly take home income at age (46y)	Ordinal	Ordered logistic regression	6,895 (91.8)
Covariates			
Coordination (10y)	Ordinal	Ordered logistic regression	6,280 (83.7)
Cognition (10y)	Continuous	Predictive mean matching	5,542 (74.0)
Body Mass Index (10y)	Continuous	Predictive mean matching	5,928 (79.0)
Leisure-time physical activity (10y)	Ordinal	Ordered logistic regression	6,512 (86.7)
Health status (10y)	Ordinal	Ordered logistic regression	5,725 (76.4)
Height (46y)	Continuous	Predictive mean matching	7,456 (99.2)
Body Mass Index (46y)	Continuous	Predictive mean matching	7,290 (97.0)
Smoking (42y)	Ordinal	Ordered logistic regression	7,019 (93.4)
Sedentariness (42y)	Ordinal	Ordered logistic regression	6,145 (81.9)
Leisure-time physical activity (42y)	Ordinal	Ordered logistic regression	6,917 (92.1)
Health status (42y)	Ordinal	Ordered logistic regression	7,456 (99.2)
Occupational activity (46y)	Ordinal	Ordered logistic regression	6,202 (82.7)
Auxiliary variables			
Father's age at completion of education	Continuous	Predictive mean matching	6,686 (89.0)
Mother's age at completion of education	Continuous	Predictive mean matching	6,910 (92.0)
Mother's age at deliver	Continuous	Predictive mean matching	6,915 (92.1)
Mother's marital status at birth	Ordinal	Ordered logistic regression	6,948 (92.5)
Number of older siblings at the birth	Continuous	Predictive mean matching	6,955 (92.6)

* For the percentage reported, the numerator is the observed data divided by the denominator (total analytic sample size: n=7,519)

B.5 Predictors of missingness in the BCS70

Table B.5.1: A comparison of the distributions of variables included in the multiple imputation models by completeness of data for grip strength analyses.

Factors	Total N *	Mean (SD) or N (%)* No missing data (N=2,723) †	Incomplete data (N=4,894) ‡	p-val[b]
Father's occupational class (5y)§	7,198			<0.001
I Professional/II Intermediate		1,058 (25.7)	1,040 (33.8)	
III Skilled Non-manual		483 (11.7)	306 (10.0)	
III Skilled Manual		1,762 (42.7)	1,301 (42.3)	
IV Partly skilled/V Unskilled		820 (19.9)	428 (13.9)	
Mother's highest qualification age 5y	5,931			0.002
Higher vocational/degree		243 (8.5)	322 (10.5)	
A-level/equivalent		126 (4.4)	146 (4.7)	
Vocational/O-level/equivalent		989 (34.6)	1,116 (36.3)	
No qualification		1,498 (52.5)	1,491 (48.5)	
Father's highest qualification age 5y	5,565			<0.001
Higher vocational/degree		432 (17.3)	600 (19.5)	
A-level/equivalent		196 (7.9)	278 (9.0)	
Vocational/O-level/equivalent		719 (28.9)	915 (29.8)	
No qualification		1,143 (45.9)	1,282 (41.7)	
Father's occupational class (16y)§	6,798			<0.001
I Professional/II Intermediate		1,335 (32.8)	1,021 (37.5)	
III Skilled Non-manual		483 (11.9)	291 (10.7)	
III Skilled Manual		1,613 (39.6)	1,058 (38.9)	
IV Partly skilled/V Unskilled		644 (15.8)	353 (13.0)	
Own occupational class (30y)§	6,253			0.001
I Professional/II Intermediate		1,494 (42.8)	1,276 (46.2)	
III Skilled Non-manual		878 (25.2)	717 (26.0)	
III Skilled Manual		671 (19.2)	470 (17.0)	
IV Partly skilled/V Unskilled		447 (12.8)	300 (10.9)	
Own occupational class (46y)	6,404			<0.001
I Professional/II Intermediate		1,514 (45.5)	1,510 (49.1)	
III Skilled Non-manual		742 (22.3)	724 (23.5)	
III Skilled Manual		713 (21.4)	572 (18.6)	
IV Partly skilled/V Unskilled		360 (10.8)	269 (8.7)	
Own highest qualification (46y)	7,512			<0.001
Degree and higher		1,063 (24.0)	915 (29.8)	
Advance and vocational qualification		585 (13.2)	490 (15.9)	
GCSEs		1,386 (31.2)	976 (31.7)	

Factors	Total N *	Mean (SD) or N (%)† No missing data (N=2,723) †	Incomplete data (N=4,894) ‡	p-val[b]
No qualification		1,403 (31.6)	694 (22.6)	
Birth weight, kg	7,046.0	3.29 (0.5)	3.34 (0.5)	<0.001
BMI (10y)	6,016.0	16.89 (2.1)	16.78 (2.0)	0.023
Disability (10y)	6,606			0.049
No		3,259 (92.3)	2,887 (93.9)	
Yes, slight		248 (7.0)	175 (5.7)	
Yes, severe		24 (0.7)	13 (0.4)	
Sedentariness (10y)	6,626			0.7
Often		2,795 (78.7)	2,434 (79.2)	
Sometimes		714 (20.1)	608 (19.8)	
Never or hardly ever		42 (1.2)	33 (1.1)	
Leisure-time physical activity (10y)	6,607			0.4
Often		1,875 (53.1)	1,646 (53.5)	
Sometimes		1,362 (38.6)	1,201 (39.1)	
Never or hardly ever		295 (8.4)	228 (7.4)	
Height (46y)	7,553.0	169.81 (9.4)	170.50 (9.2)	<0.001
BMI (46y)	7,387.0	28.56 (5.6)	28.24 (5.3)	0.002
Smoking status (42y)	7,111			<0.001
Never smoker		1,798 (44.5)	1,568 (51.0)	
Ex-smoker		1,177 (29.2)	900 (29.3)	
Current smoker (less than daily)		218 (5.4)	175 (5.7)	
Current smoker (daily)		843 (20.9)	432 (14.0)	
Sedentariness (42y)	6,368			<0.001
0 to <1 hour		590 (16.5)	481 (17.2)	
1 to <3 hours		2,048 (57.3)	1,718 (61.5)	
3 to <5 hours		699 (19.6)	477 (17.1)	
5+ hours		238 (6.7)	117 (4.2)	
Leisure-time physical activity (42y)	7,008			<0.001
0 days		1,183 (30.1)	761 (24.7)	
1 day per a week		448 (11.4)	380 (12.4)	
2 days per a week		539 (13.7)	503 (16.4)	
3 days per a week		563 (14.3)	477 (15.5)	
4/5 days per a week		653 (16.6)	557 (18.1)	
6/7 days per a week		547 (13.9)	397 (12.9)	
Occupational activity (46y)	6,291			<0.001
Sitting occupation		1,703 (53.0)	1,735 (56.4)	
Standing occupation		512 (15.9)	460 (15.0)	
Physical work		840 (26.1)	743 (24.2)	
Heavy manual work		161 (5.0)	137 (4.5)	
Father's age at completion of education	6,781	16.22 (4.8)	16.36 (4.2)	0.083
Mother's age at completion of education	7,007	15.88 (4.4)	15.99 (3.2)	0.200

Factors	Total N *	Mean (SD) or N (%)† No missing data (N=2,723) †	Incomplete data (N=4,894) ‡	p-val[b]
Mother's age when giving birth	7,012.0	25.88 (5.4)	26.21 (5.3)	0.015
Mother marital status at childbirth	7,045			<0.001
Married		3,676 (92.5)	2,994 (97.4)	
Separated		64 (1.6)	15 (0.5)	
Divorced		18 (0.5)	4 (0.1)	
Widowed		5 (0.1)	0 (0.0)	
Single		209 (5.3)	60 (2.0)	
Number of older siblings	7,052	1.05 (1.3)	0.94 (1.2)	<0.001

* Maximum N, though N varies due to missing data on each SEP indicator; † Those participants in the main analytic sample (N=7'617) who have complete data for all key variables (father's occupational class (5y), mother's highest qualification (5y), father's highest qualifications (5y), father's occupational class (5y), own occupational class (30y), own occupational class (46y), own highest qualification (46y), birth weight, BMI (10y), leisure-time physical activity (10y), Sedentariness (10y), disability (10y), height (46y), BMI (46y), smoking status (42y), Sedentariness (42y), leisure-time physical activity (42y), occupational activity (46y) and grip strength at age 46).
‡ Those participants in the main analytic sample who have missing data on at least one key variable (father's occupational class (5y), mother's highest qualification (5y), father's highest qualifications (5y), own occupational class (30y), own occupational class (46y), own highest qualification (46y), birth weight, BMI (10y), leisure-time physical activity (10y), Sedentariness (10y), disability (10y), height (46y), BMI (46y), smoking status (42y), Sedentariness (42y), leisure-time physical activity (42y) and/or occupational activity (46y)); [b] Statistical tests of sex difference: chi-square test of independence; ‡ Ascertained when the BCS70 participant was age 5/16y. § With value from birth if missing (5y); with values from age 10 if missing at age 16y; with values from age 30 if missing at age 26y.

Table B.5.2: A comparison of the distributions of variables included in the multiple imputation models by completeness of data for standing balance analyses.

Factors	Total N *	Mean (SD) or N (%)*		p-val[b]
		No missing data (N=1,896) †	Incomplete data (N=5,695) ‡	
Sex	7,591			0.5
Female		968 (51.1)	2,957 (51.9)	
Male		928 (48.9)	2,738 (48.1)	
Father's occupational class (5y)§	7,176			<0.001
I Professional		174 (9.2)	382 (7.2)	
II Intermediate		461 (24.3)	1,079 (20.4)	
III Skilled non-manual		193 (10.2)	587 (11.1)	
III Skilled manual		804 (42.4)	2,248 (42.6)	
IV Partly skilled		207 (10.9)	738 (14.0)	
V Unskilled		57 (3.0)	246 (4.7)	
Mother's highest qualification (5y)	5,909			0.4
Higher vocational/degree		243 (8.5)	322 (10.5)	
A-level/equivalent		126 (4.4)	146 (4.7)	
Vocational/O-level/equivalent		989 (34.6)	1,116 (36.3)	
No qualification		1,498 (52.5)	1,491 (48.5)	
Father's highest qualification (5y)	5,543			0.12
Higher vocational/degree		377 (19.9)	649 (17.8)	
A-level/equivalent		164 (8.6)	305 (8.4)	
Vocational/O-level/equivalent		564 (29.7)	1,062 (29.1)	
No qualification		791 (41.7)	1,631 (44.7)	
Family housing tenure (5y)	6,209			<0.001
Owned Outright		252 (13.3)	585 (13.6)	
Being Bought		1,054 (55.6)	1,986 (46.0)	
Council Rented		408 (21.5)	1,259 (29.2)	
Private Rent Unfurnished		76 (4.0)	226 (5.2)	
Private Rent Furnished		11 (0.6)	36 (0.8)	
Tied to Occupation		85 (4.5)	179 (4.2)	
Other		10 (0.5)	42 (1.0)	
Own occupational class (46y)	6,386			<0.001
I Professional		166 (8.8)	312 (6.9)	
II Intermediate		773 (40.8)	1,761 (39.2)	
III Skilled non-manual		469 (24.7)	998 (22.2)	
III Skilled manual		335 (17.7)	945 (21.0)	
IV Partly skilled		130 (6.9)	377 (8.4)	
V Unskilled		23 (1.2)	97 (2.2)	

Factors	Total N *	Mean (SD) or N (%)† No missing data (N=1,896) †	Incomplete data (N=5,695) ‡	p-val[b]
Own highest qualification (46y)	7,488			<0.001
Degree and higher		600 (31.6)	1,378 (24.6)	
Advance and vocational qualification		303 (16.0)	769 (13.8)	
GCSEs		617 (32.5)	1,742 (31.2)	
No qualification		376 (19.8)	1,703 (30.5)	
Own housing tenure (46y)	7,539			<0.001
Own outright		281 (14.8)	799 (14.2)	
Own (mortgage/loan)		1,351 (71.3)	3,360 (59.5)	
Part rent, part mortgage (shared equity)		14 (0.7)	49 (0.9)	
Rent it		211 (11.1)	1,231 (21.8)	
Live rent-free, incl. relatives/friends		28 (1.5)	131 (2.3)	
Other		11 (0.6)	73 (1.3)	
Weekly take home income (46y)	6,967			<0.001
£2,000 and above		99 (5.2)	252 (5.0)	
£1,750 to £1,999		43 (2.3)	95 (1.9)	
£1,500 to £1,749		94 (5.0)	188 (3.7)	
£1,250 to £1,499		119 (6.3)	295 (5.8)	
£1,000 to £1,249		225 (11.9)	517 (10.2)	
£750 to £999		407 (21.5)	873 (17.2)	
£500 to £749		416 (21.9)	1,025 (20.2)	
£200 to £499		333 (17.6)	1,165 (23.0)	
£100 to £199		62 (3.3)	308 (6.1)	
£50 to £99		27 (1.4)	175 (3.5)	
Below £50		71 (3.7)	178 (3.5)	
Coordination (10y)	6,352			0.006
Normal limb coordination		1,700 (89.7)	3,862 (86.7)	
Questionably clumsy		131 (6.9)	370 (8.3)	
Mildly clumsy		56 (3.0)	186 (4.2)	
Moderate/markedly clumsy		9 (0.5)	38 (0.9)	
Edinburgh reading test (10y)	5,614	0.3 (0.90)	-0.1 (0.97)	<0.001
Body Mass Index (kg/m2) (10y)	6,000	16.8 (2.00)	16.9 (2.10)	0.037
Leisure-time physical activity (10y)	6,584			0.9
Often		1,012 (53.4)	2,491 (53.1)	
Sometimes		730 (38.5)	1,831 (39.1)	
Never or hardly ever		154 (8.1)	366 (7.8)	
Number of health conditions (10y)	5,797			0.069
No condition		1,073 (56.6)	2,135 (54.7)	
1 condition		511 (27.0)	1,015 (26.0)	
2 conditions		232 (12.2)	543 (13.9)	

Factors	Total N *	Mean (SD) or N (%)† No missing data (N=1,896) †	Incomplete data (N=5,695) ‡	p-val[b]
3+ conditions		80 (4.2)	208 (5.3)	
Height (cm) (46y)	7,528	170.5 (9.26)	169.9 (9.31)	0.011
Body Mass Index (kg/m2) (46y)	7,362	28.3 (5.36)	28.5 (5.54)	0.3
Cognition (42y)	6,868			<0.001
16-20 words		580 (30.6)	1,272 (25.6)	
11-15 words		982 (51.8)	2,483 (49.9)	
6-10 words		298 (15.7)	1,019 (20.5)	
0-5 words		36 (1.9)	198 (4.0)	
Smoking status (42y)	7,091			<0.001
Never smoker		991 (52.3)	2,369 (45.6)	
Ex-smoker		568 (30.0)	1,502 (28.9)	
Current smoker (less than daily)		98 (5.2)	296 (5.7)	
Current smoker (daily)		239 (12.6)	1,028 (19.8)	
Sedentary behaviour (42y)	6,217			0.2
0 to <1 hour		121 (6.4)	294 (6.8)	
1 to <3 hours		933 (49.2)	2,089 (48.3)	
3 to <5 hours		628 (33.1)	1,371 (31.7)	
5+ hours		214 (11.3)	567 (13.1)	
Leisure-time physical activity (42y)	6,989			<0.001
6/7 days per a week		234 (12.3)	712 (14.0)	
4/5 days per a week		335 (17.7)	868 (17.0)	
3 days per a week		301 (15.9)	737 (14.5)	
2 days per a week		325 (17.1)	717 (14.1)	
1 day per a week		258 (13.6)	571 (11.2)	
0 days		443 (23.4)	1,488 (29.2)	
Number of health conditions (42y)	7,094			0.001
No condition		1,531 (80.7)	4,010 (77.1)	
1 condition		320 (16.9)	1,008 (19.4)	
2 conditions		43 (2.3)	149 (2.9)	
3+ conditions		2 (0.1)	31 (0.6)	
Occupational activity (46y)	6,274			0.001
Heavy manual work		81 (4.3)	215 (4.9)	
Physical work		428 (22.6)	1,148 (26.2)	
Standing occupation		281 (14.8)	693 (15.8)	
Sitting occupation		1,106 (58.3)	2,322 (53.0)	
Father's age at completion of education	6,758	16.4 (4.10)	16.2 (4.72)	0.3
Father's age at completion of education	6,982	16.0 (3.27)	15.9 (4.13)	0.6
Mother's age at birth	6,987	26.3 (5.40)	25.9 (5.32)	0.008
Mother's marital status at birth	7,020			<0.001

Factors	Total N *	No missing data (N=1,896) †	Incomplete data (N=5,695) ‡	p-val[b]
		Mean (SD) or N (%)†		
Married		1,847 (97.6)	4,802 (93.6)	
Separated		9 (0.5)	70 (1.4)	
Divorced		1 (0.1)	21 (0.4)	
Widowed		0 (0.0)	5 (0.1)	
Single		35 (1.8)	230 (4.5)	
Number of older siblings at birth	7,027	0.9 (1.17)	1.0 (1.27)	0.001

* Maximum N, though N varies due to missing data on each SEP indicator; † Those participants in the main analytic sample (N=7'617) who have complete data for all key variables (father's occupational class (5y), mother's highest qualification (5y), father's highest qualifications (5y), father's occupational class (16y), own occupational class (30y), own occupational class (46y), own highest qualification (46y), birth weight, BMI (10y), leisure-time physical activity (10y), sedentary behaviour (10y), disability (10y), height (46y), BMI (46y), smoking status (42y), sedentary behaviour (42y), leisure-time physical activity (42y), occupational activity (46y) and grip strength at age 46); ‡ Those participants in the main analytic sample who have missing data on at least one key variable (father's occupational class (5y), mother's highest qualification (5y), father's highest qualifications (5y), father's occupational class (16y), own occupational class (30y), own occupational class (46y), own highest qualification (46y), birth weight, BMI (10y), leisure-time physical activity (10y), sedentary behaviour (10y), disability (10y), height (46y), BMI (46y), smoking status (42y), sedentary behaviour (42y), leisure-time physical activity (42y) and/or occupational activity (46y)); [b] Statistical tests of sex difference: chi-square test of independence; ‡ Ascertained when the BCS70 participant was age 5/16y; § With value from birth if missing at 5y.

B.6 Tables and figures for the BCS70 analyses

B.6.1 Grip strength

Table B.6.1: Associations between childhood socioeconomic position and grip strength at age 46 years in the BCS70 (N=7,617*; 3,922 Women and 3,695 Men).

