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The health economics of physical inactivity and sedentary behaviour
Healthcare expenditure and cost-effective interventions

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"Medicine is failed prevention"

Sir Michael Marmot

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Abbreviations

ACSM	American College of Sports Medicine
AIC	Akaike information criteria
AUD	Australian dollar
BCC	Belfast City Council
BCI	Behaviour change intervention
BCR	Benefit-cost ratio
BCT	Behaviour change technique
BCW	Behaviour change wheel
BIC	Bayesian information criteria
BMI	Body mass index
CBA	Cost-benefit analysis
CCA	Cost-consequence analysis
CCG	Connswater Community Greenway
CEA	Cost-effectiveness analysis
CENTRAL	Cochrane Central Register of Controlled Trials
CI	Confidence interval
CoDA	Compositional data analysis
CRD	Centre for Reviews and Dissemination
CTTI	Clinical Trials Transformation Initiative
CUA	Cost-utility analysis
CVD	Cardiovascular disease
DALY	Disability-adjusted life-year
DARE	Database of Abstracts of Reviews of Effects
DCEA	Distributional cost-effectiveness analysis
DHT	Digital health technology
EED	Economic Evaluation Databases
EtD	Evidence-to-Decision
EUR	Euro
GAPPA	Global Action Plan for Physical Activity
GBP	British pound
GLM	Generalised linear models

GPAQ	General Practice Assessment Questionnaire
HCHS	Hospital and community health services
HEPA	Health-Enhancing Physical Activity
HES	Hospital Episode Statistics
HSE	Health Survey for England
HTA	Health Technology Assessment
iCAT_SR	Intervention Complexity Assessment Tool for Systematic Reviews
ICER	Incremental cost-effectiveness ratio
IPAQ	International Physical Activity Questionnaire
IQR	Interquartile range
ISBNPA	International Society of Behavioral Nutrition and Physical Activity
ISPAH	International Society for Physical Activity and Health
LMIC	Low-middle income countries
MET	Metabolic equivalents of task
MVPA	Moderate-vigorous physical activity
NHS	National Health Service
NI	Northern Ireland
NICE	National Institute for Clinical Excellence
NMA	Network meta-analysis
NSPV	Net social present value
NZD	New Zealand Dollar
ONS	Office for National Statistics
PAF	Population attributable fraction
PARC	Physical Activity and the Rejuvenation of Connswater
PEDW	Patient Episode Database in Wales
PHI	Public health intervention
PSSRU	Personal Social Services Research Unit
QALY	Quality-adjusted life year
QOL	Quality of life
RCT	Randomised controlled trials
RoB	Risk of bias

RR	Relative risk
SES	Socioeconomic status
SF8	Short Form-8
SROI	Social return-on-investment
STPR	Social time preference rate
T2D	Type 2 diabetes
UGS	Urban green space
UK	United Kingdom
UN	United Nations
US	United States
USD	United States dollar
WEMWBS	Warwick-Edinburgh Mental Wellbeing Scale
WHO	World Health Organization
WTP	Willingness-to-pay

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Abstract

Physical inactivity and sedentary behaviour increase the risk of premature mortality and chronic diseases such as cardiovascular disease (CVD), type 2 diabetes (T2D), and cancers. Globally, the prevalence of these risk factors is increasing, putting many people at increased risk. Physical inactivity and sedentary behaviour are an economic burden due to direct healthcare costs and indirect costs from reduced productivity, increased absenteeism, and other out-of-pocket costs. Previous studies have estimated the healthcare costs associated with physical inactivity using a prevalence-based approach and self-reported data, however no estimates were available for sedentary behaviour and none had estimated the costs using objectively measured data. The Global Action Plan for Physical Activity (GAPPA) from the World Health Organisation (WHO) has set out ambitious targets to reduce physical inactivity by 15% by 2030, however there is no indication that we are on course to meet those goals. Greater understanding of the economic burden of physical inactivity and sedentary behaviour could be used to build a financial case to persuade policymakers to prioritise interventions that can increase activity. Importantly, the interventions to reduce physical inactivity and sedentary behaviour should be both cost-effective overall and reduce existing health inequalities. Therefore, the aim of this thesis was to estimate the direct healthcare costs associated with prolonged sedentary behaviour and physical inactivity in the United Kingdom (UK) and to explore the cost-effectiveness of interventions to reduce physical inactivity, using both individual and population-level perspectives.

Study one (see Chapter 2): The aim of this study was to estimate the annual direct healthcare costs of prolonged sedentary behaviour to the National Health Service (NHS) in the UK. There is moderate-strong evidence that prolonged sedentary behaviour increases the risk of five diseases: CVD, T2D, lung cancer, colon cancer, and endometrial cancer. Population attributable fractions (PAFs) were calculated for these five diseases using relative risks (RRs) extracted from meta-analyses and information on the prevalence of sedentary behaviour. The PAFs represent the proportion of incident cases of the diseases which are attributable to sedentary behaviour in the population. The PAFs were then applied to NHS budgetary data to estimate the proportion of costs attributable to sedentary behaviour. After adjustment for potential double-counting due to comorbidities, the estimated total annual cost to

the NHS was £0.7bn in 2016-17 costs. Sedentary behaviour places a substantial economic burden on the NHS in the UK.

Study two (see Chapter 3): This study aimed to assess the relationship between physical activity level and inpatient healthcare use and costs in a large sample (n = 86,067) of the UK Biobank cohort. The UK Biobank study links sociodemographic and lifestyle information with health data and NHS records, including inpatient hospital records. Participants were divided into tertiles based on their physical activity recorded by accelerometers over one week. Subsequent inpatient hospital episodes were monetised using 2017 unit costs of health and social care from the Personal Social Services Research Unit (PSSRU). Generalised linear models (GLMs), adjusted for potential confounders such as BMI, health status and sociodemographic factors, estimated the differences in monthly days spent as a hospital inpatient and monthly inpatient costs. The more active tertiles spent on average 0.3 and 0.5 fewer days per year as an inpatient and £3.09 and £3.81 less in inpatient costs per month than the least active tertile. The effect of physical activity level on inpatient costs appeared to be stronger in women and the lowest income groups. The findings indicate that policymakers should aim to reduce physical inactivity in the UK population overall and consider interventions that target women and lower-income groups, which may improve health inequalities.

Study three (see Chapter 4): This study aimed to assesses which characteristics of physical activity and sedentary behaviour interventions are associated with cost-effectiveness in healthy adults. A systematic review was conducted to identify economic evaluations of physical activity and sedentary behaviour interventions which had included healthy adults in randomised controlled trial (RCT) studies compared to usual care or a suitable control group. The characteristics of interest were behaviour change techniques (BCTs); complexity measured by the intervention Complexity Assessment Tool for Systematic Reviews (iCAT_SR) tool; and intensity of the interventions measured by intervention duration, number of contact points, and number of contact hours. Thirty-three studies, describing 25 interventions, were eligible for inclusion. Physical activity outcomes were converted to MET-hours where possible and ICERs were calculated based on the cost of the interventions. Cost-effectiveness ranged from £0.04 to £62.82 per metabolic equivalent of task- (MET-) h/week gained. BCT clusters (1) Goals and planning; (2) Feedback and monitoring;

(3) Social support; (4) Shaping knowledge; and (9) Comparison of outcomes were most frequently used in the most cost-effective interventions, indicating that those clusters might be associated with greater cost-effectiveness. In terms of complexity, the more cost-effective interventions were slightly less complex than the less cost-effective interventions. A minimum level of complexity might be necessary to achieve effectiveness; however, increasing complexity may lead to high costs that risk reduced cost-effectiveness. No relationship was identified between intervention intensity and cost-effectiveness. These findings could be useful to researchers developing cost-effective physical activity and sedentary behaviour interventions.

Study four (see Chapter 5): This study aimed to conduct a social return on investment (SROI) of the Connswater Community Greenway (CCG), an urban regeneration project in Belfast, Northern Ireland (NI). The benefits arising from the CCG in eight different areas were explored. There was sufficient evidence available to monetise the benefits in five areas: property values; flood alleviation; tourism; biodiversity; and climate change. Over the CCG's expected lifetime of 40 years, the total social present value was estimated to be between £205,123,322 and £227,689,852. The cost of the CCG is an estimated £40 million. Therefore, the benefit-cost ratio (BCR) of the CCG is between 5.13 and 5.69. The results indicate that the CCG is likely to be a good investment.

In summary, this thesis estimated the economic burden of sedentary behaviour and physical inactivity and explored the cost-effectiveness of interventions to reduce these risk factors. Prolonged sedentary behaviour costs the NHS in the UK £0.7bn annually, after adjusting for confounders including physical activity and body mass index (BMI). Similarly, physical inactivity leads to increased inpatient hospital use and costs in the UK. At a population level, it is likely that physical inactivity costs the NHS hundreds of millions of pounds annually in inpatient costs alone. The effect may be stronger in women and low-income groups, presenting further evidence of health inequalities within the UK population. Physical inactivity and sedentary behaviour present an economic burden to the UK and urgent measures are required to encourage the population to become more active. Public health interventions (PHIs) have the potential to address the growing prevalence of physical inactivity using individual-level and population-level approaches. A systematic review identified certain BCT clusters that may be associated with greater cost-effectiveness in physical activity interventions and found that complexity is important in interventions to achieve behaviour change. The intensity of the intervention did not appear to be associated with its cost-effectiveness. Finally, a SROI of the CCG found that the regeneration of the urban greenway was likely to be a good value investment for Belfast. Although there was insufficient evidence of an increase in physical inactivity in CCG residents, other social benefits identified results in a positive BCR.

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 The aim of the thesis

The aim of this thesis was to estimate the direct healthcare costs associated with prolonged sedentary behaviour and physical inactivity in the United Kingdom (UK) and to explore the cost-effectiveness of interventions to reduce physical inactivity, using both individual and population-level perspectives. Four studies were conducted to achieve these aims. The first two studies focused on the economic costs associated with risk factors. The first of these estimated the direct healthcare costs associated with prolonged sedentary behaviour in the UK using a prevalence-based approach. Then, the second study assessed the inpatient hospital use and costs associated with accelerometer-measured physical inactivity in the UK Biobank study. The subsequent studies shifted focus to interventions with a focus on physical activity and sedentary behaviour. The third study was a systematic review of cost-effectiveness analyses (CEAs) of physical activity interventions. The review explored the association between the characteristics of the interventions and their cost-effectiveness, specifically the behaviour change techniques (BCTs) used, the complexity, and the intensity of the interventions. Finally, the fourth study assessed the Connswater Community Greenway (CCG), an urban regeneration project, using a social return-on-investment analysis (SROI).

1.2 The spectrum of physical activity and health

Physical activity can be considered as a spectrum of energy expenditure ranging from sedentary behaviour to vigorous-intensity physical activity (Figure. 1.1, adapted from Nimmo et al. (2013)). Energy expenditure is commonly expressed in metabolic equivalents of task (METs). Sedentary behaviour is distinct from physical inactivity and refers to sitting or lying while expending less than 1.5 METs (Tremblay et al., 2017). Light-intensity physical activity is equivalent to 1.5-3 METs (e.g., slow walking). Moderate-intensity physical activity includes activities such as brisk walking, yoga, weight training at an intensity of 3-6 METs. At the extreme end of the spectrum, vigorous-intensity physical activity is high-intensity exercise such as running while expending than ≥6 METs.

1.2.1 Health outcomes associated with physical activity

There is substantial evidence that physical inactivity increases the risk of several chronic diseases and all-cause mortality (Physical Activity Guidelines Advisory Committee, 2018; Lee et al., 2012). Achieving the recommended 150 minutes per week of moderate-vigorous physical activity (MVPA) improves sleep, brain function, mental health, and physical function. Perceived quality of life (QOL) is higher in more active people. Physical activity lowers the risk of specific conditions: obesity, dementia, several cancers, osteoarthritis, hypertension, type 2 diabetes (T2D), and cardiovascular disease (CVD). Some health benefits of physical activity happen immediately as blood pressure lowers and insulin sensitivity is improved. Physically active individuals experience long-term health benefits with regular physical activity over the life course.

Evidence is growing on the negative health effects of prolonged sedentary behaviour. Similar to physical inactivity, prolonged sedentary behaviour can increase the risk of all-cause mortality, CVD, T2D, and cancer (colon, endometrial, and lung) (Physical Activity Guidelines Advisory Committee, 2018). Studies have identified that the health risks increase after about 6-8 hours (Patterson et al., 2018) or 9.5 hours (Ekelund et al., 2019b) of sedentary time during waking hours. Although sedentary behaviour has been considered an independent risk factor in many epidemiological studies, more recent evidence has suggested that there is an interaction between MVPA and sedentary behaviour. The risks associated with prolonged sedentary behaviour can be mitigated by high levels of MVPA (Ekelund et al., 2019b, 2019a). Large studies have used both self-reported and accelerometer-measured data in harmonised meta-analyses to demonstrate a non-linear, dose-response relationship between sitting time and mortality risk. National recommendations outline how much physical activity adults should aim to achieve.

1.3 Physical activity guidelines

Adults aged 19-64 years should be active every day, according to UK guidelines (UK Chief Medical Officers, 2019). Ideally, adults should do muscle-strengthening exercises at least twice a week. The guidelines recommend achieving 150 minutes of moderate-intensity physical activity, 75 minutes of vigorous-intensity physical activity, or some combination of the two, in bouts of any length. Furthermore, adults should minimize time spent sedentary. More specific, quantitative recommendations on sedentary time would be premature given the evidence currently available (Stamatakis et al., 2019a).

The guidelines for older adults aged over 65 years are similar to those for younger adults. Since older adults are generally less active, any increase in activity is better than none. Exercises such as yoga can improve balance and flexibility. Older people may especially gain health benefits by breaking sedentary time with standing. For all adults, any increase in physical activity will bring health benefits. These guidelines correspond with advice from the World Health Organisation (WHO) (2010).

1.4 Prevalence of physical inactivity and sedentary behaviour

Just over a quarter of the world's population (27.5%, 95% CI: 25.0-32.2) is insufficiently physically active (Guthold et al., 2018). Guthold et al. (2018) produced the most recent globally comparable statistics. The authors pooled data from 358 surveys on self-reported physical activity and age-standardised the results using regression models. Altogether, the data represents 1.9 million people worldwide, although data were not available for all countries. Women (31.7% insufficiently active, 95% CI: 28·6–39·0) are typically less active than men (23.4%, 95% CI: 21.1-30.7). High-income countries (36.8%, 95% CI: 35·0–38·0) are doing less activity than low-income countries (16·2%, 95% CI: 14·2–17·9). However, low-income countries were represented by data from one country (Benin) only. Globally, the proportion of insufficiently active people has not significantly changed between 2001 and 2016, although inactivity levels have risen in high-income countries. Over a third of the UK's population are not achieving sufficient physical activity (35.9%, 95% CI: 29.4–42.9). Keeping with global trends, women in the UK are less active than their male counterparts. Two out of five UK women (40.0%, 95% CI: 32.8-47.7) are insufficiently active compared with 31.5% (95% CI: 25.8-37.8) of men. In terms of sedentary behaviour, the average men and women spent an average of 78 and 74 days per year sitting (British Heart Foundation, 2017b).

1.4.1 Measurement of physical activity

Physical activity questionnaires are self-reported measures that are commonly used to estimate physical activity and sedentary behaviour in epidemiological studies. Self-reported measures present many benefits to researchers including being low-cost, a low burden to participants, and that the physical activity questionnaires have been validated for many different populations and subgroups. They can provide sufficient information on physical activity patterns so that participants can be ranked. However, self-reported estimations of physical activity and sedentary behaviour are subject to several limitations. Recall and reporting bias is possible: a person may overestimate their activity in response to what they perceive they should be doing; an example of social desirability bias. Conversely, it might be difficult to remember all the activity achieved recently and self-report can underestimate (Ara et al., 2015; Paul et al., 2018). Physical activity questionnaires are not good at estimating energy expenditure, compared to the gold-standard method of doubly-labelled water, and capture vigorous-intensity physical activity better than light- and moderate-intensity physical activity (Ara et al., 2015). Self-reported measures should, therefore, be interpreted with caution as measurement error and bias have consequences for the subsequent analyses.

Objective measures of physical activity (such as accelerometers and pedometers) are more accurate and precise than self-reported measures (Ara et al., 2015). In recent years, these devices have become more reliable, cheaper, and more widely available. However, accelerometers themselves have limitations. They are more expensive than questionnaires, must be charged regularly, cannot measure some common non-ambulatory activities, e.g., cycling and does not provide information on what domain physical activity is accumulated in (i.e., work, domestic, occupational or leisure). It can also be difficult to translate the recorded acceleration into physical activity levels such as MVPA. A good compromise is to combine a physical activity log with an accelerometer to give a more comprehensive picture of daily activity (Ara et al., 2015). Measurement of physical activity is crucial to understanding the true prevalence of inactivity and its associations with health.

1.5 The economic impact of physical inactivity and sedentary behaviour

Due to the many health risks associated with inactivity and its high prevalence in UK adults, physical inactivity and sedentary behaviour present a large burden to the UK economy. The WHO Global Action Plan for Physical Activity (GAPPA) 2018-2030 outlines its vision for a more active global population: to reduce physical inactivity by 10% by 2025 and 15% by 2030 (Cooper, 2018). However, physical inactivity has been rising in high-income countries over the last fifteen years (Guthold et al., 2018) and without drastic, urgent action, the targets will not be met. Policies to increase physical activity have been largely unsuccessful and change is needed to address physical inactivity as a public health issue. The main reasons for policy failure are overly optimistic targets, the inconsistent implementation of national policies at a local level, inadequate collaboration and the short-term nature of the political cycle which allows politicians to avoid responsibility for long-term public health strategies (Hudson, Hunter and Peckham, 2019). Economic analysis may be crucial to improving physical activity policies by increasing awareness of the economic impact of physical inactivity and motivating politicians and decision-makers to act (Ding et al., 2017).

Previous studies have explored the economic burden of physical inactivity through direct healthcare costs due to disease, the indirect costs associated with reduced economic productivity, and out-of-pocket costs to individuals and households (Ding et al., 2017). Three studies (Allender et al., 2007; Scarborough et al., 2011; Ding et al., 2016) have provided estimates of the direct healthcare costs associated with physical inactivity in the UK using population-attributable fraction (PAF) based approaches. A PAF-based approach identifies diseases for which there is strong evidence of an increased risk from physical inactivity. The proportion of the disease attributable to physical inactivity (the PAF) is estimated using relative risks (RRs) and the prevalence of physical inactivity in the population, and the resulting PAF is multiplied by the financial budget for that disease. The results are summed for each disease to give an overall estimate of the proportion of the healthcare budget attributable to physical inactivity.

Allender et al. (2007) estimated that physical inactivity cost the National Health Service (NHS) £1.06bn (2001-02 prices) using PAFs published by the WHO on ischaemic heart disease, ischaemic stroke, breast cancer, colon/rectum cancer and diabetes mellitus. Scarborough et al. (2011) later updated this figure to £0.9bn using the 2006-07 NHS budget. The estimate for physical inactivity unexpectedly decreased between 2006-07 and 2001-02, but Scarborough et al. suggested that it is likely due to the revision of NHS costs between 1992-93 and 2006-07. In a global analysis, Ding et al. (2016) estimated that the annual healthcare costs associated with physical inactivity in the UK are £1,285,708 (2013 prices) and $67.5bn globally per annum. They used country-specific average annual costs per case of disease therefore the methodology differed from that of Allender et al. (2007) and Scarborough et al. (2011) who used NHS budgetary data. As a result, it is not possible to directly compare these findings. However, it is clear that physical inactivity increases the financial pressure on the NHS in terms of related healthcare costs, especially since the PAF approach used here typically produces conservative estimates (Ding et al., 2016). No estimates for physical inactivity had been produced using econometric methods in the UK and no specific estimates were available for sedentary behaviour. These are evidence gaps in our understanding of the economic impact of physical inactivity and sedentary behaviour in the UK.

1.6 Socioeconomic inequalities in physical activity

Reducing health inequalities should be a key objective of public health programmes (Marmot et al., 2020). In the UK, there is a clear gradient between socioeconomic status (SES) and life expectancy (Marmot and Bell, 2016). In other words, individuals with the lowest incomes typically die sooner than individuals with median incomes, who in turn die sooner than the individuals earning the highest incomes in the UK. This is a pressing issue: in an updated report on health inequities in England, Marmot (2020) found that improvements in life expectancy had slowed, especially in more deprived areas of England. In higher-income countries, individuals with lower SES are less likely to be physically active (Oude Groeniger et al., 2019) and more likely to suffer from non-communicable diseases such as CVD and T2D (Sommer et al., 2015). Theories on the determinants of health (section 1.9) explain the dramatic social gradient in health outcomes seen in the UK. Interventions present a way to increase physical activity in the population.