	Model 1 †	Model 2 ‡	Model 3 §	Model 4 ¶	Model 5 **
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Father's occupational class (5y)					
Women					
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.54 (-1.21, 0.13)	-0.39 (-1.03, 0.26)	-0.42 (-1.06, 0.23)	-0.37 (-1.01, 0.27)	-0.33 (-0.97, 0.31)
III Skilled manual	-1.30 (-1.75, -0.85)	-0.87 (-1.31, -0.44)	-0.88 (-1.31, -0.44)	-0.82 (-1.26, -0.38)	-0.74 (-1.19, -0.29)
IV Partly skilled/V Unskilled	-1.42 (-1.97, -0.87)	-0.84 (-1.37, -0.30)	-0.77 (-1.31, -0.24)	-0.74 (-1.28, -0.20)	-0.64 (-1.19, -0.08)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.001; <0.001	<0.001; <0.001	<0.01; <0.001	0.01; <0.01
Men					
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.72 (-1.77, 0.33)	-0.64 (-1.65, 0.37)	-0.60 (-1.60, 0.40)	-0.62 (-1.59, 0.35)	-0.73 (-1.70, 0.25)
III Skilled manual	-0.08 (-0.78, 0.63)	0.46 (-0.23, 1.15)	0.47 (-0.22, 1.15)	-0.29 (-0.97, 0.40)	-0.42 (-1.12, 0.27)
IV Partly skilled/V Unskilled	-0.68 (-1.59, 0.23)	0.06 (-0.83, 0.95)	0.05 (-0.83, 0.94)	-0.65 (-1.53, 0.23)	-0.77 (-1.66, 0.12)
p-values (overall; test for trend) ∞	0.29; 0.35	0.14; 0.33	0.14; 0.34	0.42; 0.2	0.28; 0.11
Mother's highest qualification (5y)					
Women					
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.48 (-1.64, 0.69)	-0.55 (-1.67, 0.56)	-0.50 (-1.61, 0.61)	-0.44 (-1.55, 0.67)	-0.39 (-1.50, 0.73)
Vocational/O-level/equivalent	-0.84 (-1.56, -0.11)	-0.68 (-1.38, 0.03)	-0.70 (-1.40, 0.00)	-0.73 (-1.42, -0.04)	-0.63 (-1.33, 0.08)
No qualification	-1.46 (-2.14, -0.78)	-1.01 (-1.67, -0.35)	-1.00 (-1.66, -0.35)	-0.99 (-1.65, -0.33)	-0.84 (-1.53, -0.16)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.01; <0.01	0.01; <0.01	0.02; <0.01	0.09; <0.05
Men					
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.65 (-2.40, 1.10)	-0.57 (-2.27, 1.12)	-0.46 (-2.15, 1.23)	-1.15 (-2.81, 0.52)	-1.28 (-2.94, 0.38)
Vocational/O-level/equivalent	0.50 (-0.61, 1.62)	0.88 (-0.21, 1.97)	0.94 (-0.15, 2.03)	0.36 (-0.71, 1.43)	0.14 (-0.94, 1.23)
No qualification qualification	0.17 (-0.89, 1.24)	0.97 (-0.07, 2.01)	1.03 (-0.01, 2.07)	0.02 (-1.02, 1.06)	-0.27 (-1.33, 0.78)
p-values (overall; test for trend) ∞	0.45; 0.7	0.07; <0.05	0.06; <0.05	0.23; 0.75	0.24; 0.8
Father's highest qualification (5y)					

Table B.6.1: Associations between childhood socioeconomic position and grip strength at age 46 years in the BCS70 (N=7,617*; 3,922 Women and 3,695 Men).

	Model 1 †	Model 2 ‡	Model 3 §	Model 4 ¶	Model 5 **
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Women					
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.22 (-1.03, 0.60)	0.08 (-0.72, 0.87)	0.05 (-0.74, 0.83)	0.07 (-0.70, 0.85)	0.15 (-0.63, 0.93)
Vocational/O-level/equivalent	-0.58 (-1.18, 0.02)	-0.34 (-0.92, 0.24)	-0.35 (-0.93, 0.22)	-0.32 (-0.90, 0.25)	-0.23 (-0.81, 0.35)
No qualification	-1.00 (-1.55, -0.45)	-0.50 (-1.03, 0.04)	-0.54 (-1.07, 0.00)	-0.45 (-1.00, 0.10)	-0.31 (-0.87, 0.26)
p-values (overall; test for trend) ∞	<0.01; <0.001	0.18; <0.05	0.15; <0.05	0.28; 0.06	0.54; 0.19
Men					
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	0.13 (-1.20, 1.45)	0.40 (-0.88, 1.67)	0.26 (-1.01, 1.53)	-0.22 (-1.47, 1.03)	-0.36 (-1.62, 0.89)
Vocational/O-level/equivalent	0.44 (-0.51, 1.38)	0.70 (-0.22, 1.61)	0.62 (-0.30, 1.53)	-0.10 (-1.00, 0.79)	-0.27 (-1.18, 0.64)
No qualification	0.63 (-0.23, 1.49)	1.22 (0.37, 2.07)	1.19 (0.35, 2.04)	-0.12 (-0.97, 0.74)	-0.31 (-1.19, 0.57)
p-values (overall; test for trend) ∞	0.45; 0.12	0.03; <0.01	0.03; <0.01	0.93; 0.84	0.85; 0.55

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included. † Model 1: unadjusted (p-values from formal tests of sex interaction: p=0.01 for Fathers occupational class (5y), p=0.03 for Mother's highest qualification (5y) and p=0.01 for Father's highest qualification (5y)); ‡ Model 2: adjusted for height (46y). § Model 3: Model 2 + birth weight, BMI (10y) (kg/m2), Playing sport in spare time (10y), watching TV in spare time at age (10y) and disability (10y); ¶ Model 4: Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (46y) and occupational activity (46y); ** Model 5: Model 4 + Own occupational class and own highest qualification (46y). ∞ P-trend: p-value not presented if there was significant deviation from linearity; †† Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

Table B.6.2: Associations between childhood and adolescent socioeconomic position and grip strength at age 46 years in the BCS70 (N=7,617*; 3,922 Women and 3,695 Men).

	Model 1†	Model 2‡	Model 3§	Model 4¶
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Father's occupational class (16y)				
Women				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.18 (-0.82, 0.45)	-0.02 (-0.64, 0.59)	-0.04 (-0.66, 0.57)	-0.03 (-0.65, 0.58)
III Skilled manual	-0.97 (-1.41, -0.54)	-0.67 (-1.09, -0.24)	-0.64 (-1.06, -0.22)	-0.60 (-1.03, -0.17)
IV Partly skilled/V Unskilled	-1.57 (-2.15, -0.98)	-0.93 (-1.50, -0.36)	-0.87 (-1.44, -0.30)	-0.79 (-1.36, -0.21)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.01; <0.001	<0.01; <0.001	<0.01; <0.01
Men				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.79 (-1.83, 0.25)	-0.54 (-1.55, 0.47)	-0.63 (-1.63, 0.37)	-0.67 (-1.64, 0.30)
III Skilled manual	0.43 (-0.28, 1.14)	1.10 (0.40, 1.79)	1.07 (0.38, 1.75)	0.34 (-0.35, 1.03)
IV Partly skilled/V Unskilled	-0.54 (-1.47, 0.39)	0.23 (-0.67, 1.13)	0.34 (-0.56, 1.24)	-0.58 (-1.47, 0.31)
p-values (overall; test for trend) ∞	0.06; -	<0.01; -	<0.01; -	0.08; -

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included; † Model 1: unadjusted (p-values from formal tests of sex interaction: p<0.001 for Father's occupational class (16y)); ‡ Model 2: adjusted for height (46y); § Model 3: Model 2 + birth weight, BMI (10y) (kg/m2), Playing sport in spare time (10y), watching TV in spare time at age (10y) and disability (10y); ¶ Model 4: Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (46y) and occupational activity (46y); ∞ P-trend: p-value not presented if there was significant deviation from linearity. †† Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

Table B.6.3: Associations between adulthood socioeconomic position and grip strength at age 46 years in the BCS70 (N=7,617*; 3,922 Women and 3,695 Men).

	Model 1 †	Model 2 ‡	Model 3 §	Model 4 ¶
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Own occupational class (30y)				
Women				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.54 (-0.98, -0.09)	-0.42 (-0.85, 0.01)	-0.36 (-0.78, 0.07)	-0.29 (-0.71, 0.14)
III Skilled manual	-0.79 (-1.57, 0.00)	-0.49 (-1.25, 0.26)	-0.49 (-1.24, 0.26)	-0.50 (-1.27, 0.27)
IV Partly skilled/V Unskilled	-0.81 (-1.42, -0.19)	-0.45 (-1.05, 0.15)	-0.33 (-0.92, 0.26)	-0.45 (-1.09, 0.20)
p-values (overall; test for trend) ∞	0.01; <0.01	0.16; <0.01	0.27; 0.17	0.32; 0.11
Own occupational class (46y)				
Women				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.78 (-1.23, -0.32)	-0.57 (-1.01, -0.13)	-0.44 (-0.88, 0.00)	-0.33 (-0.77, 0.11)
III Skilled manual	-0.50 (-1.20, 0.20)	-0.20 (-0.88, 0.47)	-0.17 (-0.84, 0.51)	-0.31 (-1.01, 0.39)
IV Partly skilled/V Unskilled	-0.92 (-1.56, -0.27)	-0.53 (-1.16, 0.09)	-0.49 (-1.10, 0.12)	-0.64 (-1.33, 0.05)
p-values (overall; test for trend) ∞	<0.01; <0.01	0.05; <0.01	0.14; 0.12	0.18; 0.06
Men				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.76 (-1.70, 0.17)	-0.66 (-1.57, 0.25)	-0.57 (-1.48, 0.33)	-0.84 (-1.73, 0.05)
III Skilled manual	1.33 (0.60, 2.06)	1.88 (1.17, 2.59)	1.92 (1.21, 2.62)	0.01 (-0.85, 0.88)
IV Partly skilled/V Unskilled	-0.64 (-1.81, 0.54)	-0.02 (-1.16, 1.12)	0.23 (-0.91, 1.37)	-1.25 (-2.50, 0.00)
p-values (overall; test for trend) ∞	<0.001; -	<0.001; -	<0.001; -	0.06; 0.17
Own highest qualification (46y)				
Women				
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level and vocational qualification	-0.63 (-1.21, -0.05)	-0.43 (-0.99, 0.13)	-0.50 (-1.05, 0.06)	-0.62 (-1.18, -0.05)
GCSEs	-0.65 (-1.13, -0.17)	-0.29 (-0.75, 0.18)	-0.25 (-0.71, 0.21)	-0.29 (-0.77, 0.18)
No qualification	-1.25 (-1.76, -0.75)	-0.80 (-1.29, -0.31)	-0.74 (-1.23, -0.25)	-0.76 (-1.28, -0.24)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.01; <0.001	0.02; <0.05	0.02; <0.05
Men				

Table B.6.3: Associations between adulthood socioeconomic position and grip strength at age 46 years in the BCS70 (N=7,617*; 3,922 Women and 3,695 Men).

	Model 1 †	Model 2 ‡	Model 3 §	Model 4 ¶
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level and vocational qualification	1.46 (0.46, 2.46)	1.76 (0.79, 2.73)	1.67 (0.71, 2.64)	1.12 (0.17, 2.08)
GCSEs	1.68 (0.89, 2.46)	2.16 (1.40, 2.92)	2.18 (1.43, 2.94)	0.97 (0.16, 1.77)
No qualification	1.59 (0.81, 2.36)	2.26 (1.50, 3.02)	2.34 (1.58, 3.10)	1.12 (0.29, 1.95)
p-values (overall; test for trend) ∞	<0.001; -	<0.001; -	<0.001; -	0.03; <0.05

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included; † Model 1: unadjusted (p-values from formal tests of sex interaction: p<0.01 for Own occupational class (46y)) and p<0.0001 for Own highest qualification class (46y)); ‡ Model 2: adjusted for height (46y); § Model 3: Model 2 + birth weight, BMI (10y) (kg/m2), Playing sport in spare time (10y), watching TV in spare time at age (10y) and disability (10y); ¶ Model 4: Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (46y) and occupational activity (46y); ∞ P-trend: p-value not presented if there was significant deviation from linearity; †† Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

Table B.6.4: Associations between adulthood socioeconomic position and grip strength at age 46 years in the BCS70 with individual adjustments for each adult covariate (regression models for men with sample restricted to those with valid measures of grip strength at age 46 years (maximum*N=3,695)).

	Model 4 †	Model 5 ‡	Model 6 §	Model 7 ¶	Model 8 **
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
Own occupational class (46y)					
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.71 (-1.61, 0.19)	-0.56 (-1.46, 0.35)	-0.43 (-1.33, 0.48)	-0.62 (-1.52, 0.28)	-0.83 (-1.74, 0.07)
III Skilled manual	1.83 (1.13, 2.53)	2.00 (1.28, 2.72)	2.17 (1.45, 2.89)	1.86 (1.15, 2.57)	-0.26 (-1.13, 0.62)
IV Partly skilled/V Unskilled	0.27 (-0.86, 1.39)	0.33 (-0.83, 1.48)	0.78 (-0.39, 1.96)	0.01 (-1.13, 1.15)	-1.84 (-3.08, -0.60)
p-values (overall; test for trend) ∞	<0.001; -	<0.001; -	<0.001; -	<0.001; -	0.02; 0.02
Own highest qualification (46y)					
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	
A-level and vocational qualification	1.39 (0.43, 2.35)	1.71 (0.74, 2.67)	1.82 (0.86, 2.79)	1.66 (0.70, 2.62)	1.28 (0.32, 2.24)
GCSEs	1.81 (1.05, 2.57)	2.25 (1.49, 3.02)	2.44 (1.67, 3.21)	2.16 (1.40, 2.92)	1.11 (0.31, 1.90)
No qualification	2.04 (1.29, 2.80)	2.45 (1.68, 3.23)	2.71 (1.93, 3.49)	2.34 (1.58, 3.11)	1.01 (0.19, 1.82)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.001; -	<0.001; -	<0.001; -	0.02; 0.03

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included; Model 3: adjusted for height (46y) + birth weight, BMI (10y) (kg/m2), playing sport in spare time (10y), watching TV in spare time (10y) and disability (10y); † Model 4: adjusted for Model 3 + BMI (46y) ; ‡ Model 5: adjusted for Model 3 + smoking status (42y); § Model 6: adjusted for Model 3 + watching TV during the week (42y); ¶ Model 7: adjusted for Model 3 + physical activity (46y); ** Model 8: adjusted for Model 3 + occupational activity (46y); ∞ P-trend: p-value not presented if there was significant deviation from linearity; †† Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

B.6.2 Standing balance performance

Table B.6.5: Associations between childhood SEP and standing balance time at age 46 years in the BCS70 (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Father's occupational class (5y)				
Model 1: Adjusted for sex				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.33 (0.85, 2.09)	1.21 (0.75, 1.93)	0.89 (0.67, 1.19)	0.78 (0.60, 1.02)
III Skilled non-manual	1.55 (0.95, 2.51)	1.52 (0.91, 2.52)	1.05 (0.76, 1.43)	0.61 (0.45, 0.83)
III Skilled manual	2.10 (1.39, 3.19)	1.73 (1.11, 2.68)	0.78 (0.60, 1.02)	0.55 (0.43, 0.70)
IV Partly skilled	1.70 (1.07, 2.68)	1.61 (0.99, 2.61)	0.74 (0.54, 1.02)	0.40 (0.29, 0.55)
V Unskilled	2.64 (1.55, 4.47)	1.66 (0.92, 3.00)	0.58 (0.36, 0.92)	0.34 (0.21, 0.56)
p-values (test for trend)	<0.001	0.003	0.002	<0.001
Model 2: Model 1 + height at 46y				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.32 (0.84, 2.07)	1.20 (0.75, 1.92)	0.89 (0.67, 1.19)	0.78 (0.60, 1.01)
III Skilled non-manual	1.52 (0.94, 2.46)	1.50 (0.90, 2.49)	1.04 (0.76, 1.43)	0.60 (0.44, 0.82)
III Skilled manual	2.01 (1.32, 3.05)	1.67 (1.08, 2.59)	0.77 (0.59, 1.01)	0.53 (0.41, 0.67)
IV Partly skilled	1.60 (1.01, 2.53)	1.55 (0.95, 2.51)	0.73 (0.54, 1.01)	0.38 (0.28, 0.53)
V Unskilled	2.45 (1.45, 4.16)	1.58 (0.87, 2.85)	0.57 (0.36, 0.91)	0.33 (0.20, 0.53)
p-values (test for trend)	<0.001	0.008	0.001	<0.001
Father's highest qualification (5y)				
Model 1: Adjusted for sex				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	0.89 (0.57, 1.38)	0.80 (0.46, 1.37)	0.92 (0.67, 1.26)	0.86 (0.64, 1.16)
Vocational/O-level/equivalent	1.11 (0.82, 1.52)	1.05 (0.74, 1.48)	0.93 (0.74, 1.16)	0.67 (0.54, 0.82)
No qualification	1.35 (1.03, 1.77)	1.60 (1.18, 2.17)	0.73 (0.59, 0.90)	0.49 (0.40, 0.60)
p-values (test for trend)	0.006	<0.001	0.002	<0.001
Model 2: Model 1 + height at 46y				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	0.87 (0.56, 1.35)	0.78 (0.46, 1.35)	0.92 (0.67, 1.26)	0.85 (0.63, 1.15)

Table B.6.5: Associations between childhood SEP and standing balance time at age 46 years in the BCS70 (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Vocational/O-level/equivalent	1.09 (0.80, 1.49)	1.03 (0.73, 1.46)	0.92 (0.74, 1.15)	0.66 (0.53, 0.81)
No qualification	1.28 (0.97, 1.69)	1.55 (1.14, 2.11)	0.72 (0.59, 0.89)	0.48 (0.39, 0.58)
p-values (test for trend)	0.019	<0.001	0.002	<0.001
Mother's highest qualification (5y)				
Model 1: Adjusted for sex				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	1.04 (0.59, 1.86)	0.30 (0.10, 0.88)	0.94 (0.60, 1.48)	0.90 (0.61, 1.33)
Vocational/O-level/equivalent	1.14 (0.79, 1.65)	1.16 (0.77, 1.77)	1.11 (0.84, 1.46)	0.77 (0.60, 0.99)
No qualification	1.45 (1.03, 2.04)	1.58 (1.06, 2.35)	0.87 (0.67, 1.13)	0.51 (0.40, 0.65)
p-values (test for trend)	0.003	<0.001	0.090	<0.001
Model 2: Model 1 + height at 46y				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	1.05 (0.59, 1.86)	0.30 (0.10, 0.89)	0.94 (0.60, 1.48)	0.90 (0.61, 1.33)
Vocational/O-level/equivalent	1.12 (0.77, 1.61)	1.15 (0.76, 1.74)	1.11 (0.84, 1.46)	0.76 (0.59, 0.98)
No qualification	1.37 (0.98, 1.94)	1.53 (1.02, 2.27)	0.86 (0.66, 1.13)	0.49 (0.39, 0.62)
p-values (test for trend)	0.014	<0.001	0.084	<0.001

P-value from formal tests of sex interaction for father's occupational class at age 5y: 0.93; father's highest qualification at age 5y: 0.58; mother's highest qualification at age 5y: 0.63; Note: results are combined from analyses run across 50 imputed datasets: † Relative Risk Ratio with 95% Confidence Interval.

Table B.6.6: Associations between adulthood SEP and standing balance time at age 46 years in the BCS70 (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Own occupational class (46y)				
Model 1: Adjusted for sex				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.13 (0.72, 1.77)	1.38 (0.83, 2.29)	1.27 (0.95, 1.71)	0.76 (0.58, 0.98)
III Skilled non-manual	1.59 (1.00, 2.52)	2.06 (1.23, 3.45)	1.04 (0.76, 1.43)	0.64 (0.48, 0.86)
III Skilled manual	1.80 (1.13, 2.88)	2.01 (1.19, 3.40)	0.78 (0.56, 1.07)	0.46 (0.35, 0.62)
IV Partly skilled	2.34 (1.42, 3.85)	2.33 (1.33, 4.07)	0.76 (0.51, 1.13)	0.30 (0.19, 0.45)
V Unskilled	4.81 (2.62, 8.84)	2.56 (1.19, 5.48)	0.46 (0.21, 0.97)	0.36 (0.18, 0.73)
p-values (test for trend)	<0.001	<0.001	<0.001	<0.001
Model 2: Model 1 + height at 46y				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.12 (0.71, 1.76)	1.37 (0.83, 2.28)	1.27 (0.95, 1.71)	0.75 (0.58, 0.98)
III Skilled non-manual	1.55 (0.98, 2.47)	2.03 (1.21, 3.40)	1.04 (0.76, 1.42)	0.64 (0.48, 0.85)
III Skilled manual	1.73 (1.08, 2.77)	1.96 (1.15, 3.31)	0.77 (0.56, 1.06)	0.45 (0.34, 0.61)
IV Partly skilled	2.25 (1.37, 3.71)	2.26 (1.29, 3.97)	0.76 (0.51, 1.12)	0.29 (0.19, 0.44)
V Unskilled	4.56 (2.48, 8.36)	2.46 (1.14, 5.28)	0.45 (0.21, 0.96)	0.34 (0.17, 0.70)
p-values (test for trend)	<0.001	<0.001	<0.001	<0.001
Own highest qualification (46y)				
Model 1: Adjusted for sex				
Degree and higher	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Advance and vocational qualification	1.30 (0.96, 1.77)	1.38 (0.98, 1.93)	0.94 (0.75, 1.17)	0.61 (0.48, 0.76)
GCSEs	1.63 (1.28, 2.08)	1.99 (1.52, 2.60)	0.81 (0.68, 0.97)	0.51 (0.42, 0.61)
No qualification	2.39 (1.89, 3.04)	1.85 (1.40, 2.44)	0.77 (0.64, 0.93)	0.51 (0.42, 0.62)
p-values (test for trend)	<0.001	<0.001	0.003	<0.001
Model 2: Model 1 + height at 46y				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Advance and vocational qualification	1.28 (0.94, 1.73)	1.36 (0.97, 1.91)	0.93 (0.75, 1.16)	0.60 (0.48, 0.75)
GCSEs	1.57 (1.23, 2.01)	1.94 (1.49, 2.54)	0.81 (0.67, 0.97)	0.50 (0.41, 0.60)

Table B.6.6: Associations between adulthood SEP and standing balance time at age 46 years in the BCS70 (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
No qualification	2.29 (1.80, 2.92)	1.80 (1.36, 2.37)	0.77 (0.63, 0.93)	0.49 (0.41, 0.60)
p-values (test for trend)	<0.00	<0.00	0.002	<0.00

P-value from formal tests of sex interaction for own occupational class at age 46y: 0.150; own highest qualification at age 46y: 0.089; Note: results are combined from analyses run across 50 imputed datasets; † Relative Risk Ratio with 95% Confidence Interval.

Table B.6.7: Sex-adjusted associations of occupational class from childhood to adulthood and standing balance time at age 46 years in the BCS70 on observed data (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Occupational class mobility (from 5 to 46y)*				
Model 1: Adjusted for sex				
High-High	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Low-High	1.27 (1.00, 1.60)	1.39 (1.09, 1.79)	0.84 (0.71, 0.99)	0.70 (0.59, 0.83)
High-Low	1.29 (0.86, 1.92)	1.55 (1.06, 2.27)	0.64 (0.48, 0.87)	0.61 (0.45, 0.81)
Low-Low	2.25 (1.78, 2.85)	1.71 (1.31, 2.23)	0.56 (0.46, 0.69)	0.41 (0.33, 0.51)
Model 2: Model 1 + height at 46y				
High-High	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Low-High	1.22 (0.96, 1.55)	1.36 (1.06, 1.74)	0.83 (0.71, 0.99)	0.68 (0.57, 0.81)
High-Low	1.25 (0.84, 1.87)	1.52 (1.04, 2.22)	0.64 (0.47, 0.86)	0.59 (0.44, 0.79)
Low-Low	2.13 (1.68, 2.71)	1.65 (1.26, 2.15)	0.56 (0.45, 0.68)	0.39 (0.31, 0.48)

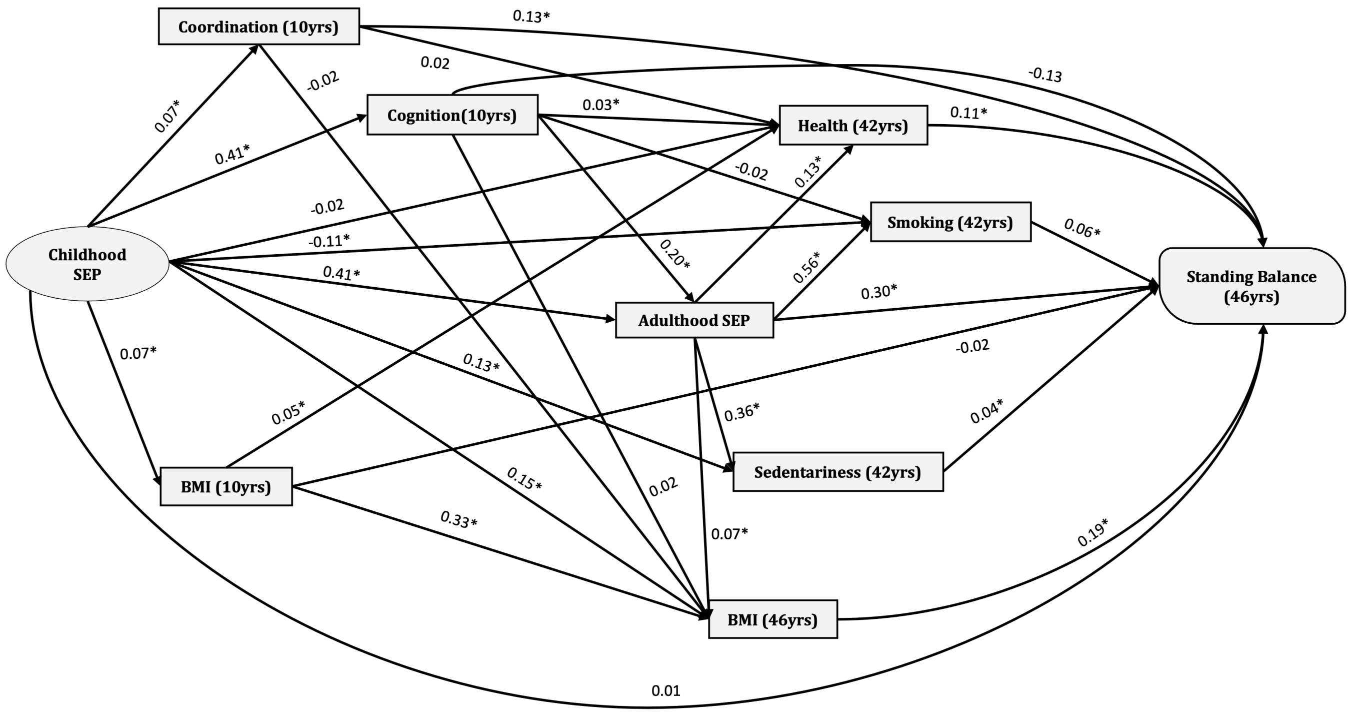
Note: results are combined from analyses run across 50 imputed datasets; * High category includes I, II and III non-manual; Low category includes III manual, IV and V; † Relative Risk Ratio with 95% Confidence Interval.

Table B.6.8: Sex and height-adjusted bivariate regression coefficients from structural equation models to test Baron and Kenny's criteria for mediation.

Relationship	Coefficient †(95% CI)
Exposure (X) ∼ outcome (Y)‡	
Childhood SEP ∼ Standing balance (46y)	0.455 (0.368, 0.542)*
Exposure (X) ∼ Mediator (M)§	
Childhood SEP ∼ Adulthood SEP	0.647 (0.596, 0.699)*
Childhood SEP ∼ Childhood leisure-time physical activity (10y)	-0.001 (-0.020, 0.017)
Childhood SEP ∼ Adulthood leisure-time physical activity (42y)	-0.015 (-0.066, 0.036)
Childhood SEP ∼ Childhood health status (10y)	0.028 (0.003, 0.054)*
Childhood SEP ∼ Adulthood health status (42y)	0.035 (0.021, 0.050)*
Childhood SEP ∼ Childhood coordination (10y)	0.016 (0.001, 0.031)*
Childhood SEP ∼ Childhood BMI (10y)	0.095 (0.035, 0.155)*
Childhood SEP ∼ Adulthood BMI (42y)	0.807 (0.630, 0.983)*
Childhood SEP ∼ Childhood cognition (10y)	0.324 (0.352, 0.297)*
Childhood SEP ∼ Adulthood cognition (42y)	0.289 (0.268, 0.310)*
Childhood SEP ∼ Adulthood sedentariness (42y)	0.168 (0.146, 0.191)*
Childhood SEP ∼ Adulthood occupational activity (42y)	0.229 (0.203, 0.256)*
Childhood SEP ∼ Adulthood smoking (42y)	0.129 (0.098, 0.169)*
Childhood SEP ∼ Adulthood cognition (42y)	0.289 (0.268, 0.310)*
Adulthood SEP ∼ Adulthood leisure-physical activity (42y)	0.000 (-0.055, 0.055)
Adulthood SEP ∼ Adulthood health status (42y)	0.070 (0.053, 0.088)*
Adulthood SEP ∼ Adulthood BMI (42y)	0.800 (0.600, 1.000)*
Adulthood SEP ∼ Adulthood cognition (42y)	0.431 (0.409, 0.452)*
Adulthood SEP ∼ Adulthood sedentariness (42y)	0.261 (0.237, 0.286)*
Adulthood SEP ∼ Adulthood smoking (42y)	0.421 (0.388, 0.453)*
Adulthood SEP ∼ Adulthood occupational activity (42y)	0.621 (0.597, 0.600)*
Mediator (M) ∼ Outcome (Y)‡	
Adulthood SEP ∼ Standing balance (46y)	0.876 (0.832, 0.92)*
Childhood leisure-time physical activity (10y) ∼ Standing balance (46y)	0.291 (0.169, 0.413)*
Adulthood leisure-time physical activity (42y) ∼ Standing balance (46y)	0.155 (0.113, 0.197)*
Childhood health status (10y) ∼ Standing balance (46y)	0.246 (0.158, 0.334)*
Adulthood health status (42y) ∼ Standing balance (46y)	0.999 (0.848, 1.150)*
Childhood coordination (10y) ∼ Standing balance (46y)	0.940 (0.787, 1.094)*
Childhood BMI (10y) ∼ Standing balance (46y)	0.096 (0.058, 0.133)*
Adulthood BMI (46y) ∼ Standing balance (46y)	0.125 (0.110, 0.140)*
Childhood cognition (10y) ∼ Standing balance (46y)	0.397 (0.478, 0.317)*
Adulthood cognition (42y) ∼ Standing balance (46y)	0.612 (0.513, 0.712)*
Adulthood sedentariness (42y) ∼ Standing balance (46y)	0.520 (0.424, 0.617)*
Adulthood smoking (42y) ∼ Standing balance (46y)	0.340 (0.272, 0.407)*
Adulthood occupational activity (42y) ∼ Standing balance (46y)	0.359 (0.283, 0.436)*

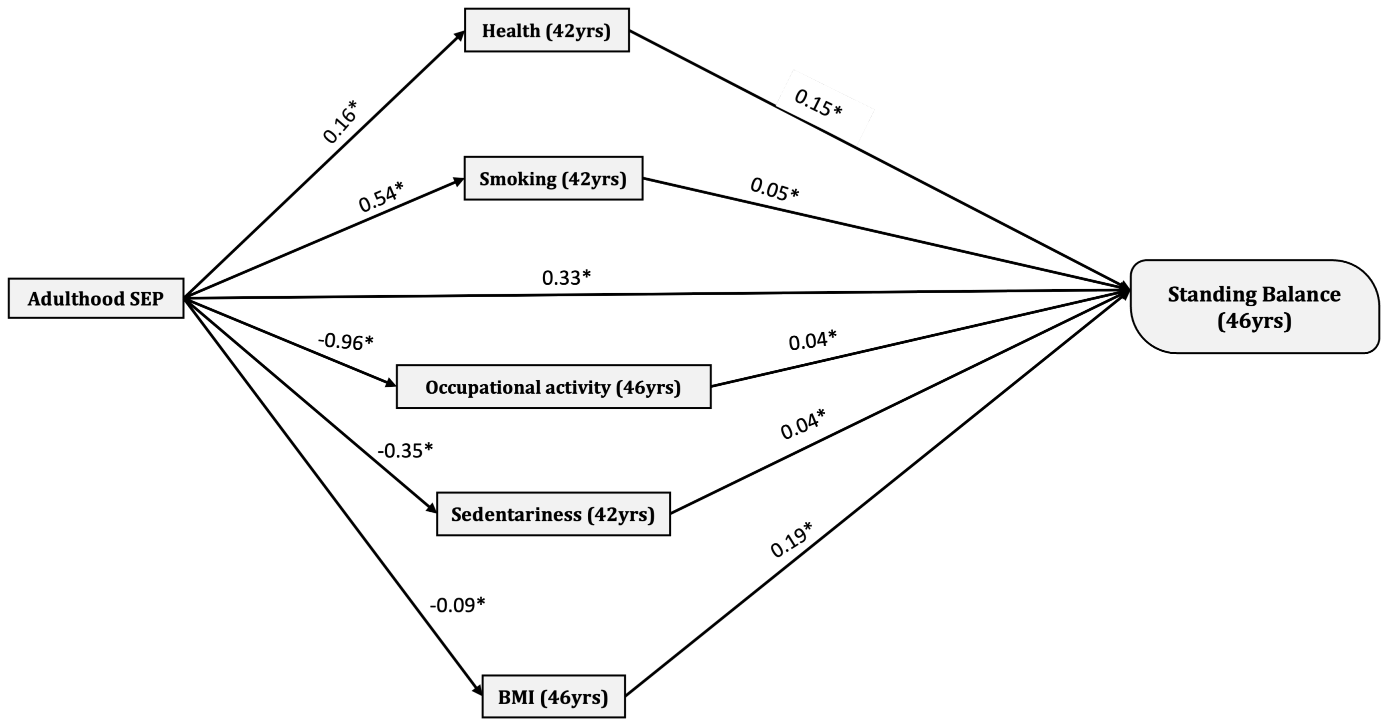
† Standardised regression coefficient: the amount standing balance performance increases if mediator or exposure was increased by a unit of 1; ‡ Pathways adjusted for sex and height at age 46; § Pathways adjusted for sex; * Statistically significant (*p*<0.05).

Figure B.6.1: Mediators of the associations between Childhood SEP and standing balance performance at age 46: mediation model with pathway coefficient.



Model fit: CF1 = 0.910; RMSEA = 0.032; SRMR = 0.036. This mediation models displays only the factors that likely to mediate observed associations between childhood SEP and standing balance performance. Pathways leading to standing balance were adjusted for sex and height at age 46, otherwise, pathways were only adjusted for sex. The coefficients represent standardised regression coefficient which quantifies the amount a mediator/outcome increases if the mediator/exposure is increased by a unit of 1.
* Statistically significant.

Figure B.6.2: Mediators of the associations between adulthood SEP and standing balance performance at age 46: mediation model with pathway coefficient.



Model fit: CF1 = 0.921; RMSEA = 0.038; SRMR = 0.039. This mediation models displays only the factors that likely to mediate observed associations between adulthood SEP and standing balance performance. Pathways leading to standing balance were adjusted for sex, height at age 46, and childhood SEP, otherwise, pathways were only adjusted for sex. The coefficients represent standardised regression coefficient which quantifies the amount a mediator/outcome increases if the mediator/exposure is increased by a unit of 1. *Statistically significant.

B.7 Tables for additional analyses in the BCS70

B.7.1 Grip strength

Table B.7.1: Unadjusted associations between of childhood socioeconomic position and grip strength at age 46 years in the BCS70 on observed data (unadjusted regression models stratified by sex (N=7,617* ; 3,922 Women and 3,695 Men)).

	Women		Men	
Socioeconomic indicators	N	Coefficient (95% CI) †	N	Coefficient (95% CI) †
Father's occupational class (5y)	3,728		3,470	
I Professional/II Intermediate		0.00 (ref)		0.00 (ref)
III Skilled non-manual		-0.57 (-1.23, 0.10)		-0.66 (-1.71, 0.39)
III Skilled manual		-1.32 (-1.78, -0.87)		-0.06 (-0.77, 0.66)
IV Partly skilled/V Unskilled		-1.42 (-1.98, -0.87)		-0.64 (-1.56, 0.29)
p-values (overall; test for trend) ††		<0.001; <0.001		<0.001; 0.4
Mother's highest qualification (5y)	3,079		2,852	
Vocational/degree and higher		0.00 (ref)		0.00 (ref)
A-level/equivalent		-0.31 (-1.47, 0.86)		-0.93 (-2.81, 0.94)
Vocational/O-level/equivalent		-0.82 (-1.56, -0.07)		0.33 (-0.88, 1.54)
No qualification		-1.46 (-2.18, -0.74)		-0.06 (-1.24, 1.11)
p-values (overall; test for trend) ††		<0.001; <0.001		<0.001; 0.99
Father's highest qualification (5y)	2,870		2,695	
Vocational/degree and higher		0.00 (ref)		0.00 (ref)
A-level/equivalent		-0.17 (-1.05, 0.71)		0.00 (-1.43, 1.43)
Vocational/O-level/equivalent		-0.51 (-1.14, 0.13)		0.37 (-0.64, 1.38)
No qualification		-0.98 (-1.57, -0.38)		0.68 (-0.26, 1.62)
p-values (overall; test for trend) ††		<0.001; <0.001		<0.001; 0.12
Father's occupational class (16y)	3,516		3,282	
I Professional/II Intermediate		0.00 (ref)		0.00 (ref)
III Skilled non-manual		-0.14 (-0.79, 0.51)		-0.85 (-1.90, 0.21)
III Skilled manual		-0.95 (-1.40, -0.51)		0.51 (-0.21, 1.22)
IV Partly skilled/V Unskilled		-1.53 (-2.12, -0.93)		-0.39 (-1.34, 0.57)
p-values (overall; test for trend) ††		<0.001; <0.001		<0.001; -

Note: results are combined from analyses run across 50 imputed datasets; P-values from formal tests of sex interaction: p=0.01 for Fathers occupational class (5y), p=0.05 for Mother's highest qualification (5y), p=0.01 for Father's highest qualification (5y) and p<001 for Father's occupational class (16y).* 70 participants unable to complete the grip strength tests for health reasons were included; † Difference in mean grip strength (kg) (95% Confidence Interval); †† P-trend: p-value not presented if there was significant deviation from linearity.