1.7 Physical activity interventions

Public health interventions (PHIs) are an organised effort or policy to improve health at a population level. A PHI programme can act at different levels: individual, community, population, and globally. PHIs vary widely in their methods, e.g., screening for disease, vaccination programmes, supplementation programmes (e.g., fluoride added to water), or behaviour change interventions (BCIs) which intend to promote healthy behaviour and can be used to tackle physical inactivity and sedentary behaviour. They are defined as 'coordinated set of activity designed to change specified behaviour patterns' (Michie, Stralen and West, 2011). Changing behaviour can be a challenging and complex process, however, BCIs to increase physical activity are generally effective (Howlett et al., 2019).

1.8 Economic evaluation of physical activity interventions

Most PHIs are cost-effective (Owen et al., 2018) although the evidence for the cost-effectiveness of physical activity interventions is mixed (Abu-Omar et al., 2017). Economic evaluation of interventions is an important step in determining if an intervention is a good investment or can be scaled up to benefit more people. In a 2019 study, Beard et al. (2019) explored the components of a broad range of PHIs associated with greater cost-effectiveness, finding that education was an important component of cost-effective interventions. Only four of the included PHIs focused on physical activity, therefore there were insufficient data to make specific conclusions on physical activity interventions. Questions remain regarding which characteristics individual-level interventions could have that might result in greater cost-effectiveness, specifically which BCTs could be included, how complex the intervention should be, and how intense it should be for participants.

Despite its widespread use, traditional economic evaluation methods such as CEA are limited for use with PHIs (Edwards and McIntosh, 2019). PHIs are typically complex and may bring about many benefits other than health-related benefits, e.g., societal, environmental, and economic. Shiell and Hawe (1996) advocated for the use of SROI analysis, which evaluates the long-term effects of PHIs in monetary terms only, making the results accessible to non-experts who may be unfamiliar with economic terms. SROI could be particularly useful for environmental interventions, which aim to increase physical activity levels as well as bring other benefits to the communities in which they are located. However, the methods have not yet been standardised and should be used and interpreted with caution (Edwards and McIntosh, 2019).

1.9 Determinants of health and physical activity

In order to find solutions to help the UK population become more physically active, it is important to first consider the determinants of health. Dahlgren and Whitehead (1991) developed a map of the main determinants of health (Figure 1.2, Dahlgren and Whitehead (1991)). Individual health and lifestyle factors may play a small role in the complex model of determinants of health status. People are influenced by their community, living and working conditions, and general socioeconomic, cultural and environmental conditions. The importance of these factors should not be underestimated. These concepts explain the dramatic health inequalities that exist, not only between countries of different income levels but within countries, including the UK (Marmot et al., 2020). The Dahlgren and Whitehead model can be used to explore the factors, which affect an individual's level of physical activity.

Research has focused more on the individual correlates of physical activity than those at the population-level, where there may be greater potential for policy change that could facilitate change. In adults, health status and self-efficacy are determinants of higher levels of physical activity. Younger age, male sex, higher education level, and normal weight are correlates of higher physical activity (Bauman et al., 2012). Environmental factors may also play a critical role in our health. Barton and Grant (2006) developed a 'health map for the local human habitat' (Figure 1.3) which consolidated the model from Dahlgren and Whitehead (1991) with ecosystem theories and the role of the built environment. The purpose is to help planners visualise the wider impacts of changes to the environment. The National Institute for Clinical Excellence (NICE) published recommendations on environmental changes to increase physical activity in the UK which includes points on the importance of community engagement, active transport, public open spaces and accessibility. Evidence suggests that environmental factors affect physical activity levels such as walkability, street connectivity, safety, greenness and attractiveness. With a greater understanding of how the determinants of physical inactivity, we can develop interventions to facilitate behaviour change.

1.10 Rationale for thesis

There are gaps in the knowledge on the topic of the health economics of physical activity and sedentary behaviour, as pointed out in this chapter. Firstly, no study has been done on the economic impact of sedentary behaviour specifically. Although previous studies have estimated the cost of physical inactivity in the UK, they have only used prevalence-based approaches and not econometric approaches, which can produce different totals and benefit from more flexible regression models. In terms of physical activity and sedentary behaviour interventions, it is still unclear which components and characteristics might lead to greater cost-effectiveness. There is also a scarcity of SROI studies and economic evaluations of urban regeneration projects in general. Finally, SES remains a strong determinant of health status despite calls to reduce health inequalities in the UK. More evidence is needed on interventions and policies to promote a more equitable distribution of health.

Four studies were conducted to meet the aims of the thesis. The first two studies estimated the economic cost of physical inactivity and sedentary behaviour using methodology that works from both an individual-level and a population-level. The third and fourth studies focused on the economic evaluation of interventions to reduce physical inactivity, likewise with both individual-level and population-level perspectives. The third study is a review of economic evaluations of physical activity interventions, which explores the intervention characteristics associated with greater cost-effectiveness. The fourth study is a SROI analysis of the CCG, a regeneration project of urban greenway in a socioeconomically disadvantage area of Belfast, Northern Ireland (NI).

1.10.1 The direct healthcare costs associated with sedentary behaviour (Study 1)

Study 1 aimed to estimate the healthcare costs associated with prolonged sedentary behaviour in the UK since this information was not available in the literature (see Chapter 2). The analysis calculated PAFs, which are the estimated proportion of the disease cases due to prolonged sedentary behaviour in the population. The PAFs were applied to NHS budgetary data to estimate the costs attributable to prolonged sedentary behaviour. The result of the study adds to the evidence on the economic burden of sedentary behaviour.

1.10.2 Inpatient healthcare costs associated with physical inactivity (Study 2)

The economic burden of physical inactivity in the UK has been explored in previous studies (Ding et al., 2016; Scarborough et al., 2011; Allender et al., 2007), however, all had used prevalence-based methods. Study 2 added to the understanding of the economic burden of physical inactivity by estimating the additional healthcare costs associated with lower physical activity levels using econometric methods.

The UK Biobank study provided an opportunity to explore this association in a large sample of over 86,000 adults who provided accelerometer data for one week. Furthermore, the physical activity data was objectively measured which reduced the risk of bias. The UK Biobank dataset was subsequently linked with NHS healthcare data. Study 2 used these data to estimate the additional inpatient hospital days and costs associated with lower levels of physical inactivity (see Chapter 3). The data available allowed the association to be explored in population subgroups, by income, age and gender.

The use of both prevalence-based and econometric techniques in the first two studies was compared and contrasted. There are benefits and limitations associated with both methods. Both studies add new evidence to the estimates of the economic burden of physical inactivity and sedentary behaviour.

1.10.3 Which characteristics of physical activity interventions are associated with greater cost-effectiveness? (Study 3)

The next step in the process of designing the studies for this thesis was to consider solutions to the pandemic of physical inactivity from an economic perspective. It was evident that interventions to increase physical activity and reduce sedentary behaviour should be cost-effective to ensure that public funds were used well and fairly. Despite the BCT framework available to classify components of interventions based on the theory of behaviour change (Michie et al., 2013), the intervention Complexity Assessment Tool for Systematic Reviews (iCAT_SR) tool to classify the complexity of an intervention (Lewin et al., 2017), and literature on the intensity of interventions, there was scarce evidence on how these components may be related to the cost-effectiveness of physical activity interventions.

Study 3 was a systematic review of economic evaluations of physical activity and sedentary behaviour interventions, which aimed to assess which characteristics of physical activity interventions were associated with greater cost-effectiveness (see Chapter 4). It specifically assessed the BCTs of each intervention, BCT clusters, complexity as measured by the iCAT_SR tool, and the intensity of the intervention measured by intervention duration, number of contact points, and number of contact hours. All of the interventions included in the review were individual-level interventions. The findings can be used to inform researchers who wish to develop cost-effective interventions with a focus on physical activity and/or sedentary behaviour.

1.10.4 An updated social return-on-investment analysis of the Connswater Community Greenway (Study 4)

The CCG is an urban regeneration project, which was completed in 2017. Nine kilometres of safe and accessible walking and cycling infrastructure connects the parks and Connswater River in a socioeconomically disadvantaged area of Belfast, NI. An initial SROI analysis (Hunter et al., 2020) was conducted while the CCG was in the process of development and construction and it was expected that the CCG would bring benefits to the residents' health, local society, environment, and economy. The estimates were built on several assumptions since the data was not yet available. Study 4 aimed to conduct a new SROI analysis of the CCG over 40 years based on before and after data (see Chapter 5).

SROI studies are gaining popularity in public health research as non-traditional methods of economic evaluations that can incorporate a wider perspective on costs and benefits. Solely focusing on the change in physical activity would miss other benefits of a community-level intervention, which can be just as relevant for population health.

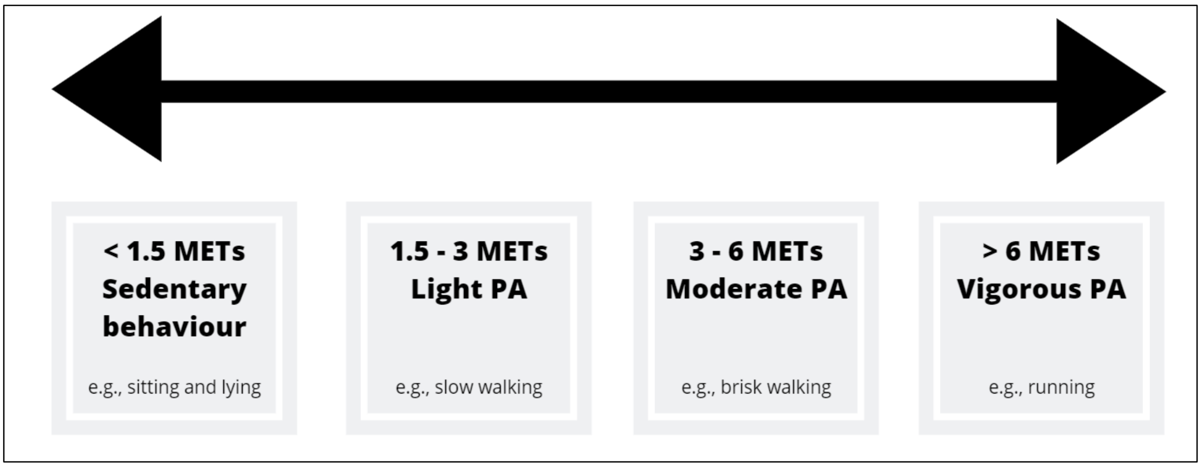
1.10.5 Discussion of findings and recommendations for future directions

The findings from each of the studies were summarised and discussed. The implications of using an individual or a population perspective in public health and health economics were considered. Finally, the thesis suggested future directions for this area of research.

1.11 Research questions

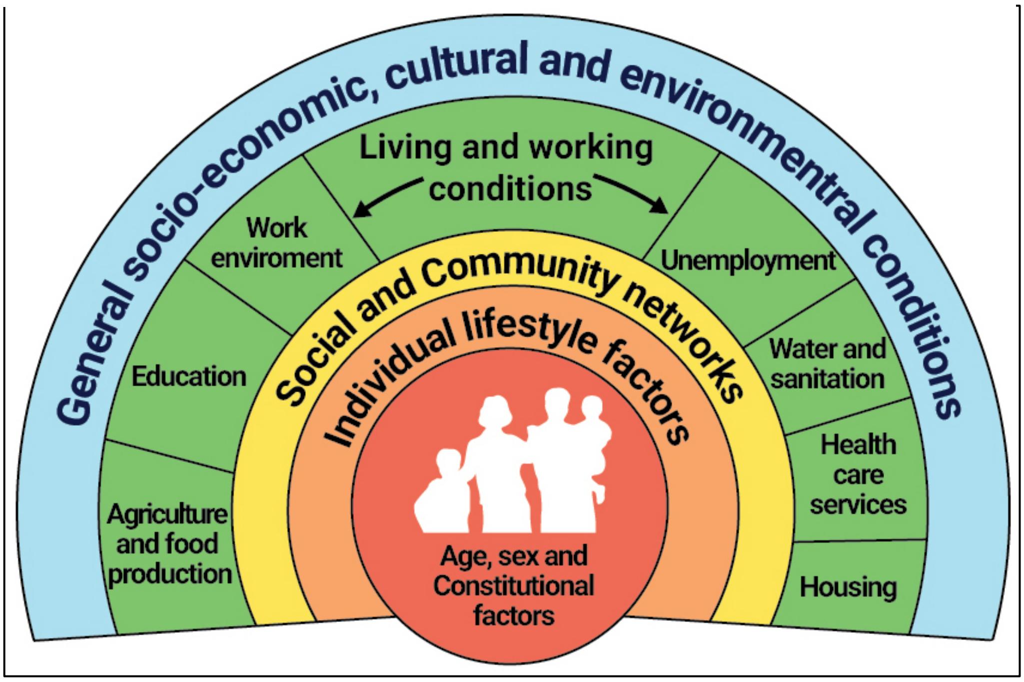
1) What are the direct healthcare costs associated with prolonged sedentary behaviour in the UK?
2) What is the association between physical inactivity and inpatient hospital use and care in the UK Biobank study?
3) Which characteristics of physical activity and sedentary behaviour interventions are associated with greater cost-effectiveness?
4) What is the SROI of the CCG?

Figure 1.1 The physical activity spectrum



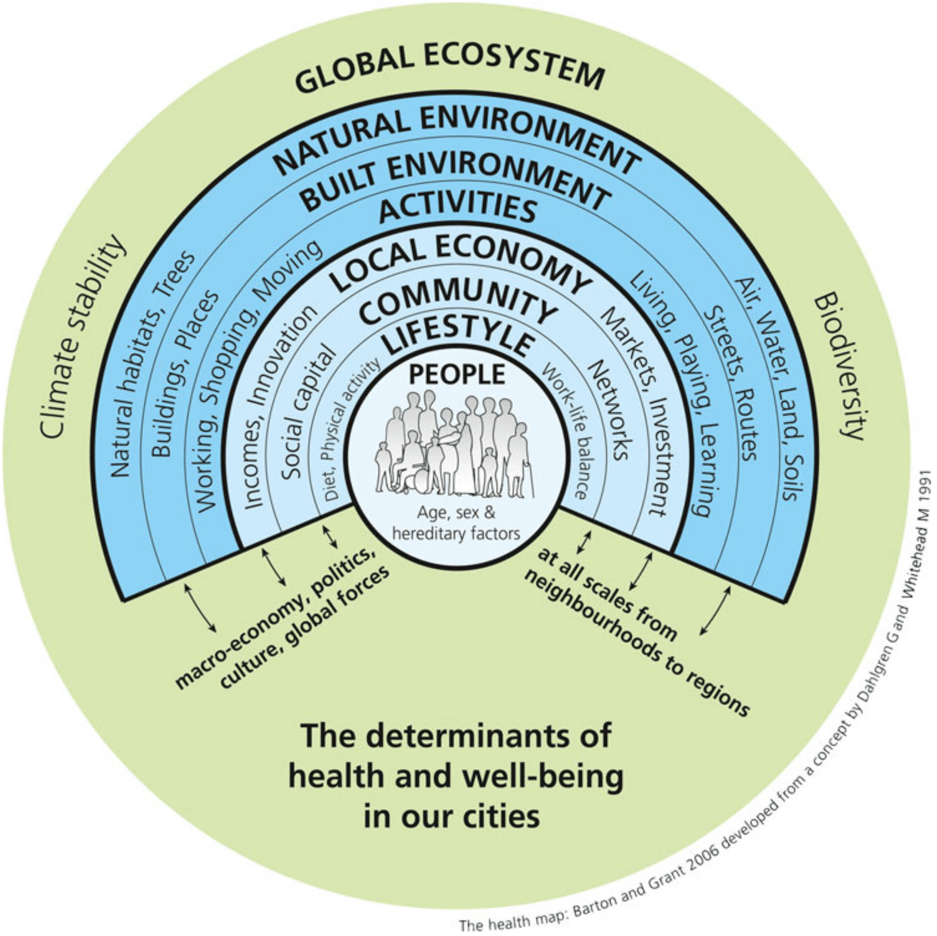
METs = metabolic equivalents of task; PA = physical activity. Nimmo et al. (2013)

Figure 1.2 The determinants of health



Dahlgren and Whitehead (1991)

Figure 1.3 The health map for the local human habitat



Barton and Grant (2006)

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CHAPTER 2

THE DIRECT HEALTHCARE COSTS ASSOCIATED WITH SEDENTARY BEHAVIOUR IN THE UNITED KINGDOM

2 THE DIRECT HEALTHCARE COSTS ASSOCIATED WITH SEDENTARY BEHAVIOUR IN THE UNITED KINGDOM

2.1 Introduction

Sedentary behaviour increases the risk of several chronic conditions, independent of physical activity level (Patterson et al., 2018). The risk of disease from prolonged sedentary behaviour is mitigated by very high levels of physical activity, as discussed in the introduction (see section 1.2.1). However, sedentary behaviour can be analysed as an independent risk factor with appropriate adjustments for confounding by physical activity level. Patterson et al. (2018) calculated PAFs for prolonged sedentary behaviour in a recent meta-analysis, using TV viewing time as the exposure in a Monte-Carlo micro-simulation. They estimated that TV viewing time was associated with 8% (6–10%) of all-cause mortality, 5% (1–8%) of CVD, and 5% (2–7%) of cancer mortality and 29% (26–32%) of T2D.

Previous studies have reported on the economic burden of physical inactivity; however, there are no estimates of the economic cost of sedentary behaviour in the UK. Although it is well established that sedentary behaviour is unhealthy, the lifestyles of UK adults have not drastically changed. It is considered normal to work long hours in a sedentary job, followed by spending time in a sedentary leisure activity such as TV watching. In order to reduce the hours that people spend in sedentary behaviour per day, we will have to make fundamental changes in work and at home. However, this is a difficult task. Assessing the economic impact of a risk factor is one way to address the policy-implementation gap (Ding et al., 2017). New evidence on the financial impact of sedentariness could act as a call to action.

Sedentary lifestyles in UK adults are likely to account for a proportion of the high prevalence of chronic disease, which presents a long-term financial burden to the NHS. Identifying and quantifying the economic cost of sedentary behaviour is important in the process of understanding its impact in the UK and informing preventive action. At the time of conducting this study, no estimates of the economic cost of sedentary behaviour in the UK could be identified.

There are two commonly used methods for estimating the economic cost of risk factors: the PAF-based or ‘top-down’ approach or econometric, ‘bottom-up’ methodology (Ding et al., 2017). The PAF-based approach uses population-level data, specifically PAFs and budgetary data, to estimate the cost of the proportion of disease attributable to the risk factor. Alternatively, the econometric method uses individual-level data in regression models to estimate the additional costs incurred by individuals exposed to the risk factor. The PAF-based approach typically produces more conservative estimates based on a limited number of diseases whereas econometric estimates are usually higher, possibly because they capture increased treatment intensity. Although there are advantages and disadvantages to both approaches, the choice of approach usually depends on which data are available.

Several studies recommend using individual data to estimate the cost of diseases when it is possible (Honeycutt et al., 2009). However, appropriate individual-level data on sedentary behaviour were not available at the time of developing and conducting this analysis. Estimates of the prevalence and risks of prolonged sedentary behaviour were available in the literature along with budgetary data from the NHS. Therefore, the economic cost of sedentary behaviour in the UK was estimated using a PAF-based approach.

PAFs estimate the proportion of disease that is due to a risk factor in a given population (Rockhill, Newman and Weinberg, 1998). It is an epidemiological measure to estimate the proportion by which disease would be reduced if a risk factor were eliminated. There are several formulas available to calculate a PAF, depending on whether confounding is present and the data available on exposures. Rockhill, Newman and Weinberg (1998) describe the appropriate formulas used to calculate PAFs, depending on whether confounding is present. Equation 2 includes the unadjusted RR (RR_{unadj}) and the prevalence of the risk factor in the overall population (p_0):

$$PAF(\%) = \frac{p_0(RR_{unadj} - 1)}{p_0(RR_{unadj} - 1) + 1} x100 \tag{2}$$

Alternatively, when confounding is present, equation 3 is suitable:

$$PAF(\%) = \frac{p_1(RR_{adj} - 1)}{RR_{adj}} x100 \tag{3}$$

Where p_1 is the prevalence of the risk factor among those who go on to develop the disease and RR_{adj} is the adjusted RR estimate.

As outlined in the introduction (section 1.5), physical inactivity has a considerable impact on the economy in the UK. Scarborough et al. (2011) estimated that physical inactivity cost the UK NHS £0.9bn per annum in direct healthcare costs at 2006-07 prices. They used a PAF-based analysis that included five diseases: coronary heart disease, cerebrovascular disease, breast cancer, colon cancer, and diabetes. This study was an update of a previous UK analysis that reported physical inactivity cost the NHS £1.6bn at 1992-93 prices. The difference in estimates may be explained by a variety of factors. These estimates have not adjusted for double-counting due to co-morbidities; i.e., patients being treated for coronary heart disease and diabetes in one healthcare episode may incur lower costs than two patients being treated separately. This example demonstrates the importance of adjusting for comorbidities as it risks overestimating the costs. This can be avoided by a simple albeit crude adjustment by estimating the number of individuals with both disorders and removing the cost of one of the diseases from this group, as Ding et al. did in their study. Ding et al. (2016) undertook a global analysis of the costs of physical inactivity in 2013 prices. The global estimate was $53.8bn (international dollars, equivalent to £33.1bn. In the UK specifically, they estimated that physical inactivity cost $1.8bn (£1.1bn) in direct healthcare costs and $0.6bn (£0.4bn) in indirect costs, which were productivity losses from mortality related to inactivity. The analysis also used PAFs, based on the same diseases as Scarborough et al. included previously.

Given the gap in evidence regarding the economic burden associated with sedentary behaviour, this chapter aimed to estimate the direct healthcare costs of prolonged sedentary behaviour to the NHS in the UK in one year (2016/17).

2.2 Methods

2.2.1 General approach

This study estimated the direct healthcare costs of UK adults associated with prolonged sedentary behaviour from a health and social care perspective in the UK, i.e., the NHS. Costs that arise directly from healthcare, e.g., primary care, hospital treatment, and prescriptions, are direct healthcare costs. Indirect healthcare costs are the costs that are not directly related to medical care, e.g., hospital building costs and human resources. Other costs are loss of productivity costs. These occur when a person can no longer work to the same extent as before due to disability or death related to the risk factor. This analysis has only included direct healthcare costs due to the availability of data.

However, it should be acknowledged that disease and death due to sedentary behaviour is likely to lead to increased indirect healthcare costs and loss of productivity costs.

Prolonged sedentary behaviour was defined as at least six hours of self-reported sedentary behaviour during waking hours, based on a recent meta-analysis which observed a steep risk increase in adverse health outcomes from six to eight hours of sedentary time (Patterson *et al*., 2018). The PAF-based approach seeks to apportion healthcare expenditures across a range of diseases that are attributable in part to sedentary behaviour based on RRs of disease, the prevalence of sedentary behaviour, and healthcare expenditure. The following steps were used to estimate the healthcare costs attributable to prolonged sedentary behaviour, based on the methodology used by Ding et al. (2016):

Step 1. Identify diseases associated with sedentary behaviour

Step 2. Quantify the increased risk to health due to sedentary behaviour

Step 3. Estimate the prevalence of sedentary behaviour in UK adults

Step 4. Calculate PAFs for each health outcome

Step 5. Estimate NHS expenditure for each disease

Step 6. Calculate costs attributable to sedentary behaviour

2.2.2 Step 1. Identify diseases associated with sedentary behaviour

The Physical Activity Guidelines Advisory Committee (2018) summarised the existing evidence for sedentary behaviour in 2018. Moderate to strong evidence was available for a causal association between sedentary behaviour and five diseases: CVD, T2D, lung cancer, endometrial cancer, and colon cancer. The report summarises many years of observational research on the harms of sedentary behaviour and presents evidence that reducing sedentary behaviour should be formally added to the US guidelines on physical activity. The last search date of the report was 30th January 2017. This report was used as it was the most recent summary of evidence on the harms of sedentary behaviour at the time of conducting this analysis. The report gave full detail of a grading rubric used to assess the strength of the evidence presented. The grading rubric was based on the population of interest, risk of bias, study limitations, consistency, and effect estimates. Since the report had been published in the same year as the analysis of this study was conducted, it was considered unnecessary to update.

2.2.3 Step 2. Quantify the increased risk to health due to sedentary behaviour

Estimates on the RRs of sedentary behaviour to known diseases were identified in a recent report from the United States (US) Government were used (Physical Activity Guidelines Advisory Committee, 2018). They had conducted meta-analyses of several studies. Meta-analysis is a method of systematically assessing quantitative data from multiple studies. The pooled results from several studies are consolidated to produce a more precise overall estimate. Meta-analyses are the top-ranked form of clinical evidence, according to the hierarchy of evidence. Meta-analyses were deemed to be appropriate for this analysis in order to identify the most precise estimates for the RRs in relation to sedentary behaviour.

A non-systematic literature search was conducted on PubMed to identify relevant studies. Meta-analyses were chosen if they had employed a prospective design, used healthy participants at baseline, and adjusted for physical activity in their statistical model. Due to the variations in definitions of sedentary behaviour, studies were used which had investigated the association by comparing the individuals who reported the most sedentary time compared to the least. Overall sedentary time was prioritised over television viewing time as television-viewing time might not represent an individual's total sedentary behaviour which could include working, using a computer, or reading, etc. Alternatively, sedentary behaviour could have been considered as a numerical variable and the risk per hour of inactivity estimated. It could have been achieved by calculating the median hours from the reported categories of sedentary time. However, this approach would have added additional assumptions into the model as that was not how the data was originally collected. Studies that had used total overall sedentary time as an exposure were prioritised (e.g., instead of television viewing time alone). RRs were extracted from the primary studies included in the meta-analyses if they had a prospective design, participants were considered healthy at baseline, and they had adjusted for physical activity in the model. Studies that did not meet all of those criteria were excluded. When necessary, the RRs were pooled using Review Manager (RevMan version 5.3).

RR estimates were required that were both adjusted for known confounders and crude or minimally-adjusted estimates for calculating the PAFs using the two formulas in step 4 (section 2.2.5. Adjusted RR estimates were available for all studies. However, crude or minimally adjusted estimates were missing from some and those authors were contacted by email to request that information. Studies that had adjusted for more than age and sex in their minimally adjusted model were excluded in sensitivity analyses, in which no large differences in the RRs were seen. Crucially, none of the minimally-adjusted RRs had adjusted for physical activity level. , an important confounder in the association between sitting time and health (Ekelund *et al.*, 2016). The purpose of this exercise was to identify the risk specifically due to sedentary behaviour. These estimates have all been adjusted for physical activity level therefore they could theoretically be compared to PAFs calculated for physical activity in the same way.

Twelve authors (16 studies) were emailed and asked to provide a crude or minimally-adjusted RR estimate if not reported in the publication. Eight authors (67%) responded, and five of those were able to provide additional results. This approach is limited by the authors' responses: some did not respond at all. This may bias the estimations in some bias, although it is unclear in which direction.

2.2.4 Step 3. Estimate the prevalence of sedentary behaviour in UK adults

The Health Survey for England (HSE) 2012 (NHS England, 2013) reported that 30% of adults in England spent at least six hours/day sedentary on weekdays, and 37% of adults at the weekend. Ideally, the data would have been collected to find how many adults spend at least six hours sedentary on an average day in a representative sample across the four countries in the UK, but the data did not exist. These figures were used to estimate the percentage of UK adults who are sedentary on any given day of the week in the following formula:

$$\frac{(\text{weekday prevalence}) * 5 \ + \ (\text{weekend day prevalence}) * 2}{7} \qquad (1)$$

The PAF formula (section 2.2.5) requires the prevalence of prolonged sedentary behaviour at baseline in those who later became diseased, e.g., the prevalence of sedentary behaviour at baseline in the women who would go on to develop endometrial cancer in future. This information is not readily available as the prevalence of sedentary behaviour at baseline was not commonly reported for those who would only go on to develop the disease. Therefore, prevalence adjustment factors were calculated using data from cohort studies as Lee et al. (2012) and Ding et al. (2016) also did. Cohort studies were identified which fitted the criteria were outlined in section 2.2.3 and had also measured and reported prolonged sedentary behaviour for the total population and for cases only at baseline. Studies of European populations, larger samples, and longer follow-up times were chosen when available. The proportion of sedentary cases at baseline was divided by the overall proportion of sedentary participants at baseline to produce an adjustment factor. For example, Stamatakis et al., (2017) reported that 34.1% of all study participants and 38.3% of diabetes cases were sedentary at baseline. The adjustment factor was 1.12 (38.3/34.1). The adjustment factor was then multiplied by the prevalence of sedentary behaviour in the general population in order to estimate the additional prevalence among cases. This approach is limited as it is only a crude estimation of the prevalence. It may under- or overestimate the prevalence of sedentary behaviour would then affect the PAF calculated and the subsequent cost estimations.

2.2.5 Step 4. Calculate population attributable fractions for each health outcome

PAFs estimate the contribution of a risk factor to the total burden of a disease in a given population. In the present study, the PAFs estimate the theoretical reduction in disease that would occur if prolonged sedentary behaviour was eliminated. Two equations were used to calculate PAFs in this analysis, both described by Rockhill, Newman and Weinberg (1998). The first (equation 2) is appropriate to use when confounding is present:

$$PAF(\%) = \frac{p_1(RR_{adj} - 1)}{RR_{adj}} x100 \qquad (2)$$

Where p_1 is the prevalence of sedentary behaviour among cases and RR_{adj} is the pooled adjusted RR, comparing the most sedentary individuals with the least sedentary.

PAFs were calculated to estimate the theoretical reduction in disease that would occur if prolonged sedentary behaviour was eliminated.

Equation 2 integrates the pooled adjusted RR (RR_{adj}) estimates and the proportion of sedentary individuals who became cases (p_1). PAFs were also calculated using another formula (equation 3), which is appropriate to use when no confounding is present (Rockhill, Newman and Weinberg, 1998). The PAFs calculated from equation 3 were incorporated into Monte Carlo simulations to calculate 95% confidence intervals (CIs) for the adjusted PAFs. The following equation includes the unadjusted RR (RR_{unadj}), comparing most sedentary individuals with the least sedentary, and the prevalence of sedentary behaviour in the overall UK population (p_0):

$$PAF(\%) = \frac{p_0(RR_{unadj} - 1)}{p_0(RR_{unadj} - 1) + 1} x100 \quad (3)$$

2.2.6 Step 5. Estimate NHS expenditure for each disease

Healthcare budgets for specific disease groupings were available for the NHS in England for the nearest financial year 2012-13 (NHS England, 2015), Wales for 2016-17 (Statistics for Wales, 2018), and Scotland 2011-12 (Scottish Government, 2015). The healthcare budgets covered inpatient and outpatient costs, primary care expenditure, pharmaceutical expenditure, and community care services in the NHS. All costs are in pounds sterling (GBP). Costs were standardised to the year 2017 by adjusting costs for inflation using the hospital and community health services (HCHS) index, a weighted average of annual increases in pay and prices in healthcare services (Curtis and Burns, 2017a). The total budgets adjusted for inflation to 2016/17 costs were considerably lower than the actual reported total budgets for 2016/17 for England (HM Treasury, 2016) and Scotland (Audit Scotland, 2017). However, since costs for individual diseases were not available for these years, it was necessary to use inflated costs. Healthcare budget data for NI were unavailable, therefore costs were estimated for this region based on the incidence of disease compared to the rest of the UK. The budget costs for NI were estimated by extrapolating the costs for England, Scotland and Wales using the disease incidence in NI. For example, the cost of T2D in the England, Scotland, and Wales was £1.4b, £88m, and £100m respectively. New cases of diabetes in NI in 2015 accounted for 2.5% of new cases in the UK (Diabetes UK, 2017a). Therefore, using the gross expenditure for diabetes in England, Scotland, and Wales, an estimate of £42m was calculated for Northern Irish expenditure. This approach is limited as health spending in NI could be different to that in Great Britain, e.g., due to differences in efficiency. Nevertheless, the Northern Irish population accounted for 2.8% of the UK population in 2017 therefore the potential impact of measurement error on the overall UK estimate should be negligible.

2.2.7 Step 6. Calculate costs attributable to sedentary behaviour

The PAFs and the corresponding 95% CIs (step 4, equation 2) were multiplied by total disease expenditure (step 5) to estimate the NHS costs attributable to prolonged sedentary behaviour in the UK. Since the timeframe for the analysis was one year, discounting was unnecessary. One year was an appropriate timeframe since a longer period would require more assumptions, making the estimates less reliable.

There may be overlap in the health care expenditures; in as far as many patients are treated for more than one condition at one time. One patient being treated for both diabetes and CVD may cost the NHS less than the cost of two patients being treated separately. Thirty per cent of Europeans with T2D are also affected by CVD (Einarson et al., 2018). Therefore, in a sensitivity analysis, 30% of the T2D expenditure attributable to prolonged sedentary behaviour was subtracted from the total costs to adjust for potential double-counting caused by this co-morbidity.

Ding et al. (2016) used an alternative method to adjust for double-counting: by using RRs and the prevalence of CVD in the UK to estimate what percentage of individuals with T2D might also have CVD. A meta-analysis reported the RR of having CVD as being 206% higher for people with T2D compared to those without T2D (Sarwar N, Gao P et al., 2010). The prevalence of CVD in the general population is 4.28%, as reported by the British Heart Foundation (2017). Therefore, it is estimated that 8.82% of people with T2D have CVD: 8.82% of T2D expenditure was subtracted from the total costs attributable to sedentary behaviour. It was assumed that the potential double-counting relating to the other conditions was negligible and could be ignored.

In a further sensitivity analysis, the unadjusted PAFs (step 4, equation 3) were used to calculate the costs attributable to prolonged sedentary behaviour.

2.3 Results

2.3.1 Step 1. Diseases associated with sedentary behaviour

Health outcomes included in the analysis, chosen because of the moderate to strong level of evidence available, were T2D, CVD, and endometrial, colon, and lung cancers (Physical Activity Guidelines Advisory Committee, 2018).

2.3.2 Step 2. The increased risk to health due to sedentary behaviour

Meta-analyses were identified that fitted the criteria described in section 2.2.3 (Shen et al., 2014; Biswas et al., 2015; Pandey et al., 2016). The definition of sedentary behaviour differed between individual studies from each meta-analysis used in this analysis. Associations for T2D were based on TV viewing, whereas other studies predominantly used sitting time or overall sedentary time. The associations reported are for the highest versus the lowest categories of sedentary behaviour in each study, in which many of the categories differed by the hourly cut-off. Table 2.1 summarises the definition used, variations in cut-offs and the estimated median hours per day spent sedentary estimated for each category. The medians in the lowest categories for all health outcomes range from 0.0-3.8 hours/day of sedentary behaviour for all the health outcomes; medians in the highest categories range from 6.0-18.0 hours/day.

The adjusted RRs were extracted from the relevant studies. Pandey et al. (2016) reported an adjusted RR of 1.14 (95% CI 1.09, 1.19) for the association between CVD and sedentary behaviour. The RR estimate for T2D was re-pooled to exclude a cross-sectional study (Dunstan et al., 2005): the final adjusted RR estimate for T2D was 1.88 (95% CI 1.62, 2.17). Shen et al. (2014) investigated the risk of cancer associated with higher sedentary behaviour. They reported adjusted RRs for lung cancer (1.27 [95% CI 1.06, 1.52]), colon cancer (1.30 [95% CI 1.12, 1.49]), and endometrial cancer (1.28 [95% CI 1.08, 1.53]). The final adjusted RRs are presented in Table 2.2.

The unadjusted RR estimates are reported in Table 2.2. All estimates were higher than the adjusted RRs except for colon cancer. The highest estimated unadjusted RR was for T2D, based on three studies (Hu et al., 2001; Hu, 2003; Krishnan, Rosenberg and Palmer, 2009): 2.42 (95% CI: 1.94, 3.02). The estimate for CVD incidence had pooled results from seven studies (Petersen et al., 2014; Herber-Gast et al., 2013; Borodulin K, Kärki A, Laatikainen T, Peltonen M, 2012; Chomistek et al., 2013; Patel et al., 2010; Matthews et al., 2012; Katzmarzyk et al., 2009): RR=1.33, 95% CI: 1.16-1.52. The unadjusted estimate for lung cancer was from one study (Ukawa et al., 2013): RR=1.35 (95% CI: 0.95, 1.92). The unadjusted RR estimates for colon (1.10 [95% CI: 1.00, 1.20]) and endometrial cancer (1.50 [95% CI: 1.32, 1.71]) were taken from two studies (Howard et al., 2008; Simons et al., 2013) and three studies (Friberg, Mantzoros and Wolk, 2006; Patel et al., 2010; Gierach et al., 2009), respectively.

2.3.3 Step 3. The prevalence of sedentary behaviour in UK adults

Prevalence adjustment factors were calculated for each health outcome (Table 2.3). Based on the HSE data, 32% of adults in England spend at least 6 hours sedentary per day. The percentage for men (34%) was slightly higher than that for women (31%). The survey data was for England only (NHS England, 2013) but will be used to represent the whole of the UK since England comprises the majority of the UK population (84%) and lifestyles are expected to be similar. Figure 2.1 presents the estimated prevalence of sedentary behaviour for UK adults overall and for each health outcome, calculated using the prevalence adjustment factors (Table 2.3).

2.3.4 Step 4. Population attributable fractions for each health outcome

PAFs calculated using both formulas are presented in Table 2.4. The PAFs calculated using adjusted RRs (equation 2) were the most appropriate to use for this analysis, given that confounding is highly likely. The highest PAF was 16.9% (95% CI: 14.0%, 19.6%) for T2D, followed by 9.0% (95% CI: 7.3%, 10.7%) for colon cancer, 8.0% (95% CI: 6.0%, 10.0%) of endometrial cancer, 7.5% (95% CI: 3.9%, 11.0%) of lung cancer, and 4.9% (95% CI: 4.2%, 5.5%) for CVD.

2.3.5 Step 5. NHS expenditure for each disease

The estimated gross expenditures for each disease are reported in Table 2.5. T2D accounts for 90% of overall diabetes incidence, therefore total diabetes expenditure was multiplied by 0.9 to estimate the costs from T2D only (Diabetes UK, 2017b). The cost of T2D in England, Scotland, and Wales was £1.4b, £88m, and £100m, respectively. In 2015, 2.5% of incident cases of T2D in the UK were in NI (Diabetes UK, 2017a). Therefore, using the gross expenditure for diabetes in England, Scotland, and Wales, an estimate of £42m was calculated for T2D expenditure in NI. The total UK expenditure on T2D was estimated at £1.7b for 2016/17. CVD costs were extracted from the 'Problems of circulation' category in Programme Budgeting Data. The cost of CVD in the England, Scotland, and Wales was £7.1b, £8.4b, and £469m respectively. Incident cases of CVD accounted for 2.8% of all UK diagnoses in 2017 (British Heart Foundation, 2017). Therefore, based on the gross expenditure in the rest of the UK, CVD expenditure in NI was estimated at £245m. Total UK expenditure on CVD was estimated to be £8.7bn.

The expenditure for lung, colon and endometrial cancer was available for England and Scotland. England spent £180m, £252m, and £71m and Scotland spent £50m, £44m, and £9m on those cancers respectively. Only expenditure on all cancers was available in Wales. Spending was assumed to be similar to England, therefore expenditure was estimated by multiplying the English costs by the proportion of the population, giving £17m, £32m, and £8m for Wales. It should be acknowledged that this may underestimate the healthcare spending in Wales since there is evidence that Wales spends more per head on cancer care than England (Shared Services Partnership, 2014). Cancer was estimated to account for £56m of the costs attributable to sedentary behaviour in the UK. If this is an underestimate, this would result in a lower overall estimate of the costs attributable to sedentary behaviour in the UK. However, since

Wales accounts for less than 5% of the UK population, the difference would be very small in the total estimate.

Incident cases of lung, colon and endometrial cancer in NI comprised 2.7%, 2.7%, and 2.8% of UK cases respectively. Using the same methods as above, NI cancer expenditure was estimated to £7m, £9m, and £3m. Overall, the estimated UK expenditure on lung, colon and endometrial cancer was £254m, £328m, and £91m.

2.3.6 Step 6. Costs attributable to prolonged sedentary behaviour

The NHS costs attributable to prolonged sedentary behaviour are presented in Table 2.6 and Figures 2.2 and 2.3. CVD is associated with the greatest costs attributable to prolonged sedentary behaviour of £424m (95% CI: £367m, £480m), followed by £281m (95% CI: £233m, £327m) for T2D. Costs for specific cancers attributable for prolonged sedentary behaviour were much lower; £19m (95% CI: £10m, £28m) for lung cancer, £30m (95% CI: £24m, £35m) for colon cancer, and £7m (95% CI: £5m, £9m) for endometrial cancer. Figure 2.2 presents the costs attributable to prolonged sedentary behaviour by disease. Together, the total costs attributable to prolonged sedentary behaviour are £762m (95% CI: £639m, £879m) (Table 2.6). Total UK NHS health expenditure is estimated to be £65.7bn for 2016/17, indicating that prolonged sedentary behaviour accounted for 1.2% of total expenditure. £633m of the annual costs are spent in England; £64m is spent in Scotland; £45m in Wales; and £20m in NI.

After adjustment for double-counting, the NHS costs attributable to sedentary behaviour were £677m. Using the alternative method from Ding et al. (2016), after subtracting 8.82% of T2D expenditure, the total costs attributable to sedentary behaviour were £737m.

A further sensitivity analysis excluded diseases for which only moderate evidence of an association was available. The total costs attributable to sedentary behaviour were £706m (95% CI: £600m, £807m), i.e., approximately eight per cent lower. The small change is due to the much lower incidence and prevalence of the individual cancers in comparison to CVD and T2D expenditure.