Table B.7.2: Unadjusted associations between of adulthood socioeconomic position and grip strength at age 46 years in the BCS70 on observed data (unadjusted regression models stratified by sex (N=7,617* ; 3,922 Women and 3,695 Men)).

	Women		Men	
Socioeconomic indicators	N	Coefficient (95% CI) †	N	Coefficient (95% CI) †
Own occupational class (30y)	3,171		3,082	
I Professional/II Intermediate		0.00 (ref)		0.00 (ref)
III Skilled non-manual		-0.56 (-1.01, -0.12)		-1.04 (-2.00, -0.08)
III Skilled manual		-0.49 (-1.28, 0.30)		2.68 (1.95, 3.40)
IV Partly skilled/V Unskilled		-0.44 (-1.07, 0.19)		0.77 (-0.25, 1.80)
p-values (overall; test for trend) ††		<0.001; 0.08		<0.001; -
Own occupational class (46y)	3,105		3,299	
I Professional/II Intermediate		0.00 (ref)		0.00 (ref)
III Skilled non-manual		-0.64 (-1.10, -0.19)		-0.56 (-1.46, 0.33)
III Skilled manual		-0.06 (-0.74, 0.61)		1.90 (1.21, 2.60)
IV Partly skilled/V Unskilled		-0.49 (-1.13, 0.15)		0.35 (-0.79, 1.49)
p-values (overall; test for trend) ††		<0.001; -		<0.001; -
Own highest qualification (46y)	3,079		2,852	
Degree and higher		0.00 (ref)		0.00 (ref)
A-level and vocational qualification		-0.31 (-1.47, 0.86)		-0.93 (-2.81, 0.94)
GCSEs		-0.82 (-1.56, -0.07)		0.33 (-0.88, 1.54)
No qualification		-1.46 (-2.18, -0.74)		-0.06 (-1.24, 1.11)
p-values (overall; test for trend††)		<0.001; <0.001		<0.001; 0.99

Note: results are combined from analyses run across 50 imputed datasets; P-values from formal tests of sex interaction: p<0.001 for Own occupational class (30y), p<0.001 for Own occupational class (46y) and p<0.001 for Own highest qualification (46y); * 70 participants unable to complete the grip strength tests for health reasons were included; † Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval); †† P-trend: p-value not presented if there was significant deviation from linearity.

Table B.7.3: Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 years in the BCS70 on the sample who completed the grip strength assessment standing unsupported (N=6,890).

	Women (N=3,872)		Men (N=3,392)	
Socioeconomic indicators	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††
Father's occupational class (5y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.37 (-1.05, 0.31)	-0.24 (-0.89, 0.41)	-0.74 (-1.82, 0.33)	-0.70 (-1.70, 0.29)
III Skilled manual	-1.06 (-1.52, -0.59)	-0.69 (-1.15, -0.24)	-0.12 (-0.84, 0.60)	-0.37 (-1.07, 0.33)
IV Partly skilled/V Unskilled	-1.22 (-1.79, -0.65)	-0.59 (-1.15, -0.03)	-0.65 (-1.58, 0.28)	-0.66 (-1.55, 0.24)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.02; <0.01	0.36; 0.35	0.38; 0.18
Mother's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.55 (-1.75, 0.65)	-0.54 (-1.68, 0.59)	-0.43 (-2.23, 1.36)	-1.00 (-2.70, 0.71)
Vocational/O-level/equivalent	-0.83 (-1.57, -0.09)	-0.76 (-1.47, -0.06)	0.72 (-0.41, 1.85)	0.46 (-0.62, 1.53)
No qualification	-1.35 (-2.04, -0.65)	-0.98 (-1.66, -0.31)	0.24 (-0.84, 1.31)	-0.05 (-1.10, 1.00)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.03; <0.01	0.31; 0.74	0.21; 0.98
Father's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	0.05 (-0.81, 0.91)	0.30 (-0.51, 1.12)	0.28 (-1.08, 1.63)	-0.05 (-1.33, 1.23)
Vocational/O-level/equivalent	-0.45 (-1.09, 0.19)	-0.23 (-0.84, 0.38)	0.46 (-0.50, 1.42)	-0.11 (-1.03, 0.80)
No qualification	-0.72 (-1.29, -0.14)	-0.30 (-0.87, 0.28)	0.67 (-0.22, 1.55)	-0.11 (-1.00, 0.78)
p-values (overall; test for trend) ∞	0.04; <0.01	0.37; 0.17	0.49; 0.13	0.96; 0.81
Father's occupational class (16y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	0.04 (-0.61, 0.70)	0.17 (-0.46, 0.79)	-0.83 (-1.90, 0.25)	-0.69 (-1.68, 0.31)
III Skilled manual	-0.84 (-1.29, -0.39)	-0.55 (-1.00, -0.11)	0.28 (-0.45, 1.00)	0.18 (-0.52, 0.89)
IV Partly skilled/V Unskilled	-1.34 (-1.95, -0.74)	-0.67 (-1.27, -0.07)	-0.50 (-1.45, 0.45)	-0.57 (-1.49, 0.36)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.01; <0.01	0.15; 0.9	0.19; 0.66
Own occupational class (30y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.62 (-1.08, -0.17)	-0.41 (-0.84, 0.03)	-0.77 (-1.77, 0.24)	-0.87 (-1.83, 0.10)

Table B.7.3: Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 years in the BCS70 on the sample who completed the grip strength assessment standing unsupported (N=6,890).

	Women (N=3,872)		Men (N=3,392)	
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
III Skilled manual	-0.64 (-1.44, 0.17)	-0.49 (-1.27, 0.29)	2.08 (1.33, 2.82)	1.40 (0.59, 2.21)
IV Partly skilled/V Unskilled	-0.67 (-1.29, -0.05)	-0.41 (-1.05, 0.23)	0.34 (-0.70, 1.37)	0.03 (-1.03, 1.10)
p-values (overall; test for trend) ∞	0.02; <0.05	0.22; 0.13	<0.001; -	<0.001; -
Own occupational class (46y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.78 (-1.25, -0.30)	-0.43 (-0.89, 0.03)	-0.66 (-1.61, 0.29)	-0.82 (-1.72, 0.09)
III Skilled manual	-0.36 (-1.08, 0.37)	-0.26 (-0.99, 0.47)	1.47 (0.74, 2.20)	0.13 (-0.73, 0.99)
IV Partly skilled/V Unskilled	-0.62 (-1.28, 0.04)	-0.45 (-1.16, 0.26)	-0.71 (-1.91, 0.49)	-1.36 (-2.64, -0.07)
p-values (overall; test for trend) ††	<0.01; -	0.21; 0.15	<0.001; -	0.03; -
Own highest qualification (46y)				
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level and vocational qualification	-0.67 (-1.27, -0.07)	-0.67 (-1.24, -0.09)	1.61 (0.59, 2.64)	1.25 (0.28, 2.22)
GCSEs	-0.60 (-1.10, -0.11)	-0.31 (-0.80, 0.18)	1.65 (0.85, 2.45)	0.86 (0.03, 1.68)
No qualification	-0.81 (-1.34, -0.29)	-0.42 (-0.96, 0.12)	1.79 (1.00, 2.58)	1.25 (0.41, 2.09)
p-values (overall; test for trend) ††	0.01; <0.01	0.14; 0.23	<0.001; <0.001	0.02; <0.01

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests of sex interaction, p<0.001 for Own occupational class (30y), p<0.001 for Own occupational class (46y), p<0.001 for Own highest qualification (46y); Model 4: adjusted for Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (42y) and occupational activity (46y); ∞ P-trend: p-value not presented if there was significant deviation from linearity; † Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

Table B.7.4: Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those participants unable to complete the grip strength assessments for health reasons (N=7,547).

	Women (N=3,872)		Men (N=3,392)	
Socioeconomic indicators	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††
Father's occupational class (5y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.56 (-1.23, 0.11)	-0.40 (-1.04, 0.24)	-0.75 (-1.80, 0.29)	-0.65 (-1.62, 0.32)
III Skilled manual	-1.25 (-1.70, -0.80)	-0.81 (-1.25, -0.37)	-0.06 (-0.77, 0.65)	-0.29 (-0.98, 0.39)
IV Partly skilled/V Unskilled	-1.39 (-1.94, -0.84)	-0.74 (-1.28, -0.19)	-0.68 (-1.59, 0.23)	-0.66 (-1.54, 0.21)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.01; <0.001	0.26; 0.37	0.39; 0.19
Mother's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.52 (-1.69, 0.64)	-0.50 (-1.60, 0.60)	-0.67 (-2.42, 1.07)	-1.19 (-2.84, 0.47)
Vocational/O-level/equivalent	-0.79 (-1.52, -0.06)	-0.70 (-1.40, -0.01)	0.55 (-0.57, 1.67)	0.39 (-0.67, 1.45)
No qualification	-1.42 (-2.10, -0.74)	-1.00 (-1.66, -0.34)	0.21 (-0.85, 1.27)	0.04 (-1.00, 1.07)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.02; <0.01	0.39; 0.64	0.19; 0.72
Father's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.20 (-1.01, 0.62)	0.10 (-0.68, 0.88)	0.16 (-1.17, 1.49)	-0.21 (-1.46, 1.04)
Vocational/O-level/equivalent	-0.52 (-1.12, 0.08)	-0.28 (-0.86, 0.30)	0.42 (-0.53, 1.37)	-0.13 (-1.03, 0.76)
No qualification	-0.94 (-1.50, -0.39)	-0.44 (-0.99, 0.11)	0.63 (-0.23, 1.50)	-0.14 (-1.00, 0.72)
p-values (overall; test for trend) ∞	<0.01; <0.001	0.3; 0.07	0.47; 0.13	0.93; 0.8
Father's occupational class (16y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.14 (-0.78, 0.50)	0.00 (-0.61, 0.61)	-0.81 (-1.85, 0.22)	-0.70 (-1.67, 0.26)
III Skilled manual	-0.91 (-1.34, -0.47)	-0.56 (-0.99, -0.13)	0.43 (-0.28, 1.14)	0.32 (-0.37, 1.01)
IV Partly skilled/V Unskilled	-1.55 (-2.14, -0.97)	-0.81 (-1.39, -0.23)	-0.54 (-1.47, 0.38)	-0.59 (-1.49, 0.30)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.01; <0.01	0.06; -	0.08; -
Own occupational class (30y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)

Table B.7.4: Associations between indicators of childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those participants unable to complete the grip strength assessments for health reasons (N=7,547)

	Women (N=3,872)		Men (N=3,392)	
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
III Skilled non-manual	-0.52 (-0.97, -0.08)	-0.30 (-0.72, 0.13)	-0.91 (-1.89, 0.08)	-0.93 (-1.87, 0.01)
III Skilled manual	-0.68 (-1.46, 0.10)	-0.47 (-1.24, 0.29)	2.17 (1.43, 2.90)	1.50 (0.72, 2.27)
IV Partly skilled/V Unskilled	-0.79 (-1.40, -0.18)	-0.49 (-1.12, 0.15)	0.30 (-0.73, 1.33)	-0.05 (-1.10, 1.00)
p-values (overall; test for trend) ∞	0.02; <0.01	0.29; 0.09	<0.001; -	<0.001; -
Own occupational class (46y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.72 (-1.18, -0.27)	-0.30 (-0.74, 0.15)	-0.77 (-1.70, 0.16)	-0.86 (-1.74, 0.02)
III Skilled manual	-0.44 (-1.15, 0.26)	-0.28 (-0.98, 0.42)	1.37 (0.64, 2.10)	0.01 (-0.85, 0.87)
IV Partly skilled/V Unskilled	-0.82 (-1.47, -0.17)	-0.61 (-1.30, 0.09)	-0.59 (-1.77, 0.58)	-1.26 (-2.51, -0.01)
p-values (overall; test for trend) ††	<0.01; <0.01	0.23; 0.07	<0.001; -	0.05; -
Own highest qualification (46y)				
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level and vocational qualification	-0.58 (-1.16, 0.00)	-0.59 (-1.15, -0.03)	1.48 (0.48, 2.48)	1.12 (0.17, 2.07)
GCSEs	-0.57 (-1.05, -0.10)	-0.24 (-0.71, 0.24)	1.69 (0.90, 2.47)	0.96 (0.15, 1.76)
No qualification	-1.19 (-1.69, -0.68)	-0.74 (-1.26, -0.21)	1.67 (0.89, 2.45)	1.18 (0.35, 2.01)
p-values (overall; test for trend) ††	<0.001; <0.001	0.02; <0.05	<0.001; <0.001	0.02; <0.01

Note: results are combined from analyses run across 50 imputed datasets. 70 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests of sex interaction, p<0.001 for Own occupational class (30y), p<0.01 for own housing tenure (30y), p<0.01 for Own occupational class (46y), p<0.001 for Own highest qualification (46y) and p<0.01 for own housing tenure (46y); Model 4: adjusted for Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (42y) and occupational activity (46y); ∞ P-trend: p-value not presented if there was significant deviation from linearity; † Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

Table B.7.5: Associations between childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those classified as severely hampered according to the European Statistics of Income and Living Conditions (EU-SILC) classification disability definition or with missing disability data (N=7,132).

	Women (N=3,638)		Men (N=3,394)	
Socioeconomic indicators	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††	Model 1: Unadjusted Coefficient (95% CI) ††	Model 4: Fully-adjusted Coefficient (95% CI) ††
Father's occupational class (5y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.38 (-1.04, 0.29)	-0.23 (-0.87, 0.41)	-0.72 (-1.77, 0.32)	-0.63 (-1.59, 0.34)
III Skilled manual	-1.00 (-1.45, -0.56)	-0.65 (-1.08, -0.22)	0.03 (-0.67, 0.74)	-0.30 (-0.98, 0.38)
IV Partly skilled/V Unskilled	-1.15 (-1.70, -0.60)	-0.59 (-1.12, -0.05)	-0.31 (-1.23, 0.60)	-0.52 (-1.39, 0.36)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.02; <0.01	0.46; 0.83	0.52; 0.28
Mother's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	-0.38 (-1.55, 0.80)	-0.38 (-1.48, 0.73)	-0.55 (-2.27, 1.18)	-1.15 (-2.79, 0.48)
Vocational/O-level/equivalent	-0.71 (-1.43, 0.00)	-0.66 (-1.34, 0.02)	0.61 (-0.49, 1.71)	0.40 (-0.65, 1.44)
No qualification	-1.43 (-2.10, -0.75)	-1.12 (-1.76, -0.47)	0.41 (-0.64, 1.46)	0.11 (-0.91, 1.13)
p-values (overall; test for trend) ∞	<0.001; <0.001	<0.01; <0.001	0.4; 0.37	0.2; 0.59
Father's highest qualification (5y)				
Vocational/degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level/equivalent	0.05 (-0.74, 0.84)	0.27 (-0.48, 1.02)	0.31 (-1.03, 1.64)	-0.09 (-1.34, 1.17)
Vocational/O-level/equivalent	-0.47 (-1.05, 0.12)	-0.29 (-0.85, 0.27)	0.50 (-0.44, 1.43)	-0.06 (-0.96, 0.83)
No qualification	-0.72 (-1.26, -0.18)	-0.36 (-0.90, 0.18)	0.90 (0.04, 1.75)	0.09 (-0.76, 0.93)
p-values (overall; test for trend) ∞	0.02; <0.01	0.24; 0.09	0.18; <0.05	0.94; 0.8
Father's occupational class (16y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.18 (-0.81, 0.45)	-0.07 (-0.67, 0.54)	-0.86 (-1.89, 0.17)	-0.70 (-1.66, 0.26)
III Skilled manual	-0.80 (-1.23, -0.37)	-0.54 (-0.96, -0.11)	0.45 (-0.25, 1.16)	0.28 (-0.41, 0.97)
IV Partly skilled/V Unskilled	-1.32 (-1.90, -0.74)	-0.75 (-1.32, -0.19)	-0.09 (-1.03, 0.85)	-0.26 (-1.16, 0.64)
p-values (overall; test for trend) ∞	<0.001; <0.001	0.02; <0.01	0.1; -	0.23; 0.87
Own occupational class (30y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)

Table B.7.5: Associations between childhood and adulthood socioeconomic position and grip strength at age 46 in the BCS70 excluding those classified as severely hampered according to the European Statistics of Income and Living Conditions (EU-SILC) classification disability definition or with missing disability data (N=7,132).

	Women (N=3,638)		Men (N=3,394)	
Socioeconomic indicators	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††	Coefficient (95% CI) ††
III Skilled non-manual	-0.65 (-1.07, -0.22)	-0.48 (-0.88, -0.07)	-0.79 (-1.76, 0.18)	-0.85 (-1.78, 0.08)
III Skilled manual	-0.46 (-1.22, 0.30)	-0.40 (-1.15, 0.35)	2.30 (1.58, 3.02)	1.46 (0.68, 2.23)
IV Partly skilled/V Unskilled	-0.61 (-1.22, -0.01)	-0.46 (-1.09, 0.17)	0.60 (-0.42, 1.63)	0.03 (-1.03, 1.08)
p-values (overall; test for trend) ∞	0.02; <0.05	0.1; 0.09	<0.001; -	<0.001; -
Own occupational class (46y)				
I Professional/II Intermediate	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
III Skilled non-manual	-0.71 (-1.15, -0.27)	-0.36 (-0.79, 0.07)	-0.80 (-1.70, 0.11)	-1.01 (-1.87, -0.15)
III Skilled manual	-0.19 (-0.87, 0.50)	-0.12 (-0.80, 0.56)	1.53 (0.83, 2.23)	-0.07 (-0.90, 0.76)
IV Partly skilled/V Unskilled	-0.55 (-1.18, 0.07)	-0.45 (-1.13, 0.22)	-0.11 (-1.25, 1.04)	-1.23 (-2.46, -0.01)
p-values (overall; test for trend) ††	0.01; -	0.27; 0.18	<0.001; -	0.03; -
Own highest qualification (46y)				
Degree and higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-level and vocational qualification	-0.73 (-1.30, -0.17)	-0.79 (-1.34, -0.25)	1.58 (0.59, 2.56)	1.14 (0.20, 2.08)
GCSEs	-0.49 (-0.96, -0.02)	-0.29 (-0.75, 0.18)	1.75 (0.97, 2.52)	0.85 (0.06, 1.65)
No qualification	-0.82 (-1.33, -0.32)	-0.56 (-1.07, -0.04)	1.97 (1.19, 2.75)	1.18 (0.36, 2.00)
p-values (overall; test for trend) ††	<0.01; <0.01	0.02; -	<0.001; <0.001	0.02; <0.05

Note: results are combined from analyses run across 50 imputed datasets; * 70 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests of sex interaction, p=0.03 for Fathers occupation (5y), p<0.01 for Mother's highest qualification (5y), p=0.01 for Father's highest qualification (5y), p<0.03 for housing tenure (5y) and p<0.001 for fathers highest qualification at age 16y); Model 4: adjusted for Model 3 + BMI (46y) + smoking status (42y), watching TV during the week (42y), physical activity (42y) and occupational activity (46y).∞ P-trend: p-value not presented if there was significant deviation from linearity; † Coefficient (95% CI): Difference in mean grip strength (kg) (95% Confidence Interval).