Table 2.7 displays the costs attributable to diseases associated with prolonged sedentary behaviour in the UK in 2016/17 using the unadjusted PAFs (step 4, equation 3), instead of the adjusted PAFs (step 4, equation 2). The total costs are £1.4b, higher than the original estimate by a factor of 1.8. The cost of T2D attributable to prolonged sedentary behaviour would be £0.5bn (1.9 times higher); CVD would cost £0.8bn (2.0 times higher); lung cancer would cost £25m (1.3 times higher), and endometrial cancer would cost £12m (1.7 times higher). Colon cancer was the only disease to decrease in its estimate: £10m (2.9 times lower).

2.4 Discussion

2.4.1 Summary of findings

Prolonged sedentary behaviour cost the NHS £0.7bn annually in 2016-17 costs. The total costs are likely to be a conservative estimate of the true burden of prolonged sedentary behaviour. The analysis only included five diseases, but prolonged sedentary behaviour may increase the risk of other health conditions, for which sufficient evidence is not yet available. There are reported links between prolonged sedentary behaviour and several other cancers (Rezende et al., 2014), musculoskeletal disorders (Rezende et al., 2014), cognitive function (Falck, Davis and Liu-Ambrose, 2017), and mental health disorders (Hoare et al., 2016; Rezende et al., 2014; Werneck et al., 2018).

PAFs were calculated for the associations between prolonged sedentary behaviour and CVD, T2D, and colon, endometrial and lung cancers, which ranged from 4.9% to 16.9%. The PAFs can be interpreted as the theoretical reduction in cases of diseases if prolonged sedentary behaviour was eliminated. This is a highly unlikely scenario, although it illustrates the potential that PHIs to reduce prolonged sedentary behaviour might have. Patterson et al., (2018) also calculated PAFs for prolonged sedentary behaviour in a recent meta-analysis, using TV viewing time as the exposure in a Monte-Carlo micro-simulation. Due to the different methodology, direct comparison with the current findings is difficult. Nevertheless, it is interesting to note that the PAFs for T2D and CVD are of the same rank order (i.e., T2D > CVD). The PAFs for CVD are similar (5% [95% CI: 1%, 8%] from Patterson et al. vs. 4.9% (95% CI: 1.8%, 7.9%) in the present study). The similar results indicate that there is considerable agreement in the observed pattern of the relationships. Patterson et al. (2018) also calculated a PAF for all-cause mortality: it was not included here as it was not one of the health outcomes involved in the direct healthcare costs of sedentary behaviour.

Prolonged sedentary behaviour appears to cost less than the other well-known risk factors: Scarborough et al. (2011) reported that in 2006-07 poor diet cost the NHS £5.8b; smoking cost £3.3b; alcohol cost £3.3b; and overweight/obesity cost over £5b, although this included the costs from poor diet and physical activity. Prolonged sedentary behaviour appears to cost less than smoking, poor diet, and alcohol. The reasons for the variation in costs associated with different risk factors is due to the variation in their prevalence, the diseases associated, and the cost of those diseases. Smoking increases the risk of several respiratory diseases including lung cancer and chronic obstructive pulmonary disease which lead to higher mortality rates and may require expensive long-term treatment with oxygen. Excessive alcohol drinking increases the risk of many diseases as well as the risk of accidental injury or death. Both smoking and excessive drinking are prevalent in the UK (15-20% UK adults) (Scarborough et al., 2011). These risk factors are also worthy of PHIs.

A sensitivity analysis revealed large differences between PAFs using adjusted RRs and PAFs using unadjusted RRs. The total cost estimate using unadjusted PAFs was almost twice as high as the estimate using the adjusted PAFs (£1.4bn vs. £0.8bn). This is logical given that the adjusted RRs account for important confounders and demonstrates the importance of choosing the appropriate equation to calculate PAFs, especially in cost of illness studies.

2.4.2 Strengths and Limitations

This study represents the first estimation of healthcare costs associated with prolonged sedentary behaviour in the UK. PAFs were calculated using the best data available: all conditions with strong or moderate evidence of an association, as reported by the Physical Activity Guidelines Advisory Committee, (2018). The analysis followed several suggestions from a checklist for reporting estimates of the economic costs of risk factors (Ding et al., 2017), produced to standardise studies of the cost of risk factors. Importantly, all RRs used to generate the main findings had accounted for the effect of physical activity, a confounder in the relationship between prolonged sedentary behaviour and health (Ekelund et al., 2016). The costs associated with prolonged sedentary behaviour are presented with relatively narrow uncertainty limits (Table 2.6), indicating that the estimates are reasonably precise. The total costs have also been adjusted for potential double-counting of co-morbidities to produce a conservative estimation. A sensitivity analysis which calculated the costs associated with prolonged sedentary behaviour using PAFs generated with crude or minimally-adjusted RRs estimated the healthcare costs 180% higher (Table 2.7). These results underline the importance of using appropriately adjusted risk estimates to avoid inflated estimations.

The study also had several limitations. The literature on the health effects of prolonged sedentary behaviour is still growing, and the costs were restricted to diseases for which moderate or strong evidence of an association is available. A non-European study (Ukawa et al., 2013) was used to estimate the prevalence of prolonged sedentary behaviour in lung cancer cases, which may not fully reflect a UK population. Individual studies included in the meta-analyses varied in their choice of cut-off values for each category and their definition of prolonged sedentary behaviour, although they always compared the highest category of sedentary behaviour with the lowest. Crucially, six hours/day was the minimum median time spent in prolonged sedentary behaviour in the highest categories of sedentary time (Table 2.2). Nevertheless, the definition used for the prevalence of prolonged sedentary behaviour should ideally match the RR when calculating the PAF. Given that the minimum median sedentary time in the most sedentary class is 6 hours, and the definition of prolonged sedentary behaviour used in this study is spending at least six hours sedentary, the RRs reported here are plausible. Therefore, the PAFs are also reasonable estimations. There were insufficient studies with appropriate data to investigate a dose-response association for prolonged sedentary behaviour.

The study was further limited by self-reported data for prolonged sedentary behaviour. Self-reported measures are subject to more bias than objective measures. Social desirability bias occurs when participants answer in a way they perceive to be more socially acceptable, which can be conscious or unconscious. In the case of physical activity, participants may report being more active than they are. This could result in an underestimation of the harms of physical activity (Healy et al., 2011). Another example of bias related to self-reported measures is recall bias. When participants are asked to recall their behaviour in the past, it is likely to be incorrect. Recall bias may influence the estimations of associations between exposure and outcome in either direction (Healy et al., 2011).

The PAF-based approach is also limited as it is difficult to explore how costs may differ in population subgroups. The healthcare systems in the UK countries are likely to vary in efficiency, i.e., spending £1 in NI may buy less healthcare than in England. There could be subsequent unmet healthcare needs which vary by region if some healthcare systems are less efficient. Unmet healthcare needs would ultimately lead to premature mortality, adding to the indirect economic costs associated with prolonged sedentary behaviour. However, it is not possible to see the variation in healthcare spending due to the top-down methodology used here. To explore the distribution of healthcare costs in a population, econometric methods are more appropriate.

2.4.3 Implications of the study and future research

The evidence-policy gap has been widely acknowledged (Oliver et al., 2014; Brownson, Chriqui and Stamatakis, 2009). Barriers to effective policy-making may include insufficient evidence available to inform a decision, lack of involvement with researchers, and difficulties in understanding scientific reports (Brownson, Chriqui and Stamatakis, 2009). The strengths and weaknesses of this study have been presented clearly for the benefit of other researchers and policymakers. The findings could be used to make a financial case for investment in reducing sedentary behaviour in UK adults. The cost estimates and PAFs can be used to compare prolonged sedentary behaviour with other risk behaviours to inform decision making in public health. It is still unknown how much PHIs to reduce sedentary behaviour might cost, however, these findings present part of the picture. Many individuals in the UK spend their leisure time in prolonged sedentary behaviour, and the workplace represents a significant proportion of what may be unavoidable daily sitting time for many people. Studies should focus on cost-effective ways of reducing prolonged sedentary behaviour.

Previous studies of the economic cost of physical inactivity and the present study used self-reported physical activity and sedentary behaviour data. Self-reported data is subject to notable limitations including potential reporting bias and response bias. Reporting bias can arise from participants not reporting their behaviour accurately simply from memory errors. Response bias can arise due to a conscious or unconscious desire to appear more socially acceptable: social desirability bias. Nevertheless, self-reported data is a straightforward and low-cost method to collect data in large studies.

Ideally, prospective studies could use a combined method of both accelerometers and behaviour logs, repeated over time, when measuring this behaviour. Accelerometers would provide objective measures of the activity, reducing the risk of bias, and behaviour logs could provide context for the objective measures to allow for recoding if necessary. An exploration of the indirect costs of sedentary behaviour due to reduced productivity and absenteeism and other out-of-pocket costs would be an interesting study for future research. Although sedentary behaviour may not directly cause the high healthcare costs related to other risk factors, e.g., smoking tobacco, it may have indirect consequences on many people's lives. Long term sedentary behaviour could lead to reduced fitness that prevents individuals from working and fully participating in society. there could be significant economic costs from the knock-on effects. The understanding of the full economic consequences of sedentary behaviour could serve as a wake-up call to governments to invest in interventions to reduce sedentary behaviour. Furthermore, consensus on how many hours/day of sedentary behaviour is harmful would be helpful in research, in line with the more specific guidelines for physical activity (Department of Health, 2011).

2.5 Conclusion

This analysis presents the first estimate of direct healthcare costs due to prolonged sedentary behaviour in the UK. Prolonged sedentary behaviour not only increases the risk of disease for many people in the UK but also causes a considerable burden to the NHS. Diseases associated with prolonged sedentary behaviour cost the NHS £0.8bn in 2016-17 costs, reduced to £0.7bn after adjustment for co-morbidities. These findings provide information to policymakers and other researchers on the economic impact of sedentary behaviour in the UK.

Table 2.1 Sedentary time definitions, reported ranges, and estimated medians of included studies

Health outcome	Study	Definition of sedentary behaviour	Sedentary time: range reported (top row) and estimated median (bottom row) (hours/day)[1]				
			Category 1	*Category 2*	*Category 3*	*Category 4*	*Category 5*
T2D	Hu *et al.* (2001)	Television watching	0-0.14	0.29-1.43	1.57-2.86	3.00-5.71	>5.71
			0.07	0.86	2.22	4.36	8.57
	Hu *et al*. (2003)	Television watching	0-0.14	0.29-1.43	1.57-2.86	3.00-5.71	>5.71
			0.07	0.86	2.22	4.36	8.57
	Krishnan *et al*. (2009)	Television watching	0-<1	1-2	3-4	≥5	N/A
			0.50	1.50	3.50	7.50	
	Ford *et al.* (2010)	Television watching	0-<1	1-2	2-3	3-4	≥4
			0.50	1.50	2.50	3.50	6.00
CVD incidence and mortality	Matthews et al. 2014)	Overall sedentary behaviour	<5.76	5.76-8.50	8.51-12	>12	N/A
			2.88	7.13	10.26	18.00	
	Petersen *et al.* (2014)	Total sitting time	0-<6	6-10	>10	N/A	N/A
			3.00	8.00	15.00		
	Herber-Gast *et al.* (2013)	Sitting time	2.7±0.8[2]	4.9±0.7	8.4±1.8	N/A	N/A
			2.70	4.90	8.40		

Health outcome	**Study**	**Definition of sedentary behaviour**	**Sedentary time: range reported (top row) and estimated median (bottom row) (hours/day)[1]**				
			Category 1	***Category 2***	***Category 3***	***Category 4***	***Category 5***
	Matthews *et al.* (2012)	Overall sitting	<3	3-4	5-6	7-8	≥9
			1.50	3.50	5.50	7.50	13.50
	Borodulin K *et al.* (2012)	Overall daily sitting	<10	>10	N/A	N/A	N/A
			5.00	15.00			
	Chomistek *et al.* (2013)	Sitting time	≤5	5.1-9.9	≥10	N/A	N/A
			2.50	7.50	15.00		
	Kim *et al.* (2013)	Total daily sitting	<5	5-<10	≥10	N/A	N/A
			2.50	7.50	15.00		
	Patel *et al.* (2010)	Sitting time	0-<3	3-5	≥6	N/A	N/A
			1.50	4.00	9.00		
	Katzmarzyk *et al.* (2009)	Daily sitting time	None	0.25 of time	0.5 of time	0.75 of time	All of time
			0.03	4.00	8.00	12.00	16.00
Lung cancer	Lam *et al.* (2013)	Sitting	<3	3-4	5+	N/A	N/A
			1.50	3.50	7.50		
		Television viewing time	<2	≥2-<4	≥4	N/A	N/A

Health outcome	Study	Definition of sedentary behaviour	Sedentary time: range reported (top row) and estimated median (bottom row) (hours/day)[1]				
			Category 1	*Category 2*	*Category 3*	*Category 4*	*Category 5*
	Ukawa *et al.* (2013)		1.00	3.00	6.00		
Colon cancer	Howard *et al.* (2008)	Sitting	<3	3-4	5-6	7-8	≥9
			1.50	3.50	5.50	7.50	13.50
	Simons *et al.* (2013)	Sitting time per day at longest-held job	<2	2-6	>6-8	N/A	N/A
			1.00	4.00	7.00		
Endometrial cancer	Friberg *et al.* (2006)	Sitting/television viewing time	<5	≥5	N/A	N/A	N/A
			2.50	7.50			
	Patel *et al.* (2008)	Sitting	0-<3	3-5	≥6	N/A	N/A
			1.50	4.00	9.00		
	Gierach *et al.* (2009)	Sitting	<3	3-4	5-6	7+	N/A
			1.50	3.50	5.50	10.50	

N/A = Not applicable. CVD = cardiovascular. [1]Range of sedentary time as reported in the study (hours/day). Median has been estimated and is below each range. [2]Only mean hours/day was reported here as categories were tertiles. [3]Medians were estimated based on 16 hours/day waking time. [4]Categories were in quartiles, these are reported hour cut-offs.

Table 2.2 Estimated adjusted and unadjusted relative risk estimates for each health outcome associated with sedentary behaviour

Health outcome	**Adjusted RR estimate (95% CI)**	**Unadjusted RR estimate (95% CI)**
T2D	1.88 (1.62, 2.17)	2.42 (1.94, 3.02)
CVD	1.14 (1.09, 1.19)	1.33 (1.16, 1.52)
Lung cancer	1.27 (1.06, 1.52)	1.35 (0.95, 1.92)
Colon cancer	1.30 (1.12, 1.49)	1.10 (1.00, 1.20)
Endometrial cancer	1.28 (1.08, 1.53)	1.50 (1.32, 1.71)

RR = relative risk; T2D =type 2 diabetes; CVD = cardiovascular disease.

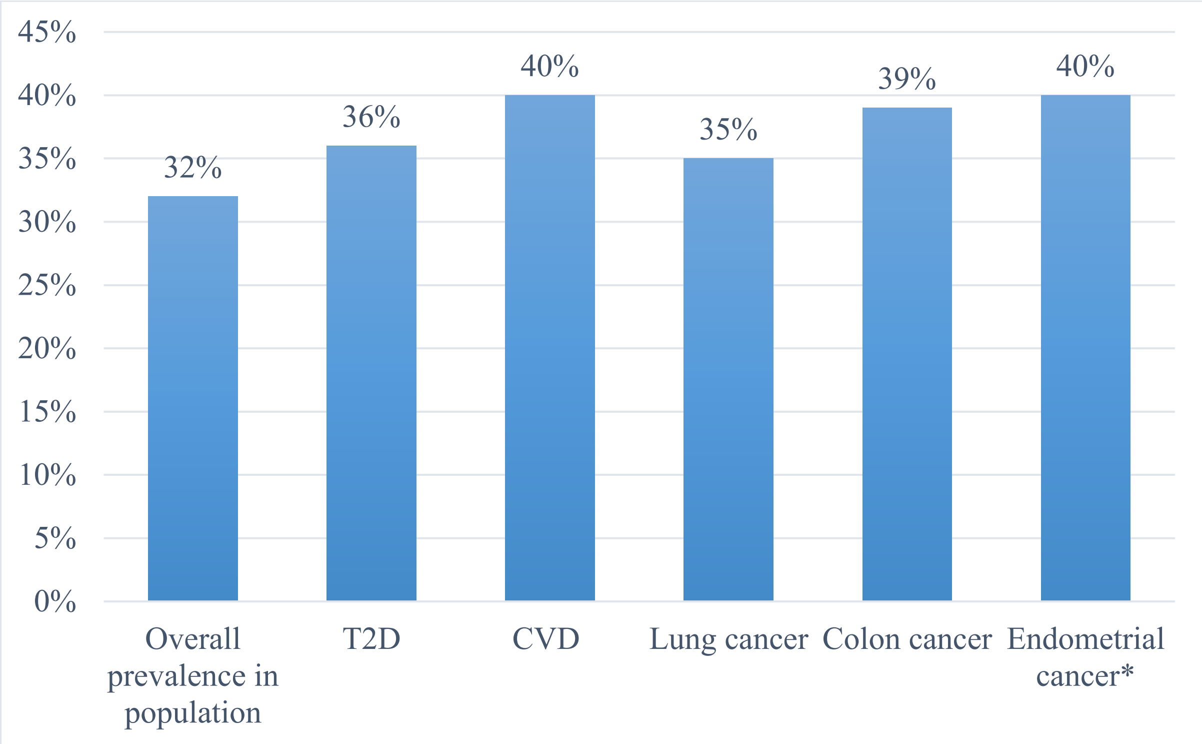
Table 2.3 Prevalence adjustment factors calculated from longitudinal study data

Disease	**Study**	**Prevalence of prolonged sedentary behaviour1 at baseline**	**Prevalence of prolonged sedentary behaviour1 in cases**	**Adjustment factor**
T2D	Stamatakis et al., 2017	0.34	0.38	1.12
CVD	Bjork Petersen et al., 2014	0.13	0.16	1.23
Lung cancer	Ukawa et al., 2013	0.25	0.28	1.10
Colon cancer	Simons et al., 2013	0.26	0.32	1.22
Endometrial cancer	Gierach et al., 2009	0.08	0.10	1.20

T2D = type 2 diabetes; CVD = cardiovascular disease.

[1]Prolonged sedentary behaviour assessed as spending at least six hours sedentary during waking hours.

Figure 2.1 Estimated prevalence of prolonged sedentary behaviour1 in UK adults overall and those with related health outcomes



*Women only. T2D =type 2 diabetes; CVD = cardiovascular disease.

[1]Prolonged sedentary behaviour assessed as spending at least six hours sedentary during waking hours.

Table 2.4 Population attributable fractions for sedentary behaviour and several health outcomes

Health outcome	PAF (%) (95% CI) using adjusted RR estimate	PAF (%) (95% CI) using unadjusted RR estimate
T2D	16.9% (14.0%, 19.6%)	31.3% (23.6%, 38.3%)
CVD incidence	4.9% (4.2%, 5.5%)	9.6% (4.3%, 14.6%)
Lung cancer	7.5% (3.9%, 11.0%)	10.1% (-11.7%, 27.6%)
Colon cancer	9.0% (7.3%, 10.7%)	3.1% (-0.5%, 6.6%)
Endometrial cancer	8.0% (6.0%, 10.0%)	13.3% (8.7%, 17.7%)

PAF = population attributable fraction; CI = confidence interval; RR = relative risk; T2= type 2 diabetes; CVD = cardiovascular disease.

Table 2.5 Gross expenditure on diseases associated with sedentary behaviour in the UK

	Gross expenditure (£million, 2016-17) by UK region				
Disease	England[1]	Scotland[1]	Wales	Northern Ireland[2]	UK Total
T2D	£1,437.66	£88.07	£100.18	£41.69	£1,667.60
CVD	£7,177.39	£838.19	£468.90	£244.41	£8,728.88
Lung cancer	£179.77	£50.19	£17.52	£6.87	£254.35
Colon cancer	£251.84	£44.24	£32.14	£8.86	£328.22
Endometrial cancer	£71.10	£9.25	£7.82	£2.54	£90.71

T2D = type 2 diabetes; CVD = cardiovascular disease.

[1]Costs inflated to 2016/17 costs from 2013/14 costs (England) and 2011/12 costs (Scotland) using HCHS index.

[2]Northern Irish costs estimated based on incidence rates in comparison with the rest of the UK.

Table 2.6 Costs attributable to prolonged sedentary behaviour by health outcome

Disease	UK NHS costs attributable to prolonged sedentary behaviour (£million, 2016-17 [95% CI])
T2D	£281.34 (£233.46, £326.85)
CVD	£424.38 (£366.61, £480.09)
Lung cancer	£19.16 (£9.92, £27.98)
Colon cancer	£29.64 (£23.96, £35.12)
Endometrial cancer	£7.29 (£5.44, £9.07)
Total costs	£761.80 (£639.40, £879.11)

UK = United Kingdom; NHS = National Health Service; CI = confidence interval; T2D = type 2 diabetes; CVD = cardiovascular disease.

Figure 2.2 Costs attributable to prolonged sedentary behaviour in the UK by disease and geographical region

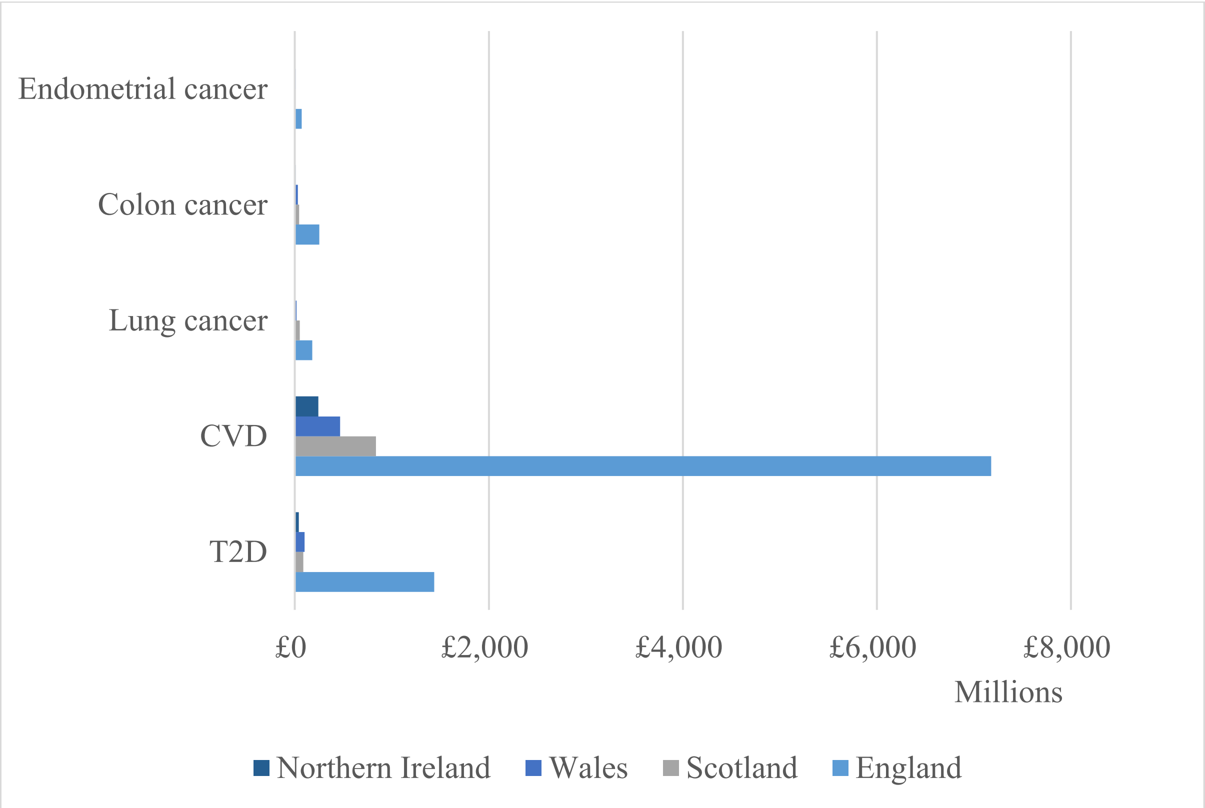
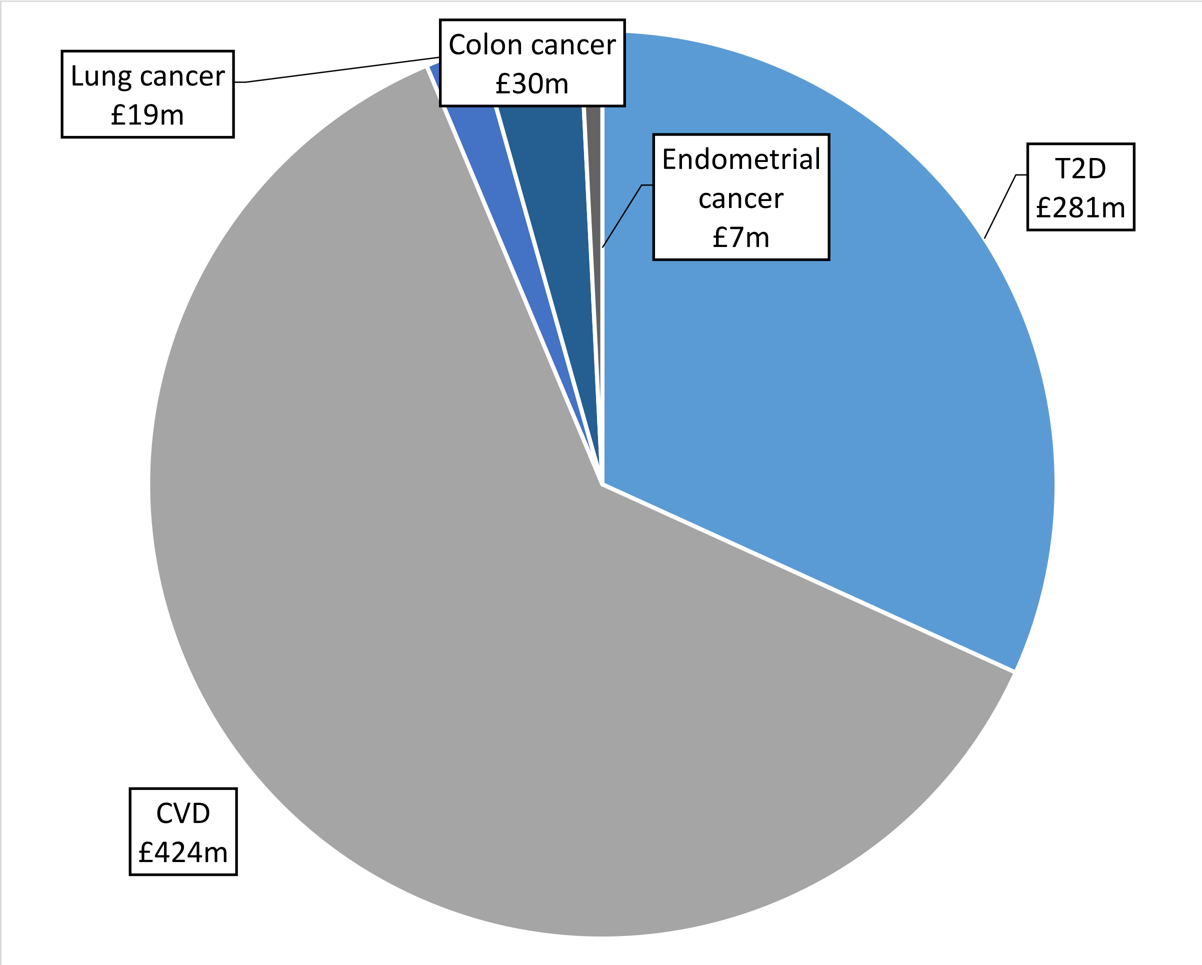


Figure 2.3 Costs attributable to prolonged sedentary behaviour by disease in 2016-17



T2D =type 2 diabetes; CVD = cardiovascular disease.

Table 2.7 Sensitivity analysis: costs attributable to sedentary behaviour using unadjusted population attributable fractions

Disease	UK NHS costs attributable to sedentary behaviour (£million, 2016-17)
T2D	£522.25
CVD	£836.34
Lung cancer	£25.70
Colon cancer	£10.21
Endometrial cancer	£12.08
Total costs	£1,406.58

UK = United Kingdom; NHS = National Health Service; CI = confidence interval; T2D = type 2 diabetes; CVD = cardiovascular disease.

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CHAPTER 3

INPATIENT CARE UTILISATION AND EXPENDITURE ASSOCIATED WITH ACCELEROMETER-MEASURED PHYSICAL ACTIVITY IN THE UK BIOBANK

3 INPATIENT CARE UTILISATION AND EXPENDITURE ASSOCIATED WITH ACCELEROMETER-MEASURED PHYSICAL ACTIVITY IN THE UK BIOBANK

3.1 Introduction

The previous chapter assessed the healthcare costs associated with sedentary behaviour using a population-level approach. This top-down approach can be a useful way to estimate healthcare costs, especially when individual-level data is not available. However, the 'bottom-up' approach, made popular in econometrics, has several advantages. Exploring healthcare costs associated with physical inactivity, not only sedentary behaviour, using an alternative approach is an interesting exercise. Furthermore, while the previous chapter used self-reported data on sedentary behaviour, the current chapter analysed objective physical activity data. The advantages and disadvantages of using both types of data are considered in this chapter and the discussion chapter of the thesis. This chapter contributes to the understanding of the financial impact of physical inactivity on the NHS using an econometric approach. To the author's knowledge, this is the first example of using the econometric approach to explore healthcare costs of physical inactivity in the UK.

There are alternatives to using the PAFs for estimating healthcare costs associated with physical inactivity and one of these involves a "bottom-up", or microcosting, approach made popular in econometrics. Microcosting is the process of estimating the cost of every treatment received by a patient (Xu et al., 2014). Its advantages include the precise counting of individual healthcare costs, which can be preferable to the more accessible population-level budget costs. Costs can be captured by directly measuring activities, using billing costs, or regression measures, as in this study. Choice of methodology depends on data availability and requirements of the stakeholders. Direct measurement involves precisely quantifying each treatment, identifying its costs and summing the total treatment costs. This can be achieved by analysing individual participant data alongside RCTs. The level of precision required means that direct measurement is a time-consuming and costly approach to microcosting. An alternate approach is to use regression to assess the marginal costs associated with an exposure or intervention.

Microcosting can, in principle, overcome some of the limitations of the PAF approach outlined in Chapter 2 using observed individual-level data to model the effect of physical inactivity on healthcare spending, adjusting for sociodemographic variables, and known confounders. The top-down PAF approach assumes that healthcare utilisation and costs occur through only a few diseases, often for which data is available, e.g., Ding et al. (2016) includes five diseases (coronary heart disease, stroke, T2D, breast cancer, and colon cancer) in an estimate for the economic cost of physical inactivity. In reality, physical activity is associated with a reduced risk of many conditions, including obesity, dementia, several cancers, osteoarthritis, hypertension and T2D (Physical Activity Guidelines Advisory Committee, 2018). The econometric approach avoids those assumptions and facilitates comparison between population subgroups.

While Chapter 2 explored the costs of sedentary behaviour using a PAF-based approach, Chapter 3 assesses the costs of physical inactivity using an econometric approach. Both analyses consider the financial cost of physical inactivity or sedentary behaviour to the NHS in the UK but using different methodologies. Chapter 2 used self-reported sedentary behaviour data, which is more commonly available although subject to reporting bias. Whereas in this chapter, objective physical activity data were recorded using accelerometers. In order to understand the economic impact of physical inactivity and sedentary behaviour, it is useful to use both approaches, analyse the results, and compare and contrast them. There are several advantages of the econometric approach over the PAF-based approach. Firstly, it is more flexible in terms of adjusting for confounding factors in the regression models. Secondly, the approach facilitates subgroup analysis, which is usually not possible when using PAF-based methods. Thirdly, the econometric method can theoretically capture all of the costs associated with the exposure, whereas the PAF-based approach requires the researcher to specify the known diseases beforehand. The methodology will be compared later in the discussion section of this chapter and the discussion chapter of the thesis.

Self-reported measures of physical activity are commonly used in epidemiological studies, partly due to the prohibitively high costs of objective measures obtained using instruments such as accelerometers. The best data available to measure sedentary behaviour for the analysis in chapter 2 was self-reported. For the analysis presented in this chapter, objective physical activity data were available in the UK Biobank dataset. Objective measures of physical activity such as accelerometers are subject to less recall bias and social desirability bias and are more reliable at capturing sedentary time and light physical activity than self-reported techniques (Lee and Shiroma, 2014; Prince et al., 2008). The error in subjective instruments leads to imprecision in estimating healthcare costs. Objective instruments such as accelerometers improve the accuracy of the estimate. Recently, accelerometers have become a cheaper and more feasible method of measurement in large epidemiological studies. For example, participants in the UK Biobank study provided physical activity data using wrist-worn accelerometers, which presents a welcome opportunity to assess the impact of physical activity on healthcare resource use using an objective measure.

Inpatient hospital data was available for all UK Biobank participants, whereas primary data was only available for 45% of the cohort. Since inpatient hospital care represents the most expensive area of healthcare and it is less likely to be biased by healthy individuals seeking unnecessary treatment. The relationship between objectively measured physical activity and subsequent inpatient days and costs in UK adults were examined using individual-level prospective data. In this chapter, these relationships are examined in the full sample and in samples partitioned by gender and by income level, to explore relationships among subgroups.

3.2 Methods

3.2.1 Study population

The UK Biobank is a large prospective study of 502,516 adults aged 40-69 living in England, Scotland and Wales (Sudlow et al., 2015). Participants gave their consent, completed an electronic questionnaire, and researchers collected biological samples and physiological measurements at UK Biobank recruitment centres between 2006 and 2010. Participants' data is linked to national health records on deaths, cancer, hospital inpatient, hospital outpatient, and primary care, with further linkages planned on other health-related records (Sudlow et al., 2015). The UK Biobank data was assessed by applying on the UK Biobank website (https://www.ukbiobank.ac.uk/enable-your-research/apply-for-access). The UK Biobank study had ethical approval from the North West—Haydock Research Ethics Committee, reference 11/NW/0382. This analysis used anonymised data and therefore did not require additional ethical approval.

The main limitation of the UK Biobank is that it does not fully represent the UK population. The participants are wealthier, more educated, and less diverse than average. Therefore, the results of any analysis on the UK Biobank data is susceptible to bias. This effect may be even more pronounced on the sample who agreed to wear an accelerometer for one week since this additional contribution required even more motivation. Nevertheless, the UK Biobank dataset can still provide us with a wealth of information on the health of the UK. Furthermore, Stamatakis et al. (2021) demonstrated that effect estimates for associations between physical inactivity and health hazards were similar in weighted and unweighted samples In other words, although biased, the data can still provide valuable information on health associations.

3.2.2 Outcome variables

3.2.2.1 Inpatient care utilisation

NHS primary care, hospital records, and death registrars from Hospital Episode Statistics (HES) in England and the Patient Episode Database in Wales (PEDW) were linked with individuals in the UK Biobank cohort. The HES records are available from 1996 to 31st March 2017 and the PEDW records from 1999 until 29th February 2016. The present analysis focused solely on inpatient activity, which is the most expensive area of healthcare for the NHS. Primary care data was only available for 45% of the cohort therefore it was not explored in this analysis. Episodes were removed that occurred before baseline to assess the prospective effect of physical activity, measured between June 2013 and December 2015. Since inpatient data from Scotland is collected differently, the data were not comparable with the English and Welsh data. Therefore, participants with a home address in Scotland or with Scottish health records were excluded from the analysis.

An inpatient is a patient who is admitted to hospital for treatment and occupies a hospital bed, without necessarily spending the night. A hospital episode is the time during which a patient is under the care of one consultant, and a hospital admission may consist of one or more episodes. The data available included the type of episode (general, maternity, or psychiatric); the type of admission (elective or non-elective); and the dates of admission and discharge. Maternity episodes or those with missing episode type (2,145 episodes had missing types, 2.9% of all episodes) were removed from the analysis. Maternal healthcare episodes were considered distinct to service use related to ill health. Episodes without a type recorded may not have been missing at random, therefore they were removed from the analysis for simplicity rather than risk biasing estimates. There were no psychiatric episodes in the sample. Length of follow-up ranged from less than 1 year to 3 years 10 months. Participants with insufficient follow-up time to provide robust estimates of service use (less than one year) were excluded. To make the inpatient data comparable, the days spent in hospital as an inpatient were summed and divided by months of follow-up to create a variable of mean monthly inpatient days. Inpatient days were discounted to reflect their present value in 2013 using the same methods as inpatient costs to reflect the time preference concept, where a hospital episode in the present year is valued differently to an episode in the future.

3.2.2.2 Inpatient care costs

Inpatient episodes were monetised using 2017 unit costs of health and social care from the Personal Social Services Research Unit (PSSRU) (Curtis and Burns, 2017). Costs were expressed as a discounted stream arising after baseline, with the years after 2013 discounted by 3.5% as recommended by the NICE (National Institute for Health and Care Excellence, 2013) (Table 3.1). The cost applied to each episode depended on whether it was a day case or if the patient stayed overnight. In the case of an overnight stay, the cost depended on the episode type: elective/non-elective and short/long stay. A long stay was defined as one that lasted at least 21 days, as defined in the NHS literature (https://improvement.nhs.uk/documents/3005/Long-stay_patients_methodology.pdf). The total discounted expenditure for all episodes experienced by each participant was divided by the months of follow-up to create a variable of mean monthly inpatient costs.

3.2.3 Explanatory variables

Researchers invited a sample of the UK Biobank cohort to wear a wrist-worn Axivity accelerometer and posted the devices to consenting individuals. Over 100,000 participants wore the accelerometer for seven days in 2013-2015. Doherty et al. cleaned and processed the raw acceleration data, producing a variable of overall acceleration average in milli-gravities, a proxy for total physical activity energy expenditure (van Hees et al., 2011). Individuals with insufficient wear time (not meeting requirements of ≥72 hours wear time and data recorded in each one-hour period of the 24-hour cycle), poorly-calibrated data, or recording problems were excluded (Doherty et al., 2017).

Participants were divided into tertiles for the analysis based on their overall acceleration average: tertile 1, least active (2.6mg to 24.0mg); tertile 2 (24.0mg to

30.4mg); tertile 3, most active (30.4mg to 224.5mg). Acceleration in milligravities is not easily conceptualised, therefore cut-off thresholds estimated by Hildebrand et al. (2014, 2017) were used to estimate the median minutes spent in activity equivalent to at least brisk walking (≥4.3 METs (Ainsworth et al., 2011), as was done in a recent study of the UK Biobank (Chudasama et al., 2019). The significance of using the thresholds in this analysis is that the physical activity measurements might be less reliable since the thresholds were developed in a separate and younger population. Brisk walking at 4.3 METs is equivalent to acceleration of at least 250mg, according to regression equations from a calibration study (Hildebrand et al., 2014). Hildebrand et al. assessed acceleration while a sample of 30 adults (aged 18 to 65 years) completed a range of activities wearing a comparable accelerometer on their wrists. Tertile 1 had a median of 30.2 mins (IQR [interquartile range]: 30.2) of at least brisk walking per week. Tertiles 2 and 3 had medians of 70.6 mins (IQR: 50.4) and 151.2 mins (IQR: 100.8), respectively (Table 3.2).

Acceleration data was also translated into time spent in physical activity states (sedentary, light-intensity, moderate-intensity, and vigorous-intensity physical activity) using threshold cut-offs estimated by Hildebrand et al. (2014, 2017) (Table 3.2). The cut-offs used were <45.8mg for sedentary behaviour; 45.8mg-93.2mg for light physical activity; 93.2mg-418.3mg for moderate physical activity; and >418.3mg for vigorous physical activity. The closest available cut-off point in the data was used to estimate the distribution of time the participants spent in each state. These are the best available cut-offs for the accelerometer used and population in the UK Biobank. A sensitivity analysis was conducted using the physical activity level self-reported by the participants to compare the different measurements of physical activity.

3.2.4 Covariates

The models adjusted for the following covariates: gender (male or female); age (continuous); ethnic background (white British, Irish, or other ethnicity); household income (< £18,000, £18,000 - £30,999, £31,000 – £51,999, £52,000 - £100,000, >£100,000); body mass index (BMI) (<18.5kg/m2, 18.5 - 25kg/m2, 25 - 30kg/m2, >30kg/m2); waist-to-hip ratio (continuous); Townsend deprivation index (quintiles); long-standing illness, disability or infirmity (yes or no); smoking status (never, previous, or current); marital status (married/cohabiting or not); and education (university level or not). The choice of these covariates was based on previous analyses on physical activity level and healthcare use (Carlson et al., 2015; Karl et al., 2018). Participants who died within two years of baseline were removed to mitigate the risk of reverse causation. At the end of life, age-related declines in physical function lead to reduced capacity for physical activity and reduced physical activity levels.

3.2.5 Statistical Analysis

The main aims of the analysis were to estimate the effect of objectively measured physical activity on inpatient care (mean monthly inpatient days) and associated costs (mean monthly inpatient costs). The statistical analysis was planned in advance, although the protocol was not published in advance. Some of the sensitivity analyses were decided after the initial data analysis had been conducted. The highly skewed distribution of the inpatient days and cost reflects the fact that many individuals did not use the healthcare service while a few individuals were heavy users of it. Generalised linear models (GLMs) were used to estimate the relationships, which can accommodate skewed data better than an ordinary least squares model (Deb, Norton and Manning, 2017). The Akaike and Bayesian information criteria (AIC and BIC) were jointly used to determine the most appropriate link function and distribution family for the GLMs.

The incremental effects of the more active tertiles (tertiles 2 and 3) were estimated on mean monthly inpatient days and costs, using the least active tertile 1 as a reference. Mean monthly inpatient days and costs were also examined in each physical activity tertile, adjusted for the covariates. The percentage difference in inpatient costs was calculated, comparing the more active tertiles with the least active tertile. The models of all participants included an interaction term for age and gender. The estimates used robust standard errors. Data analyses were performed using Stata version 15.1 (StataCorp, College Station, Texas).