B.7.2 Standing balance performance

Table B.7.6: Sex-adjusted associations between childhood and adulthood SEP and standing balance time at age 46 years in the BCS70 on observed data (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Father's occupational class (5y)				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.36 (0.87, 2.14)	1.24 (0.77, 2.00)	0.91 (0.68, 1.21)	0.78 (0.60, 1.00)
III Skilled non-manual	1.58 (0.97, 2.56)	1.54 (0.92, 2.58)	1.06 (0.77, 1.45)	0.60 (0.44, 0.81)
III Skilled manual	2.18 (1.44, 3.32)	1.81 (1.16, 2.82)	0.79 (0.61, 1.04)	0.54 (0.42, 0.69)
IV Partly skilled	1.77 (1.12, 2.80)	1.70 (1.04, 2.76)	0.75 (0.54, 1.02)	0.39 (0.29, 0.54)
V Unskilled	2.77 (1.65, 4.65)	1.74 (0.96, 3.18)	0.57 (0.35, 0.91)	0.34 (0.21, 0.55)
p-values (test for trend)	<0.001	0.001	0.002	<0.001
Father's highest qualification (5y)				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	0.93 (0.60, 1.44)	0.84 (0.49, 1.43)	0.98 (0.71, 1.36)	0.87 (0.64, 1.18)
Vocational/O-level/equivalent	1.18 (0.87, 1.59)	1.06 (0.74, 1.53)	0.98 (0.78, 1.24)	0.65 (0.52, 0.82)
No qualification	1.41 (1.07, 1.86)	1.67 (1.21, 2.30)	0.78 (0.63, 0.98)	0.49 (0.39, 0.60)
p-values (test for trend)	0.004	<0.001	0.023	<0.001
Mother's highest qualification (5y)				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	1.06 (0.61, 1.87)	0.27 (0.09, 0.79)	0.97 (0.63, 1.51)	0.93 (0.63, 1.38)
Vocational/O-level/equivalent	1.11 (0.77, 1.61)	1.09 (0.71, 1.67)	1.11 (0.84, 1.48)	0.79 (0.61, 1.02)
No qualification	1.42 (1.00, 2.02)	1.53 (1.02, 2.29)	0.87 (0.65, 1.14)	0.52 (0.40, 0.67)
p-values (test for trend)	0.009	<0.001	0.095	<0.001
Own occupational class (46y)				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.15 (0.72, 1.82)	1.40 (0.84, 2.33)	1.30 (0.97, 1.75)	0.77 (0.59, 1.00)
III Skilled non-manual	1.39 (0.87, 2.24)	2.02 (1.20, 3.38)	1.07 (0.78, 1.48)	0.65 (0.49, 0.87)
III Skilled manual	1.47 (0.91, 2.37)	1.95 (1.16, 3.30)	0.81 (0.58, 1.12)	0.48 (0.36, 0.65)
IV Partly skilled	1.79 (1.06, 3.02)	2.22 (1.26, 3.91)	0.77 (0.52, 1.16)	0.31 (0.20, 0.48)
V Unskilled	2.81 (1.43, 5.52)	2.33 (1.05, 5.14)	0.48 (0.22, 1.04)	0.36 (0.17, 0.74)
p-values (test for trend)	<0.001	<0.001	<0.001	<0.001

Table B.7.6: Sex-adjusted associations between childhood and adulthood SEP and standing balance time at age 46 years in the BCS70 on observed data (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Own highest qualification (46y)				
Model 1: Adjusted for sex				
Degree and higher	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Advance and vocational qualification	1.29 (0.95, 1.75)	1.39 (0.99, 1.94)	0.94 (0.76, 1.17)	0.61 (0.49, 0.76)
GCSEs	1.61 (1.26, 2.06)	2.00 (1.53, 2.61)	0.81 (0.68, 0.97)	0.51 (0.43, 0.61)
No qualification	2.37 (1.87, 3.01)	1.86 (1.41, 2.45)	0.77 (0.64, 0.93)	0.51 (0.43, 0.62)
p-values (test for trend)	<0.001	<0.001	0.006	<0.001

Note: results are combined from analyses run across 50 imputed datasets; † Relative Risk Ratio with 95% Confidence Interval.

Table B.7.7: Sex-adjusted associations between childhood SEP and standing balance time at age 46 years in the BCS70 excluding those participants unable to complete the standing balance assessments due to health reasons (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
Father's occupational class (5y)				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.41 (0.83, 2.40)	1.24 (0.77, 2.00)	0.91 (0.68, 1.21)	0.78 (0.60, 1.00)
III Skilled non-manual	1.47 (0.82, 2.62)	1.54 (0.92, 2.57)	1.06 (0.78, 1.46)	0.60 (0.44, 0.82)
III Skilled manual	2.06 (1.25, 3.38)	1.81 (1.16, 2.82)	0.80 (0.61, 1.04)	0.54 (0.42, 0.69)
IV Partly skilled	1.73 (1.00, 2.99)	1.70 (1.04, 2.76)	0.75 (0.54, 1.03)	0.40 (0.29, 0.54)
V Unskilled	2.79 (1.51, 5.15)	1.74 (0.96, 3.18)	0.57 (0.35, 0.91)	0.34 (0.21, 0.55)
p-values (test for trend)	<0.001	0.003	0.002	<0.001
Father's highest qualification (5y)				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	0.98 (0.59, 1.63)	0.83 (0.49, 1.43)	0.98 (0.71, 1.36)	0.87 (0.64, 1.18)
Vocational/O-level/equivalent	1.21 (0.85, 1.71)	1.06 (0.74, 1.53)	0.98 (0.78, 1.24)	0.65 (0.52, 0.82)
No qualification	1.26 (0.91, 1.75)	1.67 (1.21, 2.30)	0.79 (0.63, 0.98)	0.49 (0.39, 0.61)
p-values (test for trend)	0.141	<0.001	0.002	<0.001
Mother's highest qualification (5y)				
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	1.06 (0.54, 2.09)	0.27 (0.09, 0.79)	0.97 (0.63, 1.52)	0.93 (0.63, 1.38)
Vocational/O-level/equivalent	1.09 (0.70, 1.71)	1.09 (0.71, 1.67)	1.12 (0.84, 1.48)	0.79 (0.61, 1.02)
No qualification	1.40 (0.92, 2.14)	1.53 (1.02, 2.28)	0.87 (0.66, 1.14)	0.52 (0.40, 0.67)
p-values (test for trend)	0.024	<0.001	0.095	<0.001
Own occupational class (46y)				
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.15 (0.69, 1.93)	1.40 (0.84, 2.33)	1.30 (0.97, 1.75)	0.77 (0.59, 1.00)
III Skilled non-manual	1.36 (0.80, 2.31)	2.02 (1.20, 3.38)	1.07 (0.78, 1.48)	0.66 (0.49, 0.87)
III Skilled manual	1.57 (0.92, 2.67)	1.95 (1.16, 3.30)	0.81 (0.58, 1.12)	0.48 (0.36, 0.65)
IV Partly skilled	1.93 (1.08, 3.43)	2.22 (1.26, 3.91)	0.77 (0.52, 1.16)	0.31 (0.20, 0.48)
V Unskilled	2.74 (1.28, 5.85)	2.33 (1.06, 5.15)	0.47 (0.22, 1.03)	0.36 (0.17, 0.74)

Table B.7.7: Sex-adjusted associations between childhood SEP and standing balance time at age 46 years in the BCS70 excluding those participants unable to complete the standing balance assessments due to health reasons (Eyes closed <15sec outcome is used as the reference group) (N=7,591).

	Eyes Open <15s	Eyes Open 15-29.9s	Eyes Closed 15-29.9s	Eyes Closed 30s
Socioeconomic indicators	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†	RRR (95% CI)†
p-values (test for trend)	0.141	<0.001	0.002	<0.001
Own highest qualification (46y)				
Degree and higher	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Advance and vocational qualification	1.09 (0.76, 1.56)	1.39 (0.99, 1.94)	0.94 (0.76, 1.17)	0.61 (0.49, 0.76)
GCSEs	1.50 (1.14, 1.99)	2.00 (1.53, 2.61)	0.81 (0.68, 0.97)	0.51 (0.43, 0.61)
No qualification	1.88 (1.42, 2.48)	1.86 (1.41, 2.46)	0.77 (0.64, 0.93)	0.51 (0.42, 0.62)
p-values (test for trend)	<0.001	<0.001	0.003	<0.001

Note: results are combined from analyses run across 50 imputed datasets. † Relative Risk Ratio with 95% Confidence Interval.

Table B.7.8: Sex-adjusted associations between childhood SEP and standing balance time at age 46 years in the BCS70 using seven categories for standing balance time (Eyes closed <5sec outcome is used as the reference group) (N=7,591).

	Eyes Open		Eyes Closed			
	<15sec	15–29.9sec	5–9.9sec	10–14.9sec	15–29.9sec	30sec
Father's occupational class (5y)						
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.35 (0.84, 2.17)	1.22 (0.75, 2.01)	1.05 (0.79, 1.41)	0.97 (0.69, 1.38)	0.91 (0.66, 1.25)	0.80 (0.59, 1.07)
III Skilled non-manual	1.49 (0.89, 2.48)	1.46 (0.86, 2.49)	0.93 (0.68, 1.28)	0.94 (0.64, 1.38)	1.01 (0.71, 1.43)	0.58 (0.41, 0.83)
III Skilled manual	1.96 (1.26, 3.03)	1.61 (1.02, 2.54)	0.90 (0.69, 1.17)	0.84 (0.61, 1.16)	0.73 (0.54, 0.98)	0.51 (0.38, 0.67)
IV Partly skilled	1.51 (0.94, 2.45)	1.44 (0.87, 2.39)	0.86 (0.64, 1.17)	0.72 (0.50, 1.05)	0.66 (0.47, 0.94)	0.36 (0.25, 0.51)
V Unskilled	2.18 (1.25, 3.80)	1.37 (0.74, 2.54)	0.74 (0.49, 1.12)	0.60 (0.36, 1.02)	0.48 (0.29, 0.79)	0.28 (0.17, 0.48)
p-values (test for trend)	0.001	0.068	0.019	0.005	<0.001	<0.001
Father's highest qualification (5y)						
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	0.90 (0.57, 1.42)	0.80 (0.45, 1.43)	1.05 (0.76, 1.46)	0.95 (0.65, 1.40)	0.93 (0.64, 1.35)	0.87 (0.62, 1.23)
Vocational/O-level/equivalent	0.96 (0.69, 1.34)	0.91 (0.63, 1.31)	0.84 (0.67, 1.04)	0.67 (0.52, 0.88)	0.80 (0.63, 1.02)	0.58 (0.46, 0.73)
No qualification	1.16 (0.87, 1.55)	1.38 (1.00, 1.90)	0.83 (0.68, 1.01)	0.67 (0.52, 0.86)	0.63 (0.50, 0.80)	0.42 (0.34, 0.53)
p-values (test for trend)	0.154	0.006	0.033	0.001	<0.001	<0.001
Mother's highest qualification (5y)						
Higher vocational/degree	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
A-level/equivalent	1.17 (0.63, 2.18)	0.34 (0.12, 1.00)	1.15 (0.76, 1.74)	1.38 (0.82, 2.31)	1.06 (0.64, 1.74)	1.01 (0.65, 1.58)
Vocational/O-level/equivalent	1.13 (0.76, 1.66)	1.15 (0.74, 1.77)	0.87 (0.67, 1.13)	1.22 (0.87, 1.70)	1.09 (0.81, 1.48)	0.76 (0.57, 1.01)
No qualification	1.41 (0.98, 2.03)	1.54 (1.01, 2.33)	0.91 (0.71, 1.17)	1.06 (0.76, 1.48)	0.85 (0.63, 1.14)	0.50 (0.38, 0.65)
p-values (test for trend)	0.017	<0.001	0.339	0.669	0.059	<0.001
Own occupational class (46y)						
I Professional	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
II Intermediate	1.10 (0.68, 1.76)	1.34 (0.80, 2.27)	0.94 (0.71, 1.25)	0.98 (0.70, 1.39)	1.24 (0.89, 1.72)	0.74 (0.55, 0.99)
III Skilled non-manual	1.46 (0.90, 2.37)	1.90 (1.11, 3.24)	0.86 (0.64, 1.16)	0.85 (0.60, 1.22)	0.96 (0.67, 1.36)	0.59 (0.43, 0.82)
III Skilled manual	1.60 (0.97, 2.61)	1.78 (1.03, 3.08)	0.81 (0.60, 1.10)	0.78 (0.54, 1.13)	0.69 (0.48, 0.98)	0.41 (0.29, 0.57)
IV Partly skilled	2.25 (1.33, 3.82)	2.24 (1.25, 4.02)	0.94 (0.66, 1.35)	0.92 (0.59, 1.42)	0.73 (0.47, 1.13)	0.28 (0.18, 0.45)
V Unskilled	4.10 (2.10, 8.03)	2.18 (0.97, 4.91)	0.68 (0.38, 1.22)	0.86 (0.45, 1.65)	0.39 (0.18, 0.86)	0.31 (0.14, 0.65)
p-values (test for trend)	0.141	<0.001	0.002	<0.001		

Table B.7.8: Sex-adjusted associations between childhood SEP and standing balance time at age 46 years in the BCS70 using seven categories for standing balance time (Eyes closed $<$5sec outcome is used as the reference group) (N=7,591).

	Eyes Open		Eyes Closed			
	$<$15sec	15–29.9sec	5–9.9sec	10–14.9sec	15–29.9sec	30sec
Own highest qualification (46y)						
Degree and higher	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Advance and vocational qual.	1.27 (0.92, 1.76)	1.34 (0.94, 1.92)	0.94 (0.76, 1.17)	0.98 (0.75, 1.28)	0.91 (0.72, 1.17)	0.59 (0.46, 0.76)
GCSEs	1.46 (1.13, 1.89)	1.78 (1.35, 2.36)	0.80 (0.67, 0.95)	0.85 (0.69, 1.06)	0.72 (0.59, 0.89)	0.46 (0.37, 0.56)
No qualification	2.30 (1.78, 2.97)	1.78 (1.33, 2.38)	0.93 (0.78, 1.12)	0.92 (0.74, 1.15)	0.74 (0.60, 0.91)	0.49 (0.40, 0.61)
p-values (test for trend)	<0.001	<0.001	0.141	0.147	0.147	0.147

Note: results are combined from analyses run across 50 imputed datasets; † Relative Risk Ratio with 95% Confidence Interval.

APPENDIX C

UKB supplementary materials

C.1 Missing data and variables for multiple imputation in the UKB

Table C.1.1: Variables used in multiple imputation for grip strength analyses (N=497,844).

Variable	Type of variable	Method used to predict missing data	N (%)* with data on this variable
Exposure variable			
Highest qualification	Ordinal	CART	489,969 (98.4%)
Index of Multiple Deprivation	Ordinal	CART	485,244 (97.5%)
Occupational class (NS-SEC)	Ordinal	CART	497,844 (100%)†
Covariates			
Height	Continuous	CART	497,099 (99.9%)
Waist circumference	Continuous	CART	497,466 (99.9%)
Hip circumference	Continuous	CART	497,411 (99.9%)
Body fat percentage	Continuous	CART	489,329 (98.3%)
Co-morbidity	Ordinal	CART	481,935 (96.5%)
Smoking status	Ordinal	CART	495,949 (99.6%)
Sedentariness	Ordinal	CART	486,595 (97.7%)
Vigorous physical activity	Ordinal	CART	471,688 (94.7%)
Occupational activity	Ordinal	CART	459,599 (92.3%)†

* For the percentage reported, the numerator is the observed data divided by the denominator (total analytic sample size: n=497,844); † The maximum sample size for those in employment was 322,666. However, those who had never worked or were unemployed (N=175,178) were re-categorized in the occupational class and occupational activity variables from ”missing” to ”never worked/unemployed” in order to prevent the multiple imputation models from imputing these missing values. As a result, the maximum sample size in the occupational class became 497,844; CART: Classification and Regression Trees.

C.2 Predictors of missingness in the UKB

Table C.2.1: A comparison of the distributions of variables included in the multiple imputation models by completeness of data for grip strength analyses within the UKB.