3.2.5.1 Sensitivity analyses

There are known differences in physical activity engagement by gender and socio-economic status: men and individuals with higher socio-economic status are typically more active (Azevedo et al., 2007; Gidlow et al., 2006). Therefore, several sensitivity analyses were conducted to explore potential socio-demographic patterning in the relationships. Firstly, the main models assessed men and women separately. Then, the association between objectively measured physical activity (acceleration) was graphed as a continuous variable and inpatient costs at five-year intervals of age, for men and women. Additionally, the association between accelerometer-measured physical activity and mean monthly inpatient days by household income was assessed by running the main model with an interaction term between continuous acceleration and household income category.

Several additional sensitivity analyses were conducted. (1) Participants with long-standing illness were under-represented in the more active physical activity tertiles therefore they were excluded to explore whether the effect of physical activity on inpatient days was similar in the healthier participants. (2) Participants who had died within two years of baseline were re-included; they had been excluded to mitigate potential reverse causation. (3) Participants with less than one year of follow-up were re-included. (4) Episodes of unknown type were re-included and monetised using the methodology described in section 3.2.2.2. (5) Inpatient days were not discounted. (6) Endogeneity can occur when the error term in a model is correlated with an explanatory variable and can produce inconsistent results. Since BMI and physical activity are correlated, there is a risk of endogeneity. The residuals were obtained from a regression between BMI and the continuous objective physical activity variable (average overall acceleration). The residuals represent BMI which is not associated with the level of physical activity. The BMI residuals were input into the main model using methodology outlined by Terza, Basu and Rathouz (2008). (7) For the sake of comparison, the model used self-reported physical activity recorded at recruitment as an explanatory variable in an additional analysis. The electronic questionnaire at recruitment included an adapted version of the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). Participants provided frequency and duration of walking, moderate physical activity and vigorous physical activity. Their responses were processed and scored using estimated METs for each activity: 2.3 METs for walking, 3.0 METs for moderate activity, and 7.0 METs for vigorous activity (Donnell et al., 2020). The total estimated METs per week was used to create a binary variable which indicated whether participants achieved the equivalent of 150 minutes of walking or moderate physical activity or 75 minutes of vigorous physical activity per week, the current WHO physical activity recommendations (World Health Organisation, 2010).

3.3 Results

3.3.1 Descriptive analysis

The sample included 86,067 individuals aged 43 to 79 years at baseline with valid accelerometer data for analysis after excluding those who had died within two years of baseline, had insufficient follow-up time or lived in Scotland (Figure 3.1). Two-thirds of the participants had no inpatient episodes during the follow-up time (mean and median two years, four months), resulting in a highly skewed distribution of data. The remaining third of participants incurred mean monthly inpatient costs of £92.74 (SD = £199.68). The majority of participants were female, white British, and lived with a spouse or partner (Table 3.3). Most had never smoked and self-reported high levels of physical activity, with 70% meeting national recommendations in terms of MVPA and walking. Participants were divided into tertiles according to their level of accelerometer-measured physical activity (Table 3.4). Participants in tertile 1 achieved a median of 30.2 minutes per week of activity at an intensity equivalent to brisk walking (≥4.3 METs), whereas tertiles 2 and 3 had higher medians of 70.6 minutes and 151.2 minutes, respectively. According to objective physical activity levels, the most active individuals were more likely to be female, younger and have a higher income (Table 3.4). The least active tertile included many more people with overweight or obese BMIs and long-standing illnesses, which is suggestive of endogeneity and therefore, they were included as covariates in the subsequent analysis.

Table 3.5 displays the crude relationship between the covariates and the mean monthly inpatient days and costs. The results suggest that higher physical activity level, female gender, younger age, higher household income, normal BMI, lack of long-standing illness, not smoking, and having a university education were correlated with fewer inpatient days and lower inpatient costs. There were no large differences in days or costs for different ethnic backgrounds or marital status.

3.3.2 Main associations using GLM models

As determined jointly by the AIC and BIC, all the GLMs used a log link and a Gamma family. All statistical models adjusted for the covariates described in the methods section. First, the relationship between objectively measured physical activity and mean monthly inpatient days was investigated (Table 3.6). Higher levels of physical activity were associated with significantly fewer inpatient days. There was a decreasing trend in inpatient days with increased objective physical activity, evident in the decreasing number of predicted days. Participants in the middle tertile experienced 0.024 fewer inpatient days per month (95% CI: -0.047 to -0.001) and the most active tertile had 0.037 fewer days (95% CI: -0.059 to -0.016), equivalent to 0.3 and 0.5 fewer predicted annual inpatient days.

Secondly, the association was explored between objectively measured physical activity and mean monthly inpatient costs (Table 3.7). Monthly inpatient costs were discounted by 3.5% and represent the present value in 2013 when follow-up began. Higher levels of objective physical activity were associated with significantly lower inpatient costs. The middle tertile incurred 11.5% lower monthly costs (-£3.09 [95% CI: -£5.75 to -£0.42]) than the least active tertile and the most active tertile incurred 14.1% lower monthly inpatient costs (-£3.81 [95% CI: -£6.71 to -£0.91], equivalent to £45.72 annually). There was a negative trend between increasing objective physical activity and decreasing inpatient costs.

3.3.3 Sensitivity analysis

In sensitivity analyses, the associations were explored separately by gender. Tables 4.8 and 4.9 present the results. The models were the same as the main models used for the whole sample, except for when monthly costs were modelled in men only, which had a square root link. There was a similar decreasing trend in inpatient days seen in men and women separately, although the associations were only significant in the most active group, tertile 3. The effect of physical activity on inpatient days was stronger in men. Furthermore, men had more predicted inpatient days than women in both of the more active tertiles. With respect to inpatient costs, objective physical activity was associated with significantly lower costs in women, although not in men. There was also no clear trend in the association in men.

Figure 3.2 displays the average incremental effects of accelerometer-measured physical activity on inpatient costs for men and women separately, over an age range of 43 to 79 years. Physical activity is associated with lower inpatient costs in women compared to men from ages 40 to 61. In older age, the apparent effect of physical activity on inpatient costs is stronger for men. The CI widens with increased age, however, it appears that there is a significant difference in the effect of physical activity on inpatient costs between the youngest and oldest participants.

Figure 3.3 presents the association between accelerometer-measured physical activity and predicted mean monthly inpatient days in all participants and by household income graphically. The association between physical activity and inpatient days differs among household income categories (Fig. 3b) and from the overall estimate shown in Fig. 3a. The highest income groups (>£52,000 per annum) experience little to no change to the number of inpatient days at different levels of physical activity. There is a non-significant trend in the middle-income groups (£18,000 - £51,999 p.a.) of fewer inpatient days as physical activity level increases. However, the lowest income category (<£18,000 p.a.) experience significantly fewer inpatient days in the highest tertile of physical activity compared to the least active tertile.

Table 3.9 presents the results of the additional sensitivity analyses: (1) Participants with long-standing illness excluded; (2) Participants who died within two years of baseline included; (3) Participants with less than one year of follow-up included; (4) Episodes of unknown type included; (5) Discounting inpatient days; (6) Potential endogeneity due to BMI addressed by using residuals rather than raw variable; (7) Self-reported physical activity as the explanatory variable. The associations did not change in models (2) and (3) which suggests that the main model is robust although only a small number of participants were re-included in these cases. Similarly, the association in (6) did not change, indicating that the model is robust with respect to the relationship between inpatient days and physical activity level. The effect was attenuated slightly in models (1) and (4) when participants with long-standing illness were excluded and episodes without a type recorded were included. The effect sizes were smaller when inpatient days were not discounted in the model (5). There were no clear trends or significant associations in both inpatient days and costs when self-reported physical activity was used as the explanatory variable in (7).

3.4 Discussion

The results of the study show that higher levels of accelerometer-measured physical activity were associated with significantly fewer inpatient days and reduced inpatient costs, after adjusting for BMI, long-term illness, and other socio-demographic factors. The more active individuals incurred lower costs than the least active group (-£3.09/month [95% CI: -£5.75 to -£0.42] in tertile 2 and -£3.81/month [95% CI: -£6.71 to -£0.91] in tertile 3). Although the cost per individual is low, approximately 30 million adults aged 40-80 live in the UK (2018 estimate). If the UK Biobank is representative of the wider population, the more active tertiles of the population cost an estimated £371m and £457m less in annual inpatient hospital costs to the NHS[1]. Since this sample is likely to be healthier than the wider UK population due to selection bias, these estimates are likely to be lower bounds of the true value. Therefore, increasing physical activity in the UK could bring substantial savings for the NHS in terms of inpatient costs as well as benefits in terms of lost productivity associated with absenteeism and improved health-related QOL. Sensitivity analyses revealed that higher physical activity reduced inpatient days in men and women, but only reduced inpatient costs in women. Inpatient costs not only reflect the length of stay, but also the severity of the hospital episode. Non-elective stays and elective long stays are more expensive, while elective short stays and day cases cost less on average. The results suggest that more active adults are less likely to spend time as a hospital inpatient, and more active women, in particular, incur lower inpatient costs. These calculations indicate that the least active third of the population aged 40-70 years cost £371m more annually than the most active third. Scarborough et al. (2011) estimated that physical inactivity cost the UK £0.9bn annually, a figure not inconsistent with the £371m estimated here for inpatient costs among this age group. It would be interesting to examine data that were more representative of the whole population along with more healthcare records in order to estimate the total costs of physical inactivity in the UK using econometric methods.

The most active participants in the lowest income group experienced the most dramatic reduction in inpatient days, in stark contrast to the highest income group in which physical activity appeared to have no effect. Achieving higher levels of physical activity may offset some of the adverse health effects associated with lower SES. If the production of health is subject to diminishing returns these advantages may mean that higher levels of physical activity confer little additional benefit to those on the highest incomes. These findings have policy implications. PHIs must target lower-income groups to address this disparity for equity and efficiency reasons.

[1] To estimate the annual differences in inpatient costs at a population level, the monthly differences in costs (-£3.09 and -£ 3.81) were multiplied by 12 to find the annual costs (-£37.08 and -£45.72). Approximately 30 million adults are aged 40-80 in the UK in 2018; 10 million adults are in each tertile. Therefore, multiplying the annual costs by 10 million, the two more active tertiles in the population would consume £37.1m and £45.7m less on inpatient care than their less active counterparts. These estimates serve to illustrate that small differences at an individual level can result in large costs at a population level.

The results are in line with other econometric studies, which have also found that higher levels of physical activity were associated with lower healthcare use or costs in population-based samples (Carlson et al., 2015; Ku et al., 2017; Kang and Xiang, 2017; Karl et al., 2018). Given the differences in the samples and that most studies used self-reported physical activity, the results cannot be directly compared. However, Ku et al. (2017) and Carlson et al. (2015) also reported the percentage differences in healthcare expenditure. They observed reductions of 10% and 11.1% in health care expenditure in more active adults, similar to the reductions of 11.5% and 14.1% in inpatient costs in the more active tertiles in the present study. Karl et al. (2018) used objective measures of physical activity in addition to self-reported physical activity, although the accelerometer data was only available for a subsample. The authors reported that in a comparable sample of European adults aged 48-68 years old, accelerometer-measured physical activity produced significant effects but no effect was found in self-reported physical activity with healthcare expenditure, in line with the current findings. Although previous studies have assessed the healthcare costs of physical activity to the NHS, this is the first study to the author's knowledge that has assessed this relationship using econometric methods in a UK population.

3.4.1 Strengths and Limitations

The study had several strengths. The large sample of participants who provided accelerometer data was sufficient to identify small differences between individuals and less likely to be biased compared to self-reported data, which can over- or under-estimate true activity levels (Prince et al., 2008). An additional analysis using self-reported data found no significant results suggestive of reporting bias. The measurement of self-reported physical activity may not be sensitive enough to capture the relative activity levels of the cohort. The healthcare data was available for all participants and came from two central governmental sources (HES and PEDW), again subject to less bias than self-reported data. The analysis addressed the potential issues of reverse causality by removing participants with shorter follow-up times, participants who had died within two years of baseline, adjusting for long-term disease or disability, and various sensitivity analyses. It controlled for an extensive range of covariates and the potential for endogeneity related to BMI in the model.

Nevertheless, the analysis was limited by several factors. Healthcare data was restricted to NHS English and Welsh inpatient records since these records were complete for the entire sample. Other healthcare use and costs were not included, such as primary care, prescriptions, private care, and out-of-pocket costs. Because of this, the results do not reflect the total healthcare costs associated with physical inactivity. Inpatient care is likely to be correlated with other healthcare use, although inpatient care usually indicates more serious ill health. Healthcare data was available from 1996 to study baseline, but it was not considered in this analysis. Although legacy effects from previous healthcare use may influence activity levels and subsequent time spent in hospital, this was likely captured in the covariates of long-standing illness, BMI and waist-hip ratio. Indirect costs from loss of productivity due to illness or death have previously been estimated to make up a significant part of the burden from physical inactivity (Ding et al., 2016). Only 2.3% of the sample reported that they used private healthcare all or most of the time at recruitment, therefore these costs are not likely to materially affect the overall results but given that private healthcare use is likely correlated with income, may help to explain the relatively smaller effect among higher-income respondents.

The UK Biobank cohort is not representative of the wider population, limiting the study's external validity. The cohort is wealthier and more educated than the UK average, therefore may also experience better health than average. The effect size observed in the results may be larger in the overall UK population, especially since there is likely to be selection bias in the subsample who agreed to wear the accelerometers. The participants may have also been subject to the 'Hawthorne Effect' where participation in a study leads to improved health (McCarney et al., 2007). This could potentially cause a reduction in hospitalisations. Although there is selection bias in the UK Biobank, the results presented here are likely to be valid. Stamatakis et al., (2021) explored the issue of representativeness in the UK Biobank and reported that the association between physical activity and health outcomes was minimally affected by this issue.

Although convenient, conducting analyses with a secondary dataset has disadvantages. The UK Biobank dataset did not have all the information that was necessary to conduct the analysis and therefore, we added additional cost data derived from the PSSRU. However, given the size of the dataset and the wealth of information available, it would not have been feasible to organise and fund our own data collection for this analysis.

Finally, the accelerometer cut-off thresholds in Table 3.2 were the best available cut-offs for this data although they were derived from a small sample of younger adults (Hildebrand et al., 2017, 2014). Therefore, it is likely that they do not accurately reflect the true proportion of time spent in each activity state for all age groups. Nevertheless, they provide an interesting approximation and opportunity to compare the physical activity tertiles. Participants appear to achieve very high levels of physical activity: well above the national recommendations of 150 minutes/week of MVPA. The cut-offs used have likely over-estimated time spent in MVPA.

Future studies could explore the association between level of physical activity and other healthcare use and costs in the UK. While this analysis focussed on inpatient care, primary healthcare would be an interesting area to explore in future analyses. However, it was beyond the scope of this thesis. Importantly, there should be a focus on the impact of increasing physical activity in lower-income groups, since the benefits of increased physical activity were most apparent in the lowest income group. This has implications for policy recommendations: physical activity interventions could have a stronger impact on lower-income groups. Targeted interventions may have a larger effect in more socioeconomically disadvantaged neighbourhoods, though it would remain to be seen whether they could attain sufficient response to be cost-effective. However, even greater population health improvements could be achieved by reducing income inequalities in the UK overall (Marmot and Bell, 2016).

There are several ways to develop the analysis further. Falsification tests could be conducted to test the assumptions of the main models. It would be possible to assess healthcare utilisation and costs before and after baseline for a subgroup with data available. In cohort studies such as the UK Biobank, there is the possibility of loss to follow-up or death, which ends the observation period. In this study, death is likely to be correlated with the hospital episodes, i.e., the repeated events measured. Therefore the assumption of noninformative censoring of the repeated events is at risk of violation (Rondeau et al., 2007). Liu (2017) proposed methodology to deal with informative censoring. After using a logrank test to compare two antiepileptic treatments, she used a sensitivity analysis to deal with informative censoring and evaluate the robustness of their results. Some or all of the censored participants who were likely to have informative censoring were included again in a sensitivity analysis. Many participants had been lost to follow-up, mainly due to adverse effects from the treatment. To develop the analysis of these data further, survival analysis could be used to assess the time to an inpatient hospital episode. A subsequent sensitivity analysis could include some or all of the participants who died during follow-up to test the robustness of the results generated. Alternatively, joint frailty models can deal with informative censoring. Joint models can account for situations where individual repeated data (inpatient hospital episodes) are correlated with terminal events (deaths) (Rondeau et al., 2007). While a potentially valuable line of enquiry it was thought that this analysis was beyond the scope of the current study.

3.5 Conclusion

These results show that higher levels of objectively measured physical activity in adults are associated with fewer inpatient days and lower inpatient costs, especially in women and lower-income groups. The findings highlight the importance of maintaining high levels of physical activity to reduce risk of disease and subsequent healthcare use. The UK government should prioritise reducing income inequalities and increasing physical activity in socioeconomically disadvantaged groups to improve population health and reduce the burden on the NHS. This is not a straightforward task: various approaches can be used to increase physical activity in the population. Cost-effective interventions and policies can be targeted at both the population-level and at the individual-level to achieve overall increases in physical activity in the UK.

Table 3.1 Unit costs for inpatient hospital episodes

Year	Average cost per episode			Average cost per day case
	Elective inpatient stays	Non-elective inpatient stays (long stays†)	Non-elective inpatient stays (short stays†)	
2013	£3,903.00	£2,953.00	£628.00	£727.00
2014	£3,771.01	£2,853.14	£606.76	£702.42
2015	£3,643.49	£2,756.66	£586.24	£678.66
2016	£3,520.28	£2,663.44	£566.42	£655.71
2017	£3,401.24	£2,573.37	£547.27	£633.54

*2017 Unit costs from the Personal Social Services Research Unit (Curtis and Burns, 2017b). Costs represent the present value of the discounted stream of costs arising after baseline. Costs arising after 2013 were discounted by 3.5%.

†Long stays were defined as an episode which lasted 21 days or more, as defined in an NHS report (NHS England and NHS Improvement, 2018).

Table 3.2 Estimated time spent in each physical activity state by acceleration tertile.

Physical activity tertile	Median time spent brisk walking or equivalent (>4.3 METs) per week	Mean time spent in activity per week			
		Sedentary behaviour	Light PA	Moderate PA	Vigorous PA
1, least active	30m	130h29m	30h5m	7h18m	8m
2	1h10m	120h19m	35h29	11h53m	19m
3, most active	2h31m	111h23m	38h	17h42m	55m

METs = metabolic equivalents of task; PA = physical activity.

Figure 3.1 Flowchart of participants included in the analysis

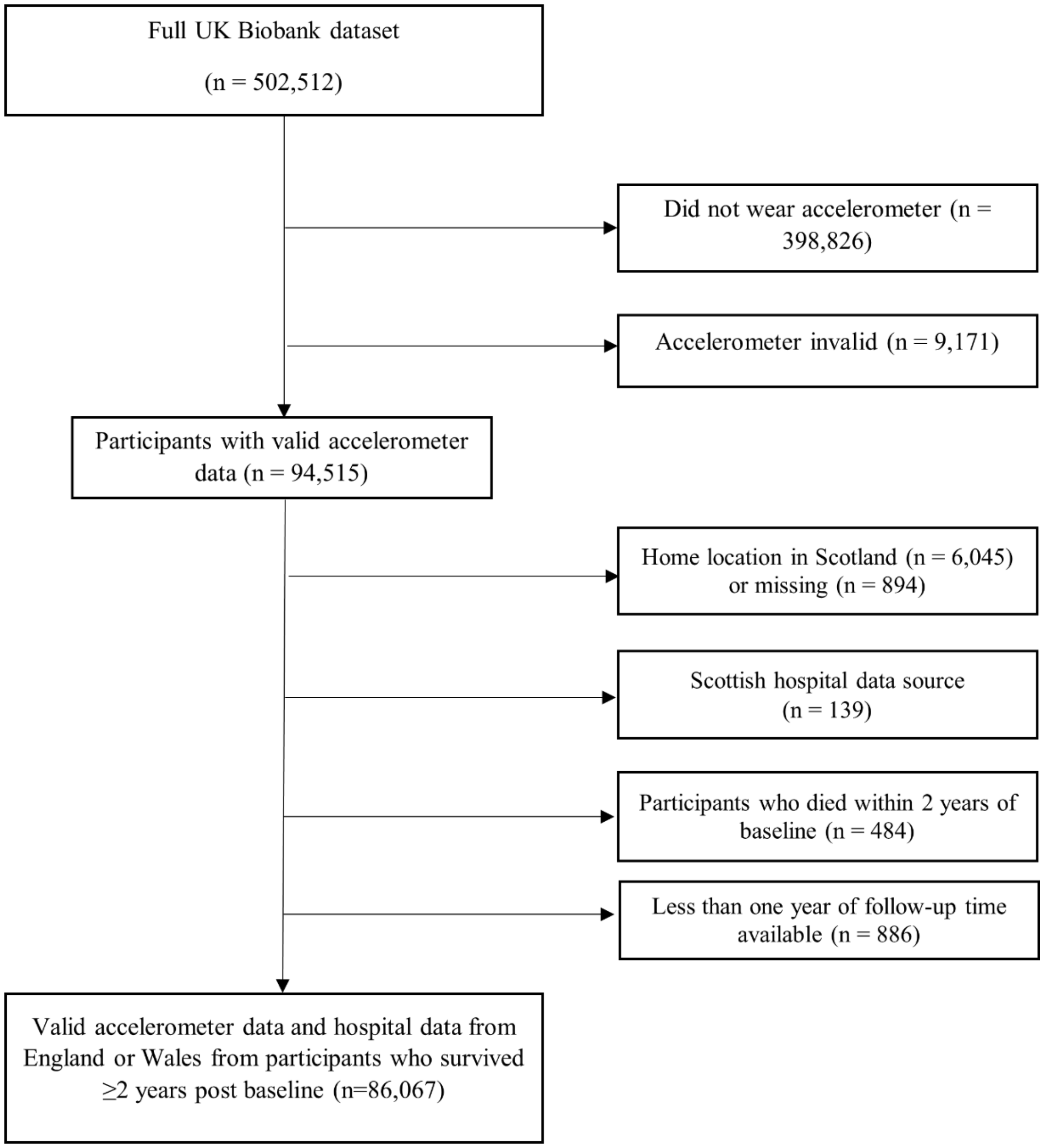


Table 3.3 Descriptive statistics by gender

		All participants	Men	Women
N		86,067	37,531	48,536
Gender	**Female**	48,536 (56.4%)		
	Male	37,531 (43.6%)		
Physical activity equivalent to ≥4.5 METs, median (IQR)		70.6 (90.7)	80.6 (90.7)	70.6 (80.6)
Age at baseline (years), mean (SD)		62.35 (7.84)	63.01 (7.91)	61.84 (7.75)
Age at baseline (years)	**40 to <50**	7,136 (8.3%)	2,953 (7.9%)	4,183 (8.6%)
	50 to <60	24,421 (28.4%)	9,548 (25.4%)	14,873 (30.6%)
	60 to <70	38,485 (44.7%)	16,909 (45.1%)	21,576 (44.5%)
	70 to <80	16,025 (18.6%)	8,121 (21.6%)	7,904 (16.3%)
Ethnic background	**White British**	77,928 (90.9%)	34,270 (91.7%)	43,658 (90.2%)
	Irish	1,959 (2.3%)	885 (2.4%)	1,074 (2.2%)
	Mixed ethnicity or other ethnic group	5,873 (6.8%)	2,216 (5.9%)	3,657 (7.6%)
Household income (before tax, £)	**Less than 18,000**	11,446 (14.8%)	4,492 (12.9%)	6,954 (16.4%)
	18,000 to 30,999	18,775 (24.4%)	8,034 (23.1%)	10,741 (25.4%)
	31,000 to 51,999	22,103 (28.7%)	10,134 (29.1%)	11,969 (28.3%)
	52,000 to 100,000	19,226 (24.9%)	9,393 (27.0%)	9,833 (23.2%)
	Greater than 100,000	5,549 (7.2%)	2,735 (7.9%)	2,814 (6.7%)
BMI in categories	**Underweight (<18.5kg/m^2)**	484 (0.6%)	71 (0.2%)	413 (0.9%)
	Normal weight (18.5 to 25kg/m^2)	33,286 (38.8%)	11,081 (29.6%)	22,205 (45.9%)
	Overweight (25 to 30kg/m^2)	35,359 (41.2%)	18,432 (49.2%)	16,927 (35.0%)
	Obese (>30kg/m^2)	16,735 (19.5%)	7,859 (21.0%)	8,876 (18.3%)

		All participants	Men	Women
Waist to hip ratio, mean (SD)		0.86 (0.09)	0.93 (0.064)	0.81 (0.068)
Long-standing illness, disability or infirmity		24,125 (28.6%)	11,651 (31.5%)	12,474 (26.3%)
Smoking status	**Never**	48,936 (57.0%)	19,435 (51.9%)	29,501 (60.9%)
	Previous	31,042 (36.2%)	14,955 (40.0%)	16,087 (33.2%)
	Current	5,855 (6.8%)	3,034 (8.1%)	2,821 (5.8%)
Marital status: living with husband, wife or partner		65,408 (91.4%)	30,334 (94.9%)	35,074 (88.6%)
University education		36,463 (42.4%)	16,470 (43.9%)	19,993 (41.2%)
Follow-up time (months), mean (SD)		28.37 (7.69)	28.37 (7.68)	28.37 (7.70)

Table 3.4 Descriptive statistics by physical activity tertile

		Physical activity (accelerometer-measured)		
		Tertile 1, least physically active	**Tertile 2**	**Tertile 3, most physically active**
N		28,719	28,687	28,661
Physical activity equivalent to ≥4.5 METs, median (IQR)		30.2 (30.2)	70.6 (50.4)	151.2 (100.8)
Gender	**Female**	14,731 (51.3%)	16,721 (58.3%)	17,084 (59.6%)
	Male	13,988 (48.7%)	11,966 (41.7%)	11,577 (40.4%)
Age at baseline (years), mean (SD)		64.68 (7.41)	62.41 (7.70)	59.96 (7.69)
Age at baseline (years)	**40 to <50**	1,339 (4.7%)	2,237 (7.8%)	3,560 (12.4%)
	50 to <60	5,876 (20.5%)	8,117 (28.3%)	10,428 (36.4%)
	60 to <70	13,609 (47.4%)	13,172 (45.9%)	11,704 (40.8%)
	70 to <80	7,895 (27.5%)	5,161 (18.0%)	2,969 (10.4%)
Ethnic background	**White British**	26,277 (91.9%)	26,069 (91.2%)	25,582 (89.6%)
	Irish	677 (2.4%)	635 (2.2%)	647 (2.3%)
	Mixed ethnicity or other ethnic group	1,650 (5.8%)	1,888 (6.6%)	2,335 (8.2%)
Household income (before tax, £)	**Less than 18,000**	4,825 (18.9%)	3,522 (13.7%)	3,099 (12.0%)
	18,000 to 30,999	6,873 (26.9%)	6,243 (24.3%)	5,659 (21.9%)
	31,000 to 51,999	6,982 (27.3%)	7,447 (29.0%)	7,674 (29.7%)
	52,000 to 100,000	5,456 (21.3%)	6,574 (25.6%)	7,196 (27.9%)
	Greater than 100,000	1,428 (5.6%)	1,925 (7.5%)	2,196 (8.5%)
BMI in categories	**Underweight (<18.5kg/m^2)**	101 (0.4%)	125 (0.4%)	258 (0.9%)
	Normal weight (18.5 to 25kg/m^2)	7,783 (27.2%)	11,094 (38.7%)	14,409 (50.3%)

		Physical activity (accelerometer-measured)		
		Tertile 1, least physically active	Tertile 2	Tertile 3, most physically active
	Overweight (25 to 30kg/m^2)	12,333 (43.1%)	12,261 (42.8%)	10,765 (37.6%)
	Obese (>30kg/m^2)	8,386 (29.3%)	5,157 (18.0%)	3192 (11.2%)
Waist to hip ratio, mean (SD)		0.88 (0.09)	0.86 (.09)	0.84 (0.08)
Long-standing illness, disability or infirmity		10,521 (37.5%)	7,655 (27.2%)	5,949 (21.1%)
Smoking status	Never	15,493 (54.1%)	16,497 (57.7%)	16,946 (59.3%)
	Previous	10,781 (37.7%)	10,287 (35.9%)	9,974 (34.9%)
	Current	2,358 (8.2%)	1,831 (6.4%)	1,666 (5.8%)
Marital status: living with husband, wife or partner		21,462 (92.1%)	21,909 (91.3%)	22,037 (90.8%)
University education		11,531 (40.2%)	12,375 (43.1%)	12,557 (43.8%)
Follow-up time (months), mean (SD)		28.11 (7.65)	28.40 (7.68)	28.59 (7.73)

Table 3.5 Crude relationship between covariates and mean monthly inpatient days and costs

Covariate		Mean monthly inpatient days	Mean monthly inpatient costs (£)
Objective physical activity level	Tertile 1	0.083	40.22
	Tertile 2	0.051	27.94
	Tertile 3	0.037	21.88
Gender	Female	0.051	27.84
	Male	0.066	32.85
Age at baseline	40-50	0.027	15.11
	50-60	0.039	21.48
	60-70	0.060	32.24
	70-80	0.092	44.36
Ethnic background	British	0.058	30.19
	Irish	0.055	29.18
	Mixed ethnicity/other	0.051	28.07
Household income	Prefer not to answer	0.058	31.82
	Do not know	0.074	37.42
	<£18,000	0.084	39.34
	£18,000 - £30,999	0.067	33.93
	£31,000 - £51,999	0.055	28.73
	£52,000 - £100,000	0.039	22.95
	>£100,000	0.036	21.26
Body mass index	Underweight	0.076	42.57
	Normal weight	0.046	24.32
	Overweight	0.057	29.53
	Obese	0.080	41.78
Long-standing illness	Yes	0.096	47.37
	No	0.042	22.87
Smoking status	Never	0.051	26.87
	Previous	0.066	34.67
	Current	0.066	31.73
Marital status	Married or living with a partner	0.054	29.15
	Not married or living with a partner	0.055	30.00
University education	Yes	0.050	26.04
	No	0.063	32.95

Table 3.6 Incremental effects and predicted average inpatient length of stay by physical activity tertile in the UK Biobank participants

Physical activity tertile	Incremental effect on mean monthly inpatient days (95% CI)*	Predicted mean monthly inpatient days (95% CI)	Predicted mean annual inpatient days†
1 (least active)	REF	0.165 (0.144, 0.186)	2.0
2	**-0.024 (-0.047, -0.001)**	0.140 (0.123, 0.157)	1.7
3 (most active)	**-0.037 (-0.059, -0.016)**	0.128 (0.116, 0.140)	1.5

*Bold text indicates significance at 5%. †Inpatient days per year were estimated by multiplying days per month by 12.

Table 3.7 Incremental effects and predicted mean monthly inpatient costs by physical activity tertile in the UK Biobank participants

Physical activity tertile	Incremental effect on mean monthly inpatient costs (95% CI)	Predicted average monthly inpatient costs (95% CI)	Percentage difference in costs
1 (least active)	REF	£27.37 (£25.09, £29.65)	REF
2	**-£3.09 (-£5.75, -£0.42)**	£24.21 (£22.63, £25.78)	-11.5%
3 (most active)	**-£3.81 (-£6.71, -£0.91)**	£23.52 (£21.67, £25.37)	-14.1%

*Bold text indicates significance at 5%.

Table 3.8 Incremental effects of physical activity on mean monthly inpatient days and costs by gender in the UK Biobank participants

	Physical activity tertile	**Incremental effect on mean monthly inpatient days (95% CI)***	**Incremental effect* (95% CI)**
Women (n=48,537)	1 (least active)	REF	REF
	2	-0.017 (-0.041, 0.008)	**-£3.73 (-£6.97**, **-£0.49)**
	3 (most active)	**-0.031 (-0.054, -0.009)**	**-£5.53 (-£8.93**, **-£2.13)**
Men (n=37,534)	1 (least active)	REF	REF
	2	-0.031 (-0.067, 0.003)	-£2.49 (-£6.33, £1.35)
	3 (most active)	**-0.047 (-0.081, -0.013)**	-£1.01 (-£5.09, £3.07)

*__Bold text__ indicates significance at 5%. CI = confidence interval

Figure 3.2 Incremental effects of physical activity by age for men and women

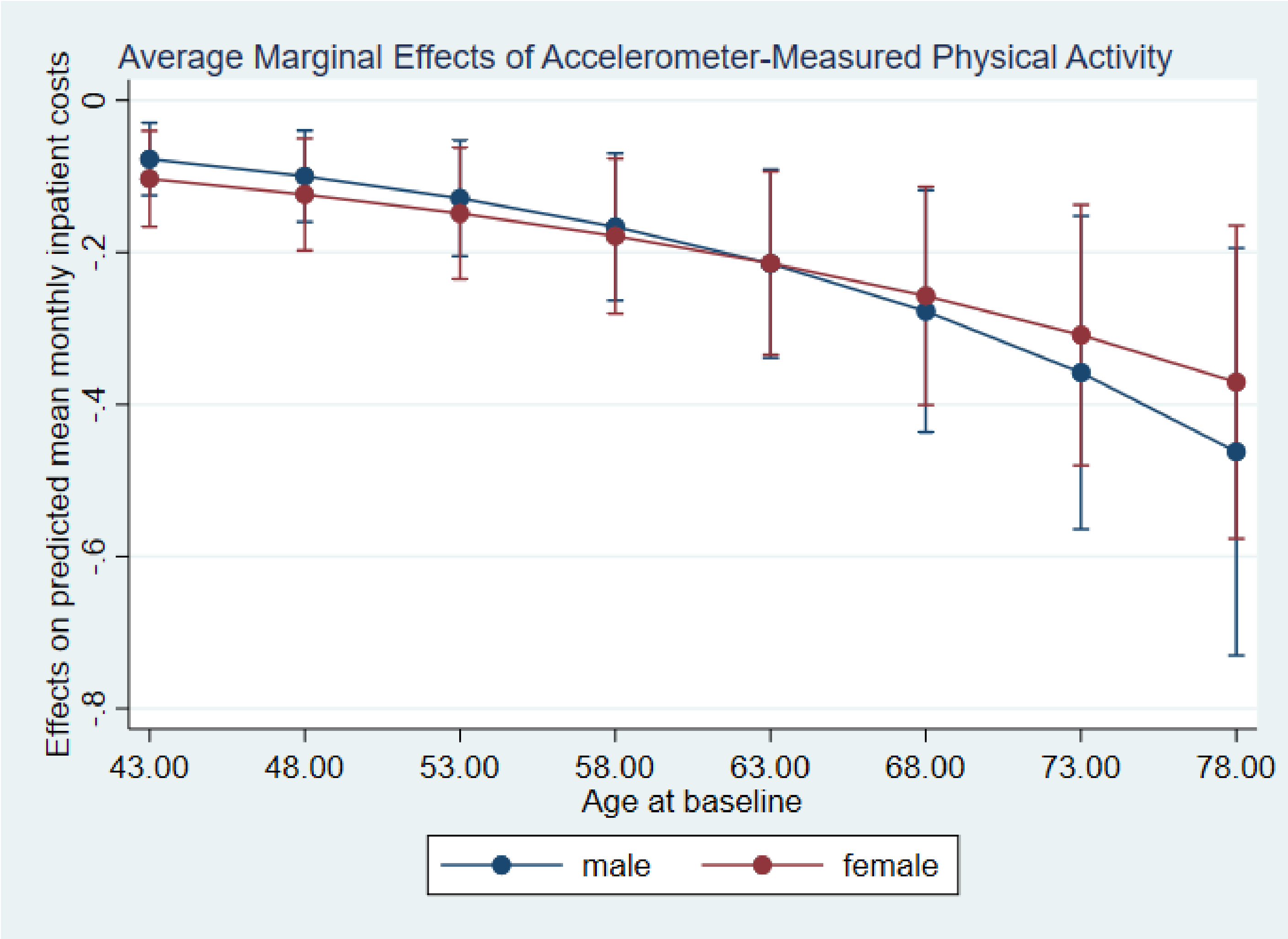
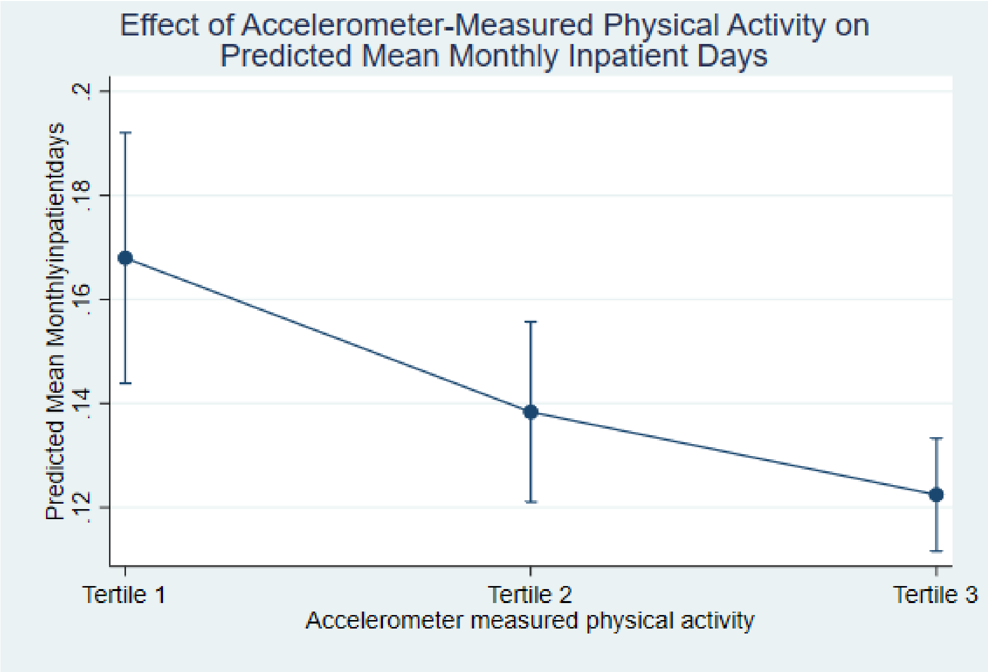


Figure 3.3 Association between accelerometer-measured physical activity and predicted mean monthly inpatient days in all participants and by household income



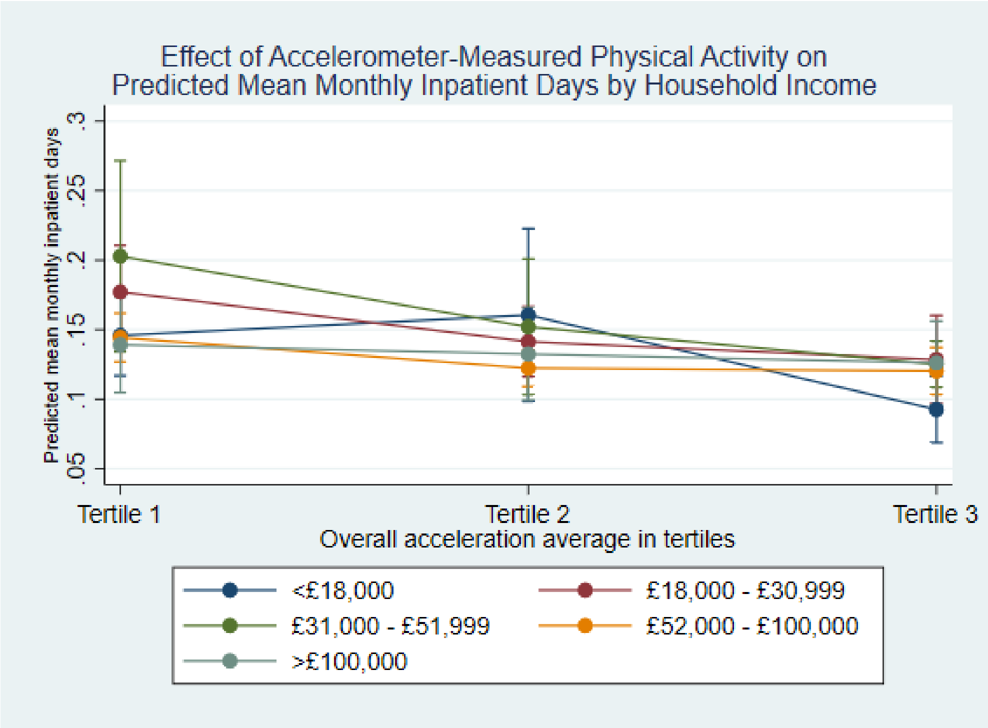


Table 3.9 Results of sensitivity analyses

Model	Physical activity tertile	Incremental effects on monthly inpatient days		Incremental effects on monthly inpatient costs
		n	All participants	
Main results for comparison	1 (least active.)	86,067	REF	REF
	2		**-0.024 (-0.047, -0.001)**	**-£3.09 (-£5.75, -£0.42)**
	3 (most active)		**-0.037 (-0.059, -0.016)**	**-£3.81 (-£6.71, -£0.91)**
(1) Excluding participants with long-term illness	1 (least active.)	61,942	REF	REF
	2		**-0.022 (-0.041, -0.003)**	**-£3.75 (-£6.11, -£1.39)**
	3 (most active)		**-0.024 (-0.041, -0.006)**	**-£2.81 (-£5.42, -£0.20)**
(2) Including participants who died within 2 years of baseline	1 (least active.)	86,589	REF	REF
	2		**-0.025 (-0.047, -0.002)**	**-£3.26 (-£5.93, -£0.59)**
	3 (most active)		**-0.038 (-0.059, -0.017)**	**-£3.90 (-£6.80, -£1.00)**
(3) Including participants with <1-year follow-up	1 (least active.)	86,953	REF	REF
	2		**-0.025 (-0.047, -0.002)**	**-£3.00 (-£5.64, -£0.36)**
	3 (most active)		**-0.038 (-0.059, -0.017)**	**-£3.70 (-£6.58, -£0.83)**
(4) Including episodes with type missing	1 (least active.)	86,067	REF	REF
	2		-0.007 (-0.14, 0.000)	**-£2.88 (-£5.61, -£0.15)**

	3 (most active)		**-0.013 (-0.020, -0.006)**	**-£4.07 (-£7.03, -£1.10)**
(5) Without discounting applied on inpatient days	1 (least active.)	86,067	REF	-
	2		-0.007 (-0.014, 0.001)	-
	3 (most active)		**-0.011 (-0.017, -0.004)**	**-**
(6) Residuals replacing BMI variable	1 (least active.)	86,067	REF	REF
	2		**-0.023 (-0.046, -0.000)**	**-£3.33 (-£5.97, -£0.69)**
	3 (most active)		**-0.036 (-0.057, -0.016)**	**-£4.49 (-£7.37, -£1.60)**
(7) Using self-reported PA as explanatory variable	low	73,017	REF	REF
	moderate		0.003 (-0.005, 0.010)	£0.86 (-£2.01, £3.73)
	high		0.004 (-0.003, 0.010)	£2.91 (£-0.11, £5.94)

3.6 References

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CHAPTER 4

CHARACTERISTICS OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR INTERVENTIONS ASSOCIATED WITH COST-EFFECTIVENESS IN ADULTS: A SYSTEMATIC REVIEW

4 CHARACTERISTICS OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR INTERVENTIONS ASSOCIATED WITH COST-EFFECTIVENESS IN ADULTS: A SYSTEMATIC REVIEW

4.1 Introduction

Chapters 2 and 3 have explored the costs of physical inactivity and sedentary behaviour. The evidence suggests that inactivity is an economic burden on the UK government in the form of direct healthcare costs, indirect healthcare costs and other costs from reduced productivity. This information can be used to make an economic argument for investment in public health investment. However, it is necessary to identify the most cost-effective ways to change behaviour, given that public funds are limited.