Factors	Total N *	Mean (SD) or N (%)* No missing data (N=390,532) ‡	Incomplete data (N=107,312) ‡	p-val[b]
Highest educational qualification	489,969			<0.001
Degree & higher		132,285 (34)	28,136 (28)	
A-levels, profess., or equiv.		91,721 (23)	21,577 (22)	
O-levels, CSEs, or equiv.		107,630 (28)	23,913 (24)	
No qualification		58,896 (15)	25,811 (26)	
Index of Multiple Deprivation	485,244			<0.001
1 (most affluent)		81,920 (21)	15,637 (17)	
2		79,522 (20)	17,771 (19)	
3		78,616 (20)	18,434 (19)	
4		76,845 (20)	20,060 (21)	
5 (least affluent)		73,629 (19)	22,810 (24)	
Occupational class (NS-SEC)	497,844			<0.001
Managerial/professional occupations		138,283 (35)	37,138 (35)	
Intermediate occupations		44,647 (11)	14,636 (14)	
Small employers & owner account workers		13,081 (3.3)	3,791 (3.5)	
Lower supervisory & technical occupations		10,290 (2.6)	3,274 (3.1)	
Semi-routine/routine occupations		40,741 (10)	16,785 (16)	
Never worked/unemployed		143,490 (37)	31,688 (30)	
Height (cm) (Mean (SD))	497,099	168.8 (9)	167.3 (9)	<0.001
Waist circumference (cm) (Mean (SD))	497,365	90.1 (13)	91.1 (14)	<0.001
Hip circumference (cm) (Mean (SD))	497,411	103.3 (9)	103.6 (10)	<0.001
Body fat percentage (%) (Mean (SD))	489,329	31.2 (9)	32.4 (9)	<0.001
Co-morbidity	481,935			<0.001
No condition		195,618 (50)	37,014 (40)	
1 condition		119,472 (31)	29,473 (32)	
2 conditions		55,624 (14)	17,199 (19)	
3+ conditions		19,818 (5.1)	7,717 (8.4)	
Smoking status	495,949			<0.001
Never		215,579 (55)	56,069 (53)	
Previous		134,381 (34)	37,519 (36)	

Factors	Total N *	Mean (SD) or N (%)† No missing data (N=390,532) †	Incomplete data (N=107,312) ‡	p-val[b]
Current		40,572 (10)	11,829 (11)	
Sedentariness	486,595			<0.001
1hr or less a day		39,817 (10)	8,241 (8.6)	
2hrs a day		74,962 (19)	13,903 (14)	
3hrs a day		88,879 (23)	19,287 (20)	
4hrs a day		75,729 (19)	20,050 (21)	
5hrs a day		47,845 (12)	14,254 (15)	
6hrs or more a day		63,300 (16)	20,328 (21)	
Vigorous physical activity	471,688			<0.001
None		145,225 (37)	31,699 (39)	
1 day a week		55,667 (14)	10,777 (13)	
2 days a week		61,926 (16)	12,638 (16)	
3 days a week		53,924 (14)	10,963 (14)	
4+ days a week		73,790 (19)	15,079 (19)	
Occupational activity	459,599			<0.001
No manual, No standing/walking		88,972 (23)	11,241 (16)	
No manual, Some standing/walking		55,157 (14)	7,316 (11)	
No manual, Mostly standing/walking		23,197 (5.9)	3,794 (5.5)	
Some manual, Some standing/walking		18,773 (4.8)	3,056 (4.4)	
Some manual, Mostly standing/walking		29,553 (7.6)	5,462 (7.9)	
Mostly manual, Mostly standing/walking		31,390 (8.0)	6,510 (9.4)	
Never worked/unemployed		143,490 (37)	31,688 (46)	

* Maximum N, though N varies due to missing data on each SEP indicator; † Those participants in the main analytic sample (N=497,844) who have complete data for all key variables (highest educational qualification, index of multiple deprivation, occupational class, height, co-morbidity, smoking status, sedentariness , vigorous physical activity (10min+), occupational activity, grip strength, age, sex and ethnicity); ‡ Those participants in the main analytic sample who have missing data on at least one key variable (highest educational qualification, index of multiple deprivation, occupational class, height, co-morbidity, smoking status, sedentariness , vigorous physical activity (10min+), occupational activity). [b] Statistical tests of sex difference: chi-square test of independence or t-test.

C.3 Tables for the UKB analyses

C.3.1 Tables for SEP and grip strength associations by age and sex

Table C.3.1: Interaction table: Unadjusted associations between SEP and grip strength in 497,844 men and women in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Socioeconomic indicators	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Highest qualification						
Men						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.74 (0.41, 1.07)	0.49 (0.20, 0.78)	0.15 (-0.10, 0.40)	0.02 (-0.20, 0.24)	-0.13 (-0.31, 0.06)	-0.23 (-0.44, -0.03)
O-levels, CSEs, or equiv.	1.39 (1.10, 1.67)	0.51 (0.25, 0.76)	-0.05 (-0.29, 0.20)	-0.40 (-0.63, -0.17)	-0.63 (-0.83, -0.43)	-0.78 (-1.01, -0.56)
No qualification	-1.85 (-2.40, -1.29)	-2.36 (-2.79, -1.93)	-2.06 (-2.38, -1.73)	-2.03 (-2.29, -1.76)	-1.89 (-2.08, -1.69)	-1.66 (-1.85, -1.46)
Women						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.59 (-0.78, -0.39)	-0.70 (-0.87, -0.52)	-0.80 (-0.96, -0.65)	-0.83 (-0.97, -0.69)	-0.71 (-0.84, -0.58)	-0.56 (-0.72, -0.40)
O-levels, CSEs, or equiv.	-1.02 (-1.20, -0.84)	-1.21 (-1.36, -1.06)	-1.29 (-1.43, -1.14)	-1.18 (-1.32, -1.04)	-1.01 (-1.14, -0.89)	-0.85 (-1.01, -0.70)
No qualification	-3.30 (-3.71, -2.88)	-3.38 (-3.69, -3.07)	-2.89 (-3.10, -2.68)	-2.46 (-2.63, -2.30)	-1.92 (-2.05, -1.79)	-1.62 (-1.76, -1.47)
IMD						
Men						
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	0.20 (-0.22, 0.61)	-0.01 (-0.37, 0.34)	-0.04 (-0.35, 0.28)	-0.17 (-0.44, 0.09)	-0.27 (-0.49, -0.06)	-0.36 (-0.58, -0.13)
3	-0.06 (-0.47, 0.36)	-0.48 (-0.83, -0.13)	-0.33 (-0.64, -0.01)	-0.73 (-1.00, -0.46)	-0.68 (-0.90, -0.46)	-0.48 (-0.71, -0.25)
4	-1.23 (-1.62, -0.84)	-1.16 (-1.51, -0.82)	-1.55 (-1.86, -1.24)	-1.50 (-1.77, -1.23)	-1.33 (-1.55, -1.11)	-1.22 (-1.45, -0.99)
5 (least affluent)	-2.28 (-2.66, -1.90)	-2.70 (-3.03, -2.37)	-2.96 (-3.27, -2.65)	-3.01 (-3.28, -2.74)	-2.76 (-2.98, -2.53)	-2.43 (-2.67, -2.20)
Women						
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	0.05 (-0.20, 0.30)	-0.13 (-0.34, 0.08)	-0.18 (-0.37, 0.01)	-0.14 (-0.31, 0.03)	-0.04 (-0.18, 0.10)	-0.12 (-0.28, 0.04)
3	-0.25 (-0.51, 0.00)	-0.32 (-0.53, -0.11)	-0.36 (-0.55, -0.17)	-0.36 (-0.53, -0.19)	-0.32 (-0.46, -0.18)	-0.38 (-0.54, -0.21)
4	-0.66 (-0.90, -0.41)	-0.84 (-1.05, -0.63)	-0.88 (-1.07, -0.69)	-0.73 (-0.90, -0.56)	-0.71 (-0.86, -0.57)	-0.65 (-0.81, -0.49)
5 (least affluent)	-1.38 (-1.62, -1.14)	-1.51 (-1.71, -1.30)	-1.65 (-1.84, -1.46)	-1.56 (-1.73, -1.39)	-1.29 (-1.44, -1.14)	-1.09 (-1.26, -0.92)

Note: results are combined from analyses run across 12 imputed datasets; * 269 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests for age and SEP interaction in men and women: $p < 0.0001$); † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.2: Associations between highest qualification and grip strength in 271,122 women* in the UKB.

Highest qualification	Coefficient (95% CI)†
Model 1	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.73 (-0.80, -0.67)
O-levels, CSEs, or equiv.	-1.11 (-1.17, -1.05)
No qualification	-2.18 (-2.25, -2.11)
Model 2	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.46 (-0.52, -0.40)
O-levels, CSEs, or equiv.	-0.78 (-0.84, -0.73)
No qualification	-1.42 (-1.49, -1.35)
Model 3	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.39 (-0.45, -0.33)
O-levels, CSEs, or equiv.	-0.70 (-0.75, -0.64)
No qualification	-1.28 (-1.35, -1.21)
Model 4	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.35 (-0.41, -0.29)
O-levels, CSEs, or equiv.	-0.64 (-0.70, -0.58)
No qualification	-1.13 (-1.20, -1.06)
Model 5	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.38 (-0.44, -0.32)
O-levels, CSEs, or equiv.	-0.68 (-0.73, -0.62)
No qualification	-1.15 (-1.22, -1.08)

Note: results are combined from analyses run across 12 imputed datasets; * 187 women unable to complete the grip strength tests for health reasons were included; Model 1: age-adjusted (p-values from formal tests for age and SEP interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; Model 5: adjusted for Model 4 + ethnicity; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.3: Associations between highest qualification and grip strength in 226,722 men* in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.74 (0.41, 1.07)	0.49 (0.20, 0.78)	0.15 (-0.10, 0.40)	0.02 (-0.20, 0.24)	-0.13 (-0.31, 0.06)	-0.23 (-0.44, -0.03)
O-levels, CSEs, or equiv.	1.39 (1.10, 1.67)	0.51 (0.25, 0.76)	-0.05 (-0.29, 0.20)	-0.40 (-0.63, -0.17)	-0.63 (-0.83, -0.43)	-0.78 (-1.01, -0.56)
No qualification	-1.85 (-2.40, -1.29)	-2.36 (-2.79, -1.93)	-2.06 (-2.38, -1.73)	-2.03 (-2.29, -1.76)	-1.89 (-2.08, -1.69)	-1.66 (-1.85, -1.46)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.07 (0.75, 1.39)	0.80 (0.52, 1.08)	0.59 (0.35, 0.83)	0.49 (0.28, 0.70)	0.33 (0.15, 0.50)	0.14 (-0.05, 0.34)
O-levels, CSEs, or equiv.	1.86 (1.60, 2.13)	0.99 (0.75, 1.23)	0.50 (0.27, 0.74)	0.09 (-0.13, 0.31)	-0.23 (-0.42, -0.04)	-0.48 (-0.70, -0.27)
No qualification	-0.50 (-1.03, 0.03)	-0.97 (-1.39, -0.56)	-0.76 (-1.07, -0.44)	-0.74 (-0.99, -0.49)	-0.77 (-0.96, -0.58)	-0.68 (-0.87, -0.49)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.19 (0.88, 1.51)	0.93 (0.65, 1.21)	0.73 (0.49, 0.98)	0.64 (0.43, 0.85)	0.46 (0.28, 0.64)	0.28 (0.08, 0.47)
O-levels, CSEs, or equiv.	2.06 (1.79, 2.33)	1.17 (0.92, 1.41)	0.66 (0.43, 0.90)	0.26 (0.04, 0.48)	-0.08 (-0.27, 0.11)	-0.34 (-0.55, -0.12)
No qualification	-0.17 (-0.70, 0.36)	-0.68 (-1.10, -0.26)	-0.46 (-0.78, -0.14)	-0.45 (-0.70, -0.19)	-0.50 (-0.69, -0.31)	-0.42 (-0.61, -0.23)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.99 (0.68, 1.31)	0.76 (0.48, 1.04)	0.56 (0.32, 0.81)	0.59 (0.37, 0.80)	0.44 (0.25, 0.62)	0.22 (0.02, 0.42)
O-levels, CSEs, or equiv.	1.47 (1.18, 1.76)	0.74 (0.47, 1.00)	0.38 (0.14, 0.63)	0.19 (-0.03, 0.42)	-0.08 (-0.28, 0.11)	-0.39 (-0.60, -0.17)
No qualification	0.12 (-0.43, 0.68)	-0.47 (-0.91, -0.03)	-0.28 (-0.62, 0.06)	-0.29 (-0.56, -0.02)	-0.41 (-0.61, -0.21)	-0.48 (-0.68, -0.29)

Note: results are combined from analyses run across 12 imputed datasets; * 82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests for age and SEP interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline. † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.4: Associations between IMD and grip strength in 497,844 men and women in the UKB.

	Model 1	Model 2	Model 3	Model 4	Model 5
IMD (quintiles)	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Men					
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	-0.17 (-0.28, -0.05)	0.04 (-0.07, 0.15)	0.07 (-0.04, 0.18)	0.03 (-0.08, 0.14)	0.02 (-0.08, 0.13)
3	-0.51 (-0.63, -0.40)	-0.13 (-0.24, -0.03)	-0.07 (-0.18, 0.04)	-0.11 (-0.22, 0.00)	-0.10 (-0.21, 0.01)
4	-1.35 (-1.46, -1.23)	-0.70 (-0.81, -0.60)	-0.60 (-0.70, -0.49)	-0.61 (-0.72, -0.50)	-0.55 (-0.65, -0.44)
5 (least affluent)	-2.72 (-2.83, -2.60)	-1.63 (-1.74, -1.52)	-1.45 (-1.56, -1.34)	-1.31 (-1.43, -1.20)	-1.24 (-1.35, -1.13)
Women					
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	-0.10 (-0.17, -0.02)	0.01 (-0.06, 0.08)	0.03 (-0.04, 0.10)	0.05 (-0.02, 0.12)	0.05 (-0.02, 0.12)
3	-0.34 (-0.41, -0.26)	-0.14 (-0.21, -0.07)	-0.09 (-0.16, -0.02)	-0.05 (-0.12, 0.01)	-0.05 (-0.12, 0.02)
4	-0.74 (-0.82, -0.67)	-0.42 (-0.49, -0.34)	-0.32 (-0.40, -0.25)	-0.24 (-0.32, -0.17)	-0.22 (-0.29, -0.15)
5 (least affluent)	-1.41 (-1.48, -1.33)	-0.85 (-0.92, -0.78)	-0.69 (-0.76, -0.62)	-0.52 (-0.59, -0.45)	-0.54 (-0.61, -0.47)

Note: results are combined from analyses run across 12 imputed datasets; 239 participants unable to complete the grip strength tests for health reasons were included; Model 1: age-adjusted (p-values from formal tests for age and SEP interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; Model 5: adjusted for Model 4 + ethnicity; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

C.3.2 Tables for ethnicity and grip strength associations

Table C.3.5: Interaction table: Unadjusted associations between ethnicity and grip strength in 497,844 men and women in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Ethnicity	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Men						
White	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
South Asian	-7.42 (-7.99, -6.85)	-6.71 (-7.30, -6.11)	-7.47 (-8.06, -6.88)	-7.86 (-8.45, -7.26)	-7.87 (-8.48, -7.26)	-7.66 (-8.23, -7.09)
Black	-0.92 (-1.59, -0.25)	-0.25 (-0.90, 0.39)	0.20 (-0.49, 0.89)	-0.24 (-1.05, 0.57)	-1.79 (-2.68, -0.90)	-1.64 (-2.46, -0.82)
Other	-4.43 (-5.22, -3.65)	-4.79 (-5.56, -4.01)	-4.45 (-5.29, -3.62)	-5.04 (-5.90, -4.18)	-5.08 (-5.98, -4.17)	-3.42 (-4.42, -2.42)
Mixed	-0.15 (-1.28, 0.98)	-0.08 (-1.22, 1.06)	0.27 (-1.08, 1.62)	-0.74 (-2.09, 0.60)	-1.09 (-2.43, 0.25)	-0.22 (-1.72, 1.27)
Women						
White	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
South Asian	-5.30 (-5.74, -4.86)	-5.29 (-5.71, -4.87)	-5.38 (-5.79, -4.97)	-5.51 (-5.93, -5.08)	-4.95 (-5.38, -4.51)	-4.46 (-4.98, -3.94)
Black	0.34 (-0.08, 0.76)	0.62 (0.25, 0.99)	0.43 (0.04, 0.83)	0.59 (0.11, 1.06)	0.36 (-0.16, 0.87)	1.25 (0.71, 1.78)
Other	-2.35 (-2.85, -1.86)	-2.80 (-3.27, -2.34)	-2.54 (-2.99, -2.09)	-2.56 (-3.01, -2.10)	-1.86 (-2.38, -1.34)	-1.28 (-1.94, -0.61)
Mixed	0.09 (-0.53, 0.70)	0.30 (-0.28, 0.88)	0.03 (-0.61, 0.68)	-0.56 (-1.30, 0.19)	-0.14 (-0.91, 0.63)	-0.96 (-1.87, -0.04)

Note: results are combined from analyses run across 12 imputed datasets; * 269 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests for age and ethnicity interaction in men and women: p <0.001); † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.6: Associations between ethnicity and grip strength in 497,844 men and women in the UKB.

	Model 1	Model 2	Model 3	Model 4
Ethnicity	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Men				
White	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
South Asian	-7.47 (-7.71, -7.23)	-5.17 (-5.40, -4.94)	-5.01 (-5.23, -4.78)	-4.85 (-5.08, -4.63)
Black	-0.63 (-0.93, -0.34)	0.34 (0.06, 0.62)	0.20 (-0.08, 0.48)	0.35 (0.07, 0.63)
Other	-4.60 (-4.94, -4.26)	-2.58 (-2.90, -2.25)	-2.62 (-2.94, -2.29)	-2.47 (-2.79, -2.15)
Mixed	-0.30 (-0.81, 0.21)	0.29 (-0.20, 0.78)	0.24 (-0.25, 0.73)	0.28 (-0.21, 0.76)
Women				
White	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
South Asian	-5.20 (-5.38, -5.03)	-3.45 (-3.62, -3.28)	-3.32 (-3.49, -3.14)	-3.32 (-3.49, -3.15)
Black	0.56 (0.38, 0.73)	0.82 (0.65, 0.99)	1.06 (0.89, 1.23)	1.18 (1.01, 1.35)
Other	-2.36 (-2.56, -2.16)	-1.11 (-1.31, -0.92)	-1.14 (-1.33, -0.95)	-1.06 (-1.25, -0.87)
Mixed	-0.07 (-0.35, 0.21)	0.31 (0.04, 0.58)	0.35 (0.08, 0.61)	0.39 (0.13, 0.66)

Note: results are combined from analyses run across 12 imputed datasets; 239 participants unable to complete the grip strength tests for health reasons were included; Model 1: age-adjusted (p-values from formal tests for age and ethnicity interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline. † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

C.3.3 Tables for SEP and grip strength associations by age, sex and ethnicity

Table C.3.7: Interaction table: Unadjusted associations between SEP and grip strength in 497,844 men and women in the UKB stratified by ethnicity.

	White	South Asian	Black	Mixed	Other
Socioeconomic indicators	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Highest qualification					
Men					
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.45 (-0.55, -0.35)	-0.81 (-1.53, -0.09)	0.17 (-0.77, 1.12)	0.03 (-1.50, 1.56)	-0.28 (-1.23, 0.67)
O-levels, CSEs, or equiv.	0.01 (-0.09, 0.11)	-1.04 (-1.72, -0.37)	2.29 (1.32, 3.25)	1.63 (0.06, 3.20)	-0.03 (-1.17, 1.10)
No qualification	-3.35 (-3.46, -3.24)	-3.27 (-4.00, -2.54)	-1.41 (-2.47, -0.36)	-1.87 (-3.63, -0.11)	-2.69 (-3.75, -1.63)
Women					
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-1.17 (-1.24, -1.10)	-0.81 (-1.33, -0.28)	-1.32 (-1.88, -0.76)	-0.49 (-1.34, 0.35)	-0.38 (-0.92, 0.16)
O-levels, CSEs, or equiv.	-1.43 (-1.49, -1.36)	-0.91 (-1.39, -0.42)	-0.59 (-1.13, -0.04)	-0.51 (-1.30, 0.28)	-0.53 (-1.12, 0.06)
No qualification	-3.75 (-3.83, -3.68)	-2.76 (-3.28, -2.23)	-3.66 (-4.37, -2.94)	-3.19 (-4.29, -2.09)	-1.97 (-2.64, -1.29)
IMD					
Men					
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	-0.16 (-0.27, -0.04)	-0.75 (-1.84, 0.33)	0.23 (-2.37, 2.83)	0.35 (-1.92, 2.62)	0.83 (-0.64, 2.30)
3	-0.37 (-0.49, -0.25)	-1.67 (-2.68, -0.66)	-1.54 (-4.10, 1.02)	0.15 (-2.04, 2.33)	-1.48 (-2.89, -0.07)
4	-0.93 (-1.05, -0.81)	-2.26 (-3.18, -1.34)	-1.98 (-4.34, 0.38)	-2.03 (-4.11, 0.06)	-1.55 (-2.85, -0.25)
5 (least affluent)	-2.11 (-2.23, -1.99)	-2.30 (-3.20, -1.40)	-3.17 (-5.44, -0.91)	-1.93 (-3.86, 0.00)	-1.43 (-2.61, -0.24)
Women					
1 (most affluent)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
2	-0.11 (-0.18, -0.03)	-0.43 (-1.19, 0.32)	1.17 (-0.35, 2.69)	0.68 (-0.53, 1.90)	-0.13 (-0.95, 0.69)
3	-0.28 (-0.36, -0.20)	-0.96 (-1.66, -0.26)	0.46 (-0.93, 1.86)	0.08 (-1.11, 1.28)	-0.27 (-1.06, 0.52)
4	-0.54 (-0.62, -0.46)	-1.60 (-2.24, -0.96)	0.55 (-0.71, 1.81)	0.24 (-0.89, 1.38)	-0.57 (-1.29, 0.16)
5 (least affluent)	-1.10 (-1.18, -1.02)	-1.73 (-2.38, -1.09)	-0.49 (-1.71, 0.73)	0.33 (-0.74, 1.40)	-1.00 (-1.69, -0.30)

Note: results are combined from analyses run across 12 imputed datasets; * 269 participants unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests for age and ethnicity interaction in men and women: p <0.001); † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.8: Associations between highest qualification and grip strength in 214,541 White men in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.56 (0.21, 0.90)	0.37 (0.07, 0.67)	0.05 (-0.20, 0.31)	-0.03 (-0.25, 0.19)	-0.20 (-0.39, -0.01)	-0.34 (-0.55, -0.14)
O-levels, CSEs, or equiv.	1.07 (0.78, 1.36)	0.24 (-0.02, 0.50)	-0.20 (-0.45, 0.05)	-0.43 (-0.66, -0.19)	-0.70 (-0.90, -0.50)	-0.89 (-1.12, -0.67)
No qualification	-1.19 (-1.81, -0.57)	-2.07 (-2.54, -1.61)	-2.02 (-2.36, -1.68)	-1.98 (-2.24, -1.71)	-1.97 (-2.17, -1.78)	-1.86 (-2.06, -1.66)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.00 (0.67, 1.33)	0.72 (0.43, 1.01)	0.53 (0.29, 0.78)	0.46 (0.24, 0.67)	0.28 (0.10, 0.46)	0.07 (-0.13, 0.27)
O-levels, CSEs, or equiv.	1.70 (1.42, 1.98)	0.83 (0.57, 1.08)	0.40 (0.16, 0.64)	0.08 (-0.15, 0.30)	-0.28 (-0.48, -0.09)	-0.55 (-0.77, -0.34)
No qualification	0.00 (-0.59, 0.60)	-0.78 (-1.23, -0.33)	-0.74 (-1.07, -0.42)	-0.71 (-0.97, -0.45)	-0.85 (-1.04, -0.66)	-0.84 (-1.03, -0.65)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.11 (0.78, 1.44)	0.84 (0.55, 1.13)	0.66 (0.41, 0.91)	0.59 (0.38, 0.81)	0.41 (0.22, 0.59)	0.20 (0.00, 0.40)
O-levels, CSEs, or equiv.	1.87 (1.59, 2.15)	0.99 (0.73, 1.24)	0.54 (0.30, 0.79)	0.23 (0.01, 0.46)	-0.14 (-0.33, 0.06)	-0.41 (-0.63, -0.20)
No qualification	0.31 (-0.29, 0.90)	-0.50 (-0.96, -0.05)	-0.48 (-0.80, -0.15)	-0.45 (-0.71, -0.18)	-0.59 (-0.79, -0.40)	-0.59 (-0.78, -0.40)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.89 (0.56, 1.23)	0.66 (0.36, 0.95)	0.49 (0.24, 0.74)	0.53 (0.31, 0.75)	0.38 (0.20, 0.56)	0.15 (-0.05, 0.35)
O-levels, CSEs, or equiv.	1.22 (0.92, 1.53)	0.52 (0.25, 0.80)	0.24 (-0.01, 0.49)	0.16 (-0.07, 0.39)	-0.13 (-0.33, 0.06)	-0.45 (-0.66, -0.23)
No qualification	0.44 (-0.18, 1.06)	-0.41 (-0.89, 0.07)	-0.38 (-0.74, -0.03)	-0.33 (-0.62, -0.05)	-0.51 (-0.71, -0.30)	-0.64 (-0.84, -0.43)

Note: results are combined from analyses run across 12 imputed datasets. *82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted; Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.9: Associations between occupational class and grip strength in 5,221 South Asian men in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.34 (-1.96, 1.28)	-0.97 (-2.63, 0.68)	0.59 (-1.04, 2.23)	-1.21 (-2.84, 0.42)	-0.53 (-2.17, 1.11)	-1.33 (-2.86, 0.20)
O-levels, CSEs, or equiv.	-0.07 (-1.51, 1.37)	-0.74 (-2.37, 0.89)	-0.75 (-2.30, 0.80)	-2.75 (-4.45, -1.04)	-0.78 (-2.41, 0.84)	-2.22 (-3.66, -0.77)
No qualification	-2.67 (-4.42, -0.91)	-4.12 (-5.96, -2.29)	-3.32 (-5.03, -1.60)	-2.67 (-4.31, -1.02)	-2.74 (-4.38, -1.11)	-2.04 (-3.59, -0.50)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.55 (-2.09, 1.00)	-0.76 (-2.33, 0.81)	0.55 (-1.04, 2.14)	-1.01 (-2.57, 0.54)	-0.54 (-2.15, 1.06)	-1.10 (-2.57, 0.38)
O-levels, CSEs, or equiv.	0.00 (-1.37, 1.37)	-0.69 (-2.23, 0.85)	-0.66 (-2.15, 0.84)	-2.52 (-4.16, -0.88)	-0.83 (-2.42, 0.75)	-2.12 (-3.52, -0.72)
No qualification	-2.09 (-3.79, -0.40)	-3.39 (-5.14, -1.64)	-2.70 (-4.39, -1.00)	-2.50 (-4.07, -0.93)	-2.43 (-4.02, -0.83)	-2.01 (-3.50, -0.52)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.39 (-1.92, 1.14)	-0.66 (-2.21, 0.90)	0.72 (-0.86, 2.31)	-0.77 (-2.30, 0.77)	-0.31 (-1.89, 1.27)	-0.99 (-2.47, 0.48)
O-levels, CSEs, or equiv.	0.21 (-1.15, 1.57)	-0.38 (-1.92, 1.15)	-0.39 (-1.89, 1.11)	-2.17 (-3.79, -0.55)	-0.59 (-2.15, 0.98)	-2.05 (-3.45, -0.66)
No qualification	-1.62 (-3.32, 0.08)	-2.97 (-4.73, -1.20)	-2.12 (-3.85, -0.38)	-1.77 (-3.36, -0.19)	-2.23 (-3.81, -0.66)	-1.81 (-3.31, -0.31)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.51 (-2.05, 1.04)	-0.67 (-2.25, 0.90)	1.06 (-0.55, 2.66)	-0.34 (-1.89, 1.22)	0.03 (-1.54, 1.60)	-0.81 (-2.32, 0.70)
O-levels, CSEs, or equiv.	0.39 (-1.03, 1.82)	-0.30 (-1.89, 1.28)	-0.17 (-1.71, 1.36)	-1.47 (-3.13, 0.19)	0.01 (-1.57, 1.59)	-1.99 (-3.46, -0.51)
No qualification	-0.85 (-2.64, 0.95)	-2.25 (-4.13, -0.37)	-0.88 (-2.71, 0.96)	-0.77 (-2.45, 0.90)	-1.42 (-3.06, 0.21)	-1.74 (-3.31, -0.17)

Note: results are combined from analyses run across 12 imputed datasets. *82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted; Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.10: Associations between occupational class and grip strength in 3,355 Black men in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.47 (-0.47, 3.40)	1.51 (-0.46, 3.49)	0.97 (-1.11, 3.05)	-0.28 (-2.56, 2.01)	0.41 (-2.45, 3.27)	-0.40 (-3.26, 2.47)
O-levels, CSEs, or equiv.	2.67 (0.83, 4.51)	3.69 (1.82, 5.56)	2.48 (0.34, 4.62)	-1.02 (-3.41, 1.37)	0.20 (-3.01, 3.41)	1.32 (-2.41, 5.06)
No qualification	-1.79 (-4.57, 1.00)	1.07 (-1.46, 3.60)	1.27 (-1.20, 3.73)	-0.29 (-2.94, 2.36)	0.36 (-2.49, 3.21)	1.77 (-0.81, 4.35)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.49 (-0.41, 3.39)	1.67 (-0.23, 3.57)	1.18 (-0.79, 3.15)	-0.26 (-2.48, 1.96)	0.62 (-2.15, 3.39)	-0.28 (-2.99, 2.44)
O-levels, CSEs, or equiv.	2.30 (0.50, 4.10)	3.68 (1.89, 5.47)	2.51 (0.48, 4.55)	-0.60 (-2.93, 1.73)	0.27 (-2.84, 3.38)	1.34 (-2.23, 4.91)
No qualification	-2.03 (-4.75, 0.69)	1.32 (-1.12, 3.75)	0.85 (-1.49, 3.19)	-0.21 (-2.79, 2.36)	0.53 (-2.23, 3.29)	1.48 (-0.96, 3.93)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.52 (-0.37, 3.42)	1.79 (-0.10, 3.68)	1.13 (-0.82, 3.07)	-0.27 (-2.44, 1.91)	0.87 (-1.89, 3.63)	-0.30 (-2.95, 2.36)
O-levels, CSEs, or equiv.	2.06 (0.27, 3.85)	3.69 (1.91, 5.48)	2.33 (0.30, 4.35)	-0.44 (-2.72, 1.85)	0.10 (-3.00, 3.19)	0.96 (-2.56, 4.48)
No qualification	-2.12 (-4.84, 0.60)	1.38 (-1.05, 3.81)	0.82 (-1.53, 3.18)	-0.23 (-2.78, 2.31)	0.48 (-2.26, 3.22)	1.21 (-1.17, 3.60)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.49 (-0.42, 3.41)	1.99 (0.07, 3.90)	1.38 (-0.60, 3.37)	-0.55 (-2.84, 1.75)	1.28 (-1.53, 4.09)	0.07 (-2.66, 2.80)
O-levels, CSEs, or equiv.	1.82 (-0.03, 3.67)	3.71 (1.87, 5.55)	2.30 (0.22, 4.39)	-0.51 (-2.88, 1.85)	0.25 (-3.00, 3.49)	0.94 (-2.71, 4.58)
No qualification	-1.36 (-4.26, 1.55)	1.98 (-0.56, 4.53)	2.28 (-0.23, 4.78)	-0.01 (-2.77, 2.76)	1.26 (-1.69, 4.22)	0.98 (-1.50, 3.46)

Note: results are combined from analyses run across 12 imputed datasets. *82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted; Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.11: Associations between highest qualification and grip strength in 2,506 men of other ethnicity in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.59 (-1.67, 2.85)	0.03 (-2.00, 2.05)	-1.03 (-3.31, 1.25)	0.52 (-1.72, 2.76)	-1.90 (-4.32, 0.53)	-0.04 (-2.90, 2.81)
O-levels, CSEs, or equiv.	3.08 (0.56, 5.60)	-1.90 (-4.38, 0.59)	-0.04 (-2.93, 2.85)	-1.22 (-3.89, 1.46)	-1.29 (-4.22, 1.64)	0.98 (-2.79, 4.74)
No qualification	-1.89 (-4.34, 0.56)	-5.06 (-7.37, -2.76)	-2.37 (-4.95, 0.21)	-4.77 (-7.54, -2.00)	-1.68 (-4.52, 1.17)	0.46 (-2.52, 3.43)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.11 (-2.04, 2.25)	0.58 (-1.35, 2.52)	-1.11 (-3.28, 1.05)	0.93 (-1.22, 3.07)	-1.54 (-3.85, 0.77)	0.08 (-2.56, 2.73)
O-levels, CSEs, or equiv.	3.34 (0.95, 5.73)	-1.01 (-3.38, 1.36)	0.34 (-2.41, 3.09)	-1.05 (-3.64, 1.53)	-1.24 (-4.03, 1.56)	0.46 (-2.98, 3.89)
No qualification	-0.71 (-3.06, 1.64)	-4.01 (-6.26, -1.76)	-1.48 (-3.95, 0.99)	-3.16 (-5.86, -0.47)	-0.90 (-3.62, 1.82)	-0.58 (-3.35, 2.18)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.23 (-1.92, 2.38)	0.65 (-1.28, 2.59)	-0.80 (-2.98, 1.39)	0.83 (-1.31, 2.98)	-1.38 (-3.72, 0.96)	0.09 (-2.56, 2.73)
O-levels, CSEs, or equiv.	3.60 (1.22, 5.99)	-0.80 (-3.19, 1.59)	0.45 (-2.31, 3.21)	-0.91 (-3.51, 1.68)	-1.41 (-4.20, 1.38)	0.59 (-2.86, 4.04)
No qualification	-0.38 (-2.73, 1.96)	-3.83 (-6.08, -1.57)	-1.08 (-3.57, 1.42)	-2.94 (-5.64, -0.24)	-0.55 (-3.30, 2.20)	-0.50 (-3.26, 2.26)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.20 (-2.09, 2.48)	-0.02 (-2.05, 2.01)	-0.98 (-3.25, 1.30)	1.28 (-0.88, 3.45)	-1.98 (-4.52, 0.55)	0.19 (-2.58, 2.96)
O-levels, CSEs, or equiv.	3.02 (0.51, 5.52)	-1.17 (-3.64, 1.30)	0.88 (-2.02, 3.78)	-0.34 (-3.01, 2.34)	-1.50 (-4.44, 1.43)	0.07 (-3.60, 3.74)
No qualification	-0.34 (-2.88, 2.20)	-3.73 (-6.14, -1.32)	-0.41 (-3.13, 2.31)	-2.55 (-5.34, 0.24)	-0.56 (-3.50, 2.38)	-0.29 (-3.36, 2.78)

Note: results are combined from analyses run across 12 imputed datasets. *82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted; Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.12: Associations between highest qualification and grip strength in 1,099 mixed men in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.34 (-2.66, 3.35)	3.37 (-0.01, 6.76)	-1.72 (-5.90, 2.45)	2.45 (-0.96, 5.86)	1.05 (-2.81, 4.91)	-4.88 (-9.50, -0.25)
O-levels, CSEs, or equiv.	2.42 (-0.66, 5.49)	2.79 (-0.35, 5.93)	1.46 (-2.43, 5.36)	-0.33 (-4.20, 3.55)	1.39 (-2.91, 5.70)	-0.23 (-6.10, 5.64)
No qualification	2.80 (-1.71, 7.32)	-0.26 (-4.80, 4.28)	-0.25 (-4.60, 4.10)	-5.88 (-10.2, -1.54)	2.69 (-1.23, 6.62)	-3.24 (-7.53, 1.04)
Model 2						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.68 (-2.11, 3.47)	3.55 (0.36, 6.74)	-1.49 (-5.45, 2.46)	2.73 (-0.48, 5.94)	0.82 (-2.89, 4.54)	-3.89 (-8.43, 0.64)
O-levels, CSEs, or equiv.	2.50 (-0.36, 5.36)	2.63 (-0.32, 5.57)	2.09 (-1.59, 5.77)	1.51 (-2.24, 5.26)	1.91 (-2.24, 6.07)	1.18 (-4.70, 7.05)
No qualification	2.72 (-1.48, 6.91)	1.79 (-2.55, 6.12)	0.38 (-3.73, 4.49)	-4.52 (-8.65, -0.40)	3.72 (-0.10, 7.53)	-1.62 (-5.90, 2.67)
Model 3						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	0.87 (-1.95, 3.69)	3.83 (0.63, 7.03)	-1.29 (-5.25, 2.67)	2.67 (-0.52, 5.85)	0.76 (-2.96, 4.47)	-3.71 (-8.19, 0.77)
O-levels, CSEs, or equiv.	2.57 (-0.29, 5.44)	2.81 (-0.17, 5.78)	2.08 (-1.59, 5.76)	1.70 (-2.03, 5.43)	2.12 (-2.03, 6.26)	0.71 (-5.10, 6.52)
No qualification	2.90 (-1.32, 7.12)	2.04 (-2.32, 6.39)	0.37 (-3.76, 4.50)	-4.02 (-8.18, 0.13)	3.74 (-0.05, 7.52)	-1.30 (-5.53, 2.93)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.13 (-3.07, 2.82)	3.95 (0.66, 7.24)	-1.23 (-5.54, 3.08)	3.39 (-0.21, 6.98)	0.77 (-3.04, 4.58)	-4.32 (-9.62, 0.97)
O-levels, CSEs, or equiv.	1.82 (-1.30, 4.95)	2.49 (-0.82, 5.79)	1.96 (-2.10, 6.02)	2.50 (-1.67, 6.67)	1.47 (-2.82, 5.76)	1.61 (-4.49, 7.71)
No qualification	1.76 (-2.85, 6.36)	4.28 (-0.69, 9.26)	1.52 (-3.35, 6.39)	-3.37 (-8.03, 1.29)	3.22 (-1.01, 7.44)	-0.77 (-5.26, 3.72)

Note: results are combined from analyses run across 12 imputed datasets; * 82 men unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted; Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline. † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