The process of behaviour change can be complex, costly, and difficult to disentangle. Several frameworks have been developed to describe the characteristics and design of BCIs. (Michie, Stralen and West (2011) developed the COM-B system and the behaviour change wheel (BCW). The COM-B system outlines three essential conditions for behaviour change: capability, opportunity and motivation, shown in Figure 4.1 (Michie, van Stralen and West, 2011, p.5). The BCW links understanding of these behavioural determinants with intervention functions to change behaviour. It incorporates the COM-B system and outlines nine functions of interventions that aim to overcome the lack of one of these essential elements, displayed in Figure 4.2 (Michie, van Stralen and West, 2011, p.7). There are three levels of the BCW: high-level policies, the more direct approach of interventions, and BCTs, the 'building blocks' of interventions (Tombor and Michie, 2019).

Interventions can be aimed towards individuals, communities, or entire populations. This chapter focuses on BCTs to change behaviour in individuals since changing behaviour on a population level requires a different approach. Changing behaviour on a population level is explored in the next chapter. BCTs are the psychological 'active ingredients' of a BCI. Michie et al. (2013) developed the BCT taxonomy, which includes 93 BCTs in 16 clusters, e.g., 'goals and planning' and 'feedback and monitoring'. The taxonomy provides researchers with a common language to describe and develop BCIs and facilitates better understanding and replication of interventions. The manner in which the BCTs are delivered in an intervention dictates its complexity and intensity. Lewin et al. (2017) developed the iCAT_SR tool to facilitate the assessment of complexity. The tool incorporates six core dimensions: number of active components in the intervention; the behaviours of recipients of the interventions; the organisational levels targeted; the degree of flexibility across sites/individuals; and the level of skill required by those delivering and receiving the intervention. The intensity of the intervention, also referred to as the ‘dose’ or ‘amount’ of the intervention delivered, has been defined and measured in various ways (Rowbotham, Conte and Hawe, 2019), e.g., the frequency of participant engagement, contact time or overall duration of the intervention. These characteristics of BCIs – BCTs, level of complexity, and intensity - may affect their effectiveness and/or cost-effectiveness.

The use of a complexity perspective in public health is important to fully consider the context and setting of PHIs (Portela, Tunçalp and Norris, 2019). Public health interventions have many components that interact with the individuals targeted and their environments. Currently, public health does not consider the implications of this complexity enough. In order to develop better evidence-based advice and guidelines, research should incorporate more of a focus on the complexity of an intervention. Taking these factors into consideration may result in more effective interventions.

In the past, interventions may have increased health inequalities as interventions that rely on individual agency were relatively less effective in disadvantaged groups, widening the health gap (White, Adams and Heywood, 2009; Lundberg, 2020). This may have been caused by the interventions relying on voluntary behaviour change which requires high levels of motivation (see Figure 4.1) (White, Adams and Heywood, 2009). The WHO-INTEGRATE evidence-to-decision (EtD) framework for developing WHO guidelines (Rehfuess et al., 2019) was developed partly due to concern that existing EtD frameworks did not sufficiently address complexity in interventions. All criteria in the framework have a complexity consideration: the balance of health benefits and harms; human rights and socio-cultural acceptability; health equity, equality, and non-discrimination; societal implications; financial and economic considerations; feasibility and health system considerations; and quality of evidence (Rehfuess et al., 2019). A simple perspective may not fully integrate all these criteria. For example, a recent review assessed complexity in interventions to reduce sedentary behaviour (Blackburn et al., 2020). Their findings suggested that interventions may need to be sufficiently complex to target complex behavioural patterns, although they reported that more complex interventions were not necessarily more effective.

Interventions to increase physical activity are generally effective at behaviour change and maintenance in healthy inactive adults (Howlett et al., 2019). Healthy inactive adults are an important target for physical activity interventions since they have the physical capability to become more physically active and a large proportion of the population falls into that category. Small individual increases in their physical activity could lead to large public health gains. Certain BCTs are associated with greater effectiveness in this population post-intervention (‘biofeedback,’ ‘demonstration of the behaviour,’ ‘behaviour practice/rehearsal,’ and ‘graded tasks’) and at follow-up (‘action planning,’ ‘instruction on how to perform the behaviour,’ ‘prompts/cues,’ ‘behaviour practice/rehearsal,’ ‘graded tasks,’ and ‘self-reward’) (Howlett et al., 2019). Subgroups within the broad classification of healthy adults may require additional considerations, such as adults with overweight or obesity, socioeconomically disadvantaged groups, pregnant women, or older adults; costs, benefits or discounts may produce different decisions in these groups. An appreciation of the mechanisms at work that underpins relationships is crucial to devising appropriate policy responses.

Another important consideration is context, which may interact with the components of an intervention and its intended population (Booth et al., 2019). Context refers to the setting of the intervention and external factors, which may influence the outcomes. For example, context is particularly relevant in the workplace, where the outcome may depend on the weather, availability of car parking, transport links, and working hours etc. As the components of an intervention are chosen, the APEASE criteria can be used to guide the development of an intervention (Tombor and Michie, 2019). The criteria consider affordability, practicability, effectiveness, acceptability, safety, and equity of the intervention (Tombor and Michie, 2019). Affordability is a key issue to consider, as well as the need to conduct a more in-depth economic evaluation to assess the cost-effectiveness. Discount rates used in economic evaluations are related to affordability. High discount rates may see issues of current cost dominate considerations of larger benefits that arise in the future.

The evidence on the cost-effectiveness of physical activity interventions is mixed, but certain interventions such as brief interventions or those using pedometers have been shown to be cost-effective (Abu-Omar et al., 2017). In terms of setting, community-based physical activity interventions are more cost-effective, especially those in which direct supervision or instruction was not required, avoiding the higher staffing costs (Roux et al., 2008; Garrett et al., 2011). Beard *et al.* (2019) conducted a review to assess the features of cost-effective BCIs targeting a broad range of behaviours: smoking, diet, alcohol, sexual health, and physical activity. They included 79 interventions and found that education (see BCW in Fig.2) is a common feature in cost-effective BCIs. Physical activity interventions in their review included 29 BCTs, with the most commonly-used BCT being 'discussion of body changes'. No reviews could be identified that specifically assessed the association between intensity of intervention and effectiveness or cost-effectiveness, however, Wu et al. (2011) suggested that lower intensity interventions that reach a greater number of people have a higher likelihood of being cost-effective. Although many cost-effective studies on physical activity interventions have been conducted (Wu et al., 2011; Müller-Riemenschneider, Reinhold and Willich, 2009), it is unknown which characteristics of physical activity interventions increase the likelihood of their cost-effectiveness. Before more interventions are designed at huge expense, it may be a useful exercise to explore the associations between cost-effectiveness, BCTs, complexity and intensity of interventions.

The objectives of this chapter were to assess which characteristics of physical activity and sedentary behaviour interventions are associated with greater cost-effectiveness in healthy adults. The specific characteristics assessed were individual BCTs; BCT clusters; complexity measured by the iCAT_SR tool; and intensity of the interventions measured by intervention duration, number of contact points, and number of contact hours. This chapter describes the methodology used in the systematic search for relevant studies and discusses the findings.

4.2 Methods

The protocol for this systematic review is published on PROSPERO (ID: CRD42019146810, https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=146810).

4.2.1 Information Sources

The systematic review was based on a search of the following 11 databases, from inception to 27th September 2019:

- Database of Abstracts of Reviews of Effects (DARE) (Centre for Reviews and Dissemination [CRD])
- CINAHL (EBSCOhost)
- Cochrane Central Register of Controlled Trials (CENTRAL) (Cochrane)
- ECON LITEMBASE (Ovid)
- Health Technology Assessment (HTA) database (CRD)
- MEDLINE (Ovid)
- NHS Economic Evaluation Databases (EED) (CRD)
- PsycINFO (Ovid)
- Scopus (Scopus)
- SPORTDiscus (EBSCOhost)
- Web of Science (Web of Science)

The electronic search strategy was developed in Ovid Medline database and is shown in Figure 4.3. Furthermore, evidence summaries for NICE (https://www.nice.org.uk/) and US Preventive Services Task Force (https://www.uspreventiveservicestaskforce.org/Page/Name/home) were hand-searched for relevant trials. Conference proceedings from the International Society for Physical Activity and Health (ISPAH), the International Society of Behavioral Nutrition and Physical Activity (ISBNPA), Health-Enhancing Physical Activity (HEPA) Europe and the American College of Sports Medicine (ACSM) from September 2014 to September 2019 were hand-searched for relevant research that had been presented. Additionally, grey literature was searched using OpenGrey (http://www.opengrey.eu/). The reference lists of relevant reviews were also checked for eligible studies.

4.2.2 Eligibility Criteria

Full economic evaluations of randomised controlled trials (RCTs) of interventions to increase physical activity were eligible for inclusion. Only RCTs were included to avoid selection bias and confounding. Simulation-based or decision models were excluded to avoid including duplicated data. There were no restrictions on language or date of publication.

The following criteria were used in screening the studies:

Population:

Healthy adults aged at least 18 years were included. If a study had also included children but reported the results for the adults separately, it was eligible for inclusion. The main aim of the review was to examine physical activity interventions for healthy adults, therefore interventions targeted at people diagnosed with a chronic disease or metabolic disorder were excluded. There were no restrictions on gender, country, body weight, or baseline activity level.

Interventions:

We included interventions that aimed to increase physical activity level or decrease sedentary behaviour. Outcomes of the intervention were followed for at least two weeks after the end of the intervention to see the longer-term effect of the intervention. There were no restrictions on the mode of delivery; frequency, duration or intensity of physical activity; target level (individual or group); or setting (community, primary care, etc.). Policies to change behaviour were not included.

Physical inactivity was defined as not achieving at least 150 minutes of MVPA or 75 minutes of vigorous activity per week (World Health Organisation, 2010). Sedentary behaviour was defined as sitting or lying while expending less than 1.5 METs during waking hours (Tremblay et al., 2017).

Control:

Studies were included if they had used either an active or inactive control. Active controls could be a minimal intervention e.g., brief advice. Inactive controls were no intervention or wait-list control.

Outcomes:

The main outcomes of the included studies were the health effects and costs associated with the intervention and its comparison and an incremental cost-effectiveness ratio (ICER) if it had been reported. All reported outcomes were extracted in the review process, although only the final outcomes measured after the intervention were used in assessing cost-effectiveness. ICERs are useful summary measures to assess the cost-effectiveness of an intervention, i.e., the cost per positive unit change in the outcome of the intervention. Any health-related outcome measure was eligible for inclusion, including health status, quality of life, and improvement of symptoms. However, using all ICERs as opposed to ICERs specifically using QALYs is limited as it is very difficult to compare the inventions.

4.2.3 Study selection

After the searches were complete, the titles and abstracts of the identified studies were imported into Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia (Available at www.covidence.org). Covidence automatically excluded duplicate articles. Two reviewers (LH and MT) independently performed title and abstract screening based on the eligibility criteria outlined above. Disagreements were resolved by discussion. Reviewers proceeded to independently screen the full-text articles of studies which had passed the initial screening. Again, any disagreement was resolved through discussion. The interrater reliability at the full-text screening stage was assessed by calculating Cohen's kappa (κ).

4.2.4 Data Extraction

One reviewer (LH) extracted data from the eligible studies and another reviewer (MT) subsequently checked all extracted information against the original publication. Table 4.1 displays the information that was extracted from each study in this process.

BCTs were extracted from all interventions. If BCTs were not explicitly listed, the BCTs were coded by analysing the description of the intervention. The complexity of the interventions was coded using the six main components in iCAT_SR tool (Lewin et al., 2017). The intensity of the interventions was measured in four different ways: 1) number of times per week the participants engaged with the intervention; 2) number of contact points between participants and person(s) delivering intervention; 3) total contact hours in the intervention, and 4) overall duration of the intervention. Each aspect of intensity was extracted from the descriptions of the interventions.

4.2.5 Measurement of effectiveness

In order to compare interventions, physical activity changes were standardised to MET-hours per week using the methods proposed by Wu et al. (2011). Table 4.2 includes the translation formulas used in the conversions. Intervention costs were divided by the duration of the intervention in days and adjusted to 2017 prices using country-specific inflation calculators (Bank of England, 2020; Inflation Tool, 2020; Reserve Bank of Australia, 2020; Reserve Bank of New Zealand, 2020; US Bureau of Labor Statistics, 2020). Costs were then converted to GBP using exchange rates available for the 1st January 2017 (OANDA Corporation, 2019). Finally, outcomes in MET-hours per week were divided by the standardised costs to generate ICERs.

4.2.6 Quality and risk of bias

Drummond's checklist for assessing economic evaluations (Drummond and et al., 1997) was used to assess the quality of the economic evaluations (see Appendix 1). The checklist is based on ten questions which focus on: 1) a well-defined question; 2) a comprehensive description of the competing alternatives; 3) effectiveness of the programme established; 4) identified costs and consequences; 5) measurement of costs and consequences; 6) valuation of costs and consequences; 7) adjustments made to costs and consequences for differential timing; 8) incremental analysis of alternatives; 9) allowance for uncertainty; and 10) presentation and discussion. Studies were assigned one point per item fulfilled on the checklist. Points were summed to generate a quality summary score out of ten. The CHEERS checklist is also available for assessing the reporting of economic evaluations (Husereau et al., 2013), however, Drummond's checklist was deemed to be sufficient for this study.

The Cochrane Rick of Bias (RoB) 2 tool (Sterne et al., 2019) was used to assess the risk of bias in the randomised trials on which the economic evaluations were based. It consists of five domains: bias arising from the randomisation process; bias due to deviations from intended interventions; bias due to missing outcome data; bias in the measurement of the outcome; and bias in the selection of the reported result. An algorithm uses the answers to each domain to assign an overall judgement on the risk of bias. Risk of bias assessment was performed for each study included in the review and reported in the results.

4.2.7 Summary Measures and Synthesis of Results

The principal summary outcome measure was the ICER of the interventions, namely the incremental difference in MET-h/week in intervention group divided by the intervention cost per person per day. This was done in order to generate a summary measure with which to compare the interventions. However, there are assumptions involved in using this approach and these measures should not be used in medical decision-making.

4.3 Results

4.3.1 Included studies

The systematic search identified 18,045 articles in the databases and 78 articles from other sources. Figure 4.4 displays the selection process. After removing duplicates, the title and abstracts of 9,895 studies were screened, identifying 356 potentially relevant articles. Articles were rejected for the following reasons:

1. Physical activity/sedentary behaviour was not a main component of the intervention (64)
2. The economic evaluation was not based on an RCT (33)
3. The control was inappropriate (65)
4. The study lacked a full economic evaluation (91)
5. The length of follow-up was insufficient (9)
6. The participants' age (1)
7. The participants' health status (22)
8. The type of report (38)

The subsequent full-text screening resulted in 33 eligible articles or funding awards, associated with 25 individual studies. The most common reasons for exclusion at that stage was a lack of economic evaluation present (91 articles), inappropriate control group (65 articles), or the intervention not featuring physical activity and sedentary behaviour as the main component (64 articles). Articles were also excluded if the report or study design was inappropriate, the study population were not suitably healthy or aged under 18 years, or the follow-up period was less than two weeks. Agreement between the two reviewers (LH and MT) was measured by Cohen's κ (κ = 0.67) which indicated good or substantial agreement.

Table 4.3 presents the characteristics of the 25 included studies. Most focused only on increasing physical activity (13) or physical activity alongside healthy eating (4). Three studies used physical activity to improve specific medical conditions or symptoms: two aimed to reduce the risk of gestational diabetes mellitus in pregnant women, and one aimed to improve menopausal symptoms. Four studies focussed on the risk of falling in older adults and lastly, one study used physical activity as a tool to help with smoking cessation. Most studies were European: based in the UK (11 studies), the Netherlands (3), and two multinational studies. The other studies were conducted in Australia (3), New Zealand (4) and the USA (2). Study populations ranged from 50 to 1,260 participants, in various settings: healthcare (12), community (8), workplace, or a sports club (2). Mean intervention length was 16 weeks and participants were followed for 30 weeks on average. Each intervention arm and control is described.

Outcomes were all converted, where possible, to the incremental change in MET-hours per week between baseline and the last follow-up time (up to 52 weeks after baseline). Six studies did not report outcomes which could be converted to MET-h/week. Twenty-seven intervention arms in 19 studies reported an increase in MET-h/week. In five arms, the incremental change in MET-hours per week was negative, i.e., the intervention arms were less active than the control groups. The largest change was an increase of 5.55 MET-h/week in the Enhanced Green Prescription study (Elley et al., 2011). The largest decrease was 1.80 MET-h/week in the 'social support' arm of the Active Women study (Goranitis et al., 2017). Overall, the mean change per participant was an increase of 0.92 MET-h/week.

4.3.2 Economic evaluation of the interventions

Most evaluations were within-trial CEAs, although two studies (Anokye, Pokhrel and Fox-Rushby, 2014; Goyder et al., 2014) used Markov models to assess cost-effectiveness over two years or a lifetime. Three studies (Anokye, Pokhrel and Fox-Rushby, 2014; Dalziel, Segal and Elley, 2006; Taylor et al., 2014) conducted both types of analysis. Details of the economic evaluations of the interventions are presented in Table 4.4. Eleven studies were limited to a healthcare or public sector perspective and thirteen studies used a broader, social perspective. Most studies used a short-term time horizon of 1-2 years. Costs were valued from years 1995 to 2017 in five currencies: Australian dollar (AUD), Euro (EUR), GBP, New Zealand dollar (NZD) and US dollar (USD). Almost all studies reported programme costs and healthcare costs. Some included administration costs e.g., the overhead costs, or planning costs of meetings to develop the intervention and some did not. Several reported costs related to productivity or absenteeism. Four studies reported out-of-pocket costs to participants and two reported the 'opportunity costs' of the intervention programme.

The standardised intervention costs per participant per day (GBP, 2017) and ICERs are included in Table 4.4. ICERs were calculated for the 20 intervention arms in 14 studies which showed a positive overall change in physical activity in MET-h/week. The ICERs represent the increase in MET-h/week divided by the intervention costs per day (GBP 2017), where a lower ICER indicates higher cost-effectiveness. The

ICERs ranged from £0.04 to £62.82 per MET-h/week gained, with a mean of £14.59 across studies. Figures 5.5 and 5.6 display the ICERs

4.3.3 Quality and risk of bias

The quality of the studies was assessed using the Drummond checklist and the results are displayed in Table 4.5. Quality was generally high as 20 out of 26 studies fulfilled 9 or 10 out of 10 points of the questionnaire. All studies had established effectiveness through an RCT and almost all had well-defined questions, comprehensive descriptions of the control groups, and reasonable valuations of the costs involved. The most common reasons for not fulfilling the quality checklist were not using a broad perspective for the economic evaluation, not addressing discounting in the analysis, or not making allowances for uncertainty in the estimates.

The RoB2 tool was used to assess the risk of bias in the RCT. Figure 4.7 displays the risk of bias in each category for all studies. Overall, ten studies (Goranitis et al., 2017; Elley et al., 2011; Wyke et al., 2019; Oostdam