C.3.4 Tables for occupational class and grip strength associations in men

Table C.3.13: Associations between occupational class and grip strength in 153,324 men* in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to 65 years
Occupational class (NS-SEC)	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.63 (-1.03, -0.24)	-0.49 (-0.85, -0.14)	-0.75 (-1.09, -0.42)	-1.13 (-1.44, -0.81)	-1.08 (-1.37, -0.79)
Small employers & owner account workers	1.40 (0.91, 1.90)	0.63 (0.18, 1.07)	0.29 (-0.11, 0.70)	0.30 (-0.08, 0.69)	-0.35 (-0.67, -0.02)
Lower supervisory & technical occupations	2.85 (2.35, 3.34)	1.45 (1.04, 1.87)	0.91 (0.53, 1.29)	0.43 (0.07, 0.78)	0.01 (-0.30, 0.33)
Semi-routine/routine occupations	-1.30 (-1.66, -0.95)	-1.24 (-1.56, -0.93)	-1.47 (-1.76, -1.18)	-1.65 (-1.92, -1.38)	-1.53 (-1.76, -1.30)
Model 2					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.39 (-0.77, -0.02)	-0.32 (-0.66, 0.02)	-0.46 (-0.78, -0.13)	-0.81 (-1.11, -0.51)	-0.75 (-1.03, -0.47)
Small employers & owner account workers	2.07 (1.60, 2.55)	1.32 (0.90, 1.75)	0.97 (0.58, 1.36)	0.98 (0.61, 1.36)	0.22 (-0.09, 0.53)
Lower supervisory & technical occupations	3.38 (2.90, 3.85)	2.11 (1.71, 2.51)	1.68 (1.32, 2.04)	1.17 (0.83, 1.51)	0.78 (0.48, 1.08)
Semi-routine/routine occupations	-0.31 (-0.65, 0.03)	-0.30 (-0.60, 0.00)	-0.51 (-0.79, -0.23)	-0.73 (-0.98, -0.47)	-0.71 (-0.93, -0.48)
Model 3					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.34 (-0.72, 0.03)	-0.29 (-0.63, 0.05)	-0.42 (-0.74, -0.09)	-0.78 (-1.08, -0.48)	-0.71 (-0.99, -0.43)
Small employers & owner account workers	2.19 (1.71, 2.66)	1.41 (0.98, 1.83)	1.07 (0.68, 1.46)	1.03 (0.66, 1.41)	0.29 (-0.02, 0.60)
Lower supervisory & technical occupations	3.47 (3.00, 3.94)	2.21 (1.81, 2.61)	1.76 (1.40, 2.12)	1.23 (0.89, 1.57)	0.82 (0.51, 1.12)
Semi-routine/routine occupations	-0.19 (-0.53, 0.15)	-0.18 (-0.48, 0.12)	-0.40 (-0.68, -0.12)	-0.64 (-0.90, -0.38)	-0.61 (-0.84, -0.39)
Model 4					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.67 (-1.05, -0.29)	-0.48 (-0.82, -0.14)	-0.50 (-0.82, -0.18)	-0.76 (-1.05, -0.46)	-0.67 (-0.94, -0.39)
Small employers & owner account workers	0.90 (0.38, 1.42)	0.57 (0.12, 1.03)	0.56 (0.14, 0.98)	0.76 (0.37, 1.15)	0.14 (-0.19, 0.47)
Lower supervisory & technical occupations	2.10 (1.58, 2.61)	1.27 (0.83, 1.70)	1.05 (0.66, 1.45)	0.87 (0.49, 1.24)	0.64 (0.30, 0.98)
Semi-routine/routine occupations	-1.36 (-1.75, -0.96)	-1.01 (-1.35, -0.67)	-0.97 (-1.29, -0.65)	-0.90 (-1.19, -0.61)	-0.73 (-0.98, -0.48)

Note: results are combined from analyses run across 12 imputed datasets. * 29 men (employed and of working age) unable to complete the grip strength tests for health reasons were included; Model 1: unadjusted (p-values from formal tests for age and SEP interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline. † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.3.14: Associations between occupational class and grip strength in 153,324 men* in the UKB with individual adjustments for each health and behavioural factors. stratified by age.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to 65 years
Occupational class (NS-SEC)	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 4a					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.33 (-0.71, 0.04)	-0.26 (-0.60, 0.08)	-0.39 (-0.71, -0.07)	-0.74 (1.00, -0.45)	-0.68 (-0.96, -0.41)
Small employers & owner account workers	2.20 (1.72, 2.67)	1.40 (0.98, 1.83)	1.07 (0.68, 1.46)	1.03 (0.65, 1.40)	0.26 (-0.05, 0.57)
Lower supervisory & technical occupations	3.48 (3.01, 3.95)	2.22 (1.82, 2.62)	1.75 (1.39, 2.11)	1.25 (0.92, 1.59)	0.83 (0.53, 1.13)
Semi-routine/routine occupations	-0.16 (-0.50, 0.18)	-0.15 (-0.45, 0.16)	-0.37 (-0.65, -0.09)	-0.60 (-0.86, -0.34)	-0.59 (-0.81, -0.36)
Model 4b					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.34 (-0.72, 0.03)	-0.28 (-0.62, 0.06)	-0.41 (-0.74, -0.09)	-0.79 (1.00, -0.49)	-0.72 (1.00, -0.44)
Small employers & owner account workers	2.15 (1.68, 2.63)	1.37 (0.95, 1.80)	1.04 (0.65, 1.43)	0.99 (0.62, 1.37)	0.27 (-0.04, 0.57)
Lower supervisory & technical occupations	3.45 (2.98, 3.93)	2.20 (1.81, 2.60)	1.74 (1.38, 2.10)	1.19 (0.86, 1.53)	0.80 (0.49, 1.10)
Semi-routine/routine occupations	-0.21 (-0.55, 0.14)	-0.21 (-0.51, 0.10)	-0.44 (-0.72, -0.16)	-0.68 (-0.94, -0.42)	-0.63 (-0.86, -0.41)
Model 4c					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.32 (-0.70, 0.05)	-0.31 (-0.65, 0.03)	-0.43 (-0.75, -0.11)	-0.78 (1.00, -0.49)	-0.71 (-0.99, -0.43)
Small employers & owner account workers	2.16 (1.69, 2.64)	1.40 (0.97, 1.82)	1.06 (0.67, 1.45)	1.02 (0.64, 1.39)	0.26 (-0.05, 0.57)
Lower supervisory & technical occupations	3.46 (2.99, 3.93)	2.19 (1.79, 2.58)	1.74 (1.38, 2.10)	1.21 (0.87, 1.55)	0.78 (0.48, 1.09)
Semi-routine/routine occupations	-0.17 (-0.51, 0.18)	-0.19 (-0.49, 0.11)	-0.41 (-0.69, -0.13)	-0.65 (-0.91, -0.39)	-0.63 (-0.86, -0.41)
Model 4d					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.34 (-0.72, 0.03)	-0.31 (-0.65, 0.03)	-0.39 (-0.72, -0.07)	-0.73 (1.00, -0.44)	-0.67 (-0.94, -0.39)
Small employers & owner account workers	2.02 (1.54, 2.50)	1.28 (0.85, 1.71)	0.98 (0.59, 1.37)	1.00 (0.62, 1.37)	0.25 (-0.06, 0.56)
Lower supervisory & technical occupations	3.34 (2.86, 3.81)	2.08 (1.68, 2.48)	1.68 (1.32, 2.04)	1.19 (0.85, 1.53)	0.78 (0.48, 1.09)
Semi-routine/routine occupations	-0.29 (-0.63, 0.06)	-0.30 (-0.60, 0.01)	-0.46 (-0.75, -0.18)	-0.66 (-0.92, -0.39)	-0.61 (-0.84, -0.39)

Table C.3.14: Associations between occupational class and grip strength in 153,324 men* of working age in the UKB with individual adjustments for each health and behavioural factors, stratified by age.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to 65 years
Occupational class (NS-SEC)	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 4e					
Managerial/professional occupations	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Intermediate occupations	-0.73 (1.00, -0.35)	-0.52 (-0.86, -0.17)	-0.56 (-0.88, -0.23)	-0.83 (1.00, -0.53)	-0.73 (1.00, -0.45)
Small employers & owner account workers	0.91 (0.40, 1.43)	0.60 (0.14, 1.06)	0.56 (0.15, 0.98)	0.79 (0.39, 1.18)	0.18 (-0.15, 0.51)
Lower supervisory & technical occupations	2.06 (1.54, 2.58)	1.26 (0.82, 1.70)	1.06 (0.66, 1.46)	0.85 (0.47, 1.22)	0.62 (0.28, 0.95)
Semi-routine/routine occupations	1.00 (1.00, 1.00)	1.00 (1.00, -0.70)	1.00 (1.00, -0.70)	-0.95 (1.00, -0.66)	-0.78 (1.00, -0.53)

Note: results are combined from analyses run across 12 imputed datasets. * 29 men (employed and of working age) unable to complete the grip strength tests for health reasons were included; P-values from formal tests for age and SEP interaction: p <0.001); Model 3: adjusted for height, waist-to-hip ratio and body fat percentage at baseline; Model 4a: adjusted for Model 3 + co-morbidities at baseline; Model 4b: adjusted for Model 3 + smoking status at baseline; Model 4c: adjusted for Model 3 + sedentariness at baseline; Model 4d: adjusted for Model 3 + physical activity at baseline; Model 4e: adjusted for Model 3 + occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

C.4 Tables for additional analyses in the UKB

Table C.4.1: Height-adjusted associations between highest qualification and grip strength in 226,722 men in the UKB, age stratified.

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.07 (0.75 to 1.38)	0.81 (0.54, 1.09)	0.61 (0.37, 0.85)	0.50 (0.29, 0.71)	0.33 (0.16, 0.51)	0.15 (-0.05, 0.35)
O-levels, CSEs, or equiv.	1.88 (1.62, 2.15)	1.00 (0.76, 1.24)	0.51 (0.27, 0.74)	0.09 (-0.12, 0.31)	-0.23 (-0.42, -0.04)	-0.49 (-0.70, -0.27)
No qualification	-0.45 (-0.98, 0.08)	-0.93 (-1.34, -0.51)	-0.70 (-1.01, -0.38)	-0.71 (-0.97, -0.46)	-0.74 (-0.93, -0.55)	-0.68 (-0.87, -0.49)

Note: results are combined from analyses run across 12 imputed datasets; *82 men unable to complete the grip strength tests for health reasons were included; Model 1: age-adjusted (p-values from formal tests for age and SEP interaction in men:p <0.0001); † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.4.2: Age and height-adjusted associations between SEP and grip strength in 497,844 men and women in the UKB.

Socioeconomic indicators	Coefficient (95% CI)†
Highest qualification	
Women	
Degree & higher	0.00 (ref)
A-levels, profess., or equiv.	-0.46 (-0.52, -0.40)
O-levels, CSEs, or equiv.	-0.79 (-0.84, -0.73)
No qualification	-1.43 (-1.50, -1.36)
IMD	
Men	
1 (most affluent)	0.00 (ref)
2	0.04 (-0.07, 0.15)
3	-0.13 (-0.24, -0.02)
4	-0.71 (-0.82, -0.60)
5 (least affluent)	-1.64 (-1.75, -1.53)
Women	
1 (most affluent)	0.00 (ref)
2	0.01 (-0.06, 0.08)
3	-0.14 (-0.21, -0.07)
4	-0.42 (-0.49, -0.35)
5 (least affluent)	-0.85 (-0.93, -0.78)

Note: results are combined from analyses run across 12 imputed datasets; * 269 men and women were unable to complete the grip strength tests for health reasons were included; Model 1: age and height-adjusted (p-values from formal tests for age and SEP interaction: p <0.001); † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.4.3: Associations between highest qualification and grip strength in UKB men excluding those unable to complete the grip strength assessments for health reasons (N=226,640) (Height adjusted (model 1) and fully-adjusted (model 4) regression models stratified by age).

	Below 45 years	45 to <50 years	50 to <55 years	55 to <60 years	60 to <65 years	Above 65 years
Highest qualification	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Model 1						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.07 (0.75, 1.38)	0.81 (0.53, 1.09)	0.61 (0.36, 0.85)	0.50 (0.29, 0.71)	0.33 (0.16, 0.51)	0.15 (-0.05, 0.35)
O-levels, CSEs, or equiv.	1.88 (1.62, 2.15)	1.00 (0.76, 1.24)	0.51 (0.27, 0.74)	0.09 (-0.13, 0.31)	-0.23 (-0.42, -0.04)	-0.49 (-0.70, -0.27)
No qualification	-0.45 (-0.98, 0.08)	-0.92 (-1.34, -0.51)	-0.69 (-1.01, -0.38)	-0.71 (-0.97, -0.46)	-0.74 (-0.93, -0.55)	-0.68 (-0.87, -0.49)
Model 4						
Degree & higher	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	1.02 (0.70, 1.35)	0.78 (0.49, 1.06)	0.57 (0.32, 0.83)	0.64 (0.41, 0.86)	0.41 (0.21, 0.61)	0.19 (-0.05, 0.42)
O-levels, CSEs, or equiv.	1.50 (1.20, 1.79)	0.71 (0.44, 0.98)	0.35 (0.09, 0.60)	0.19 (-0.05, 0.43)	-0.04 (-0.26, 0.17)	-0.37 (-0.62, -0.12)
No qualification	0.84 (0.21, 1.47)	-0.19 (-0.67, 0.29)	0.06 (-0.31, 0.43)	-0.03 (-0.32, 0.27)	-0.20 (-0.43, 0.02)	-0.37 (-0.60, -0.14)

Note: results are combined from analyses run across 12 imputed datasets; *82 men unable to complete the grip strength tests for health reasons were excluded; Model 1: age-adjusted (p-values from formal tests for age and SEP interaction in men:p <0.0001); Model 1: adjusted for height; Model 4: adjusted for height, waist-to-hip ratio, body fat percentage, co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.4.4: Associations between SEP and grip strength in the UKB excluding those unable to complete the grip strength assessments for health reasons (N=497,575) (age and height adjusted (model 1) and fully-adjusted (model 4) regression models stratified by age).

	Model 1	Model 4
Socioeconomic indicators	Coefficient (95% CI)†	Coefficient (95% CI)†
Highest qualification		
Women		
Degree & higher	0.00 (ref)	0.00 (ref)
A-levels, profess., or equiv.	-0.46 (-0.52, -0.40)	-0.32 (-0.39, -0.26)
O-levels, CSEs, or equiv.	-0.79 (-0.84, -0.73)	-0.64 (-0.70, -0.58)
No qualification	-1.43 (-1.50, -1.36)	-1.03 (-1.11, -0.95)
IMD		
Men		
1 (most affluent)	0.00 (ref)	0.00 (ref)
2	0.04 (-0.07, 0.15)	0.04 (-0.08, 0.15)
3	-0.13 (-0.24, -0.02)	-0.04 (-0.16, 0.08)
4	-0.70 (-0.81, -0.59)	-0.53 (-0.65, -0.42)
5 (least affluent)	-1.63 (-1.74, -1.53)	-1.10 (-1.22, -0.98)
Women		
1 (most affluent)	0.00 (ref)	0.00 (ref)
2	0.01 (-0.06, 0.07)	0.06 (-0.01, 0.14)
3	-0.14 (-0.21, -0.07)	-0.02 (-0.10, 0.06)
4	-0.42 (-0.49, -0.35)	-0.22 (-0.30, -0.14)
5 (least affluent)	-0.85 (-0.92, -0.78)	-0.40 (-0.48, -0.32)

Note: results are combined from analyses run across 12 imputed datasets; * 269 men and women whoe were unable to complete the grip strength tests for health reasons were excluded; Model 1: age and height-adjusted (p-values from formal tests for age and SEP interaction: p <0.001); Model 1: adjusted for age and height; Model 4: adjusted for age, height, waist-to-hip ratio, body fat percentage, co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline; † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).

Table C.4.5: Sensitivity analysis to examine the impact of the different categorisations used for ethnicity in the associations between ethnicity and grip strength in 497,844 men and women in the UKB.

	Model 1	Model 2	Model 3	Model 4
Ethnicity	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†	Coef. (95% CI)†
Men				
White British	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Indian	-7.59 (-7.90, -7.28)	-5.39 (-5.69, -5.09)	-5.25 (-5.55, -4.95)	-5.16 (-5.46, -4.87)
Pakistani	-6.53 (-7.05, -6.02)	-4.55 (-5.04, -4.06)	-4.30 (-4.79, -3.81)	-3.96 (-4.44, -3.47)
Black Caribbean	1.83 (1.41, 2.25)	2.39 (1.99, 2.79)	2.19 (1.79, 2.59)	2.31 (1.91, 2.70)
Black African	-3.05 (-3.46, -2.63)	-1.66 (-2.06, -1.26)	-1.74 (-2.14, -1.34)	-1.56 (-1.95, -1.17)
Chinese	-4.86 (-5.56, -4.15)	-1.95 (-2.63, -1.28)	-2.22 (-2.90, -1.55)	-2.05 (-2.72, -1.38)
Mixed	-0.30 (-0.81, 0.21)	0.29 (-0.20, 0.77)	0.24 (-0.25, 0.72)	0.27 (-0.21, 0.76)
Other	-5.75 (-6.05, -5.44)	-3.61 (-3.91, -3.32)	-3.54 (-3.83, -3.25)	-3.40 (-3.69, -3.11)
Women				
White British	0.00 (ref)	0.00 (ref)	0.00 (ref)	0.00 (ref)
Indian	-5.38 (-5.60, -5.16)	-3.62 (-3.84, -3.41)	-3.49 (-3.71, -3.28)	-3.53 (-3.75, -3.32)
Pakistani	-5.27 (-5.72, -4.82)	-3.67 (-4.11, -3.24)	-3.41 (-3.85, -2.98)	-3.29 (-3.71, -2.86)
Black Caribbean	1.07 (0.85, 1.30)	1.20 (0.99, 1.42)	1.40 (1.18, 1.61)	1.55 (1.34, 1.76)
Black African	-0.39 (-0.68, -0.10)	0.10 (-0.18, 0.38)	0.42 (0.14, 0.70)	0.49 (0.21, 0.77)
Chinese	-2.41 (-2.79, -2.04)	-0.86 (-1.22, -0.49)	-1.13 (-1.49, -0.77)	-1.02 (-1.38, -0.66)
Mixed	-0.07 (-0.35, 0.21)	0.31 (0.04, 0.58)	0.35 (0.08, 0.61)	0.39 (0.13, 0.66)
Other	-2.81 (-3.01, -2.62)	-1.52 (-1.71, -1.33)	-1.45 (-1.64, -1.26)	-1.40 (-1.59, -1.21)

Note: results are combined from analyses run across 12 imputed datasets; 239 participants unable to complete the grip strength tests for health reasons were included; Model 1: age-adjusted (p-values from formal tests for age and ethnicity interaction: p <0.001); Model 2: adjusted for height at baseline; Model 3: adjusted for Model 2 + waist-to-hip ratio and body fat percentage at baseline; Model 4: adjusted for Model 3 + co-morbidities, smoking status, sedentariness, physical activity and occupational activity at baseline. † Coefficient: Difference in mean grip strength (kg) (95% Confidence Interval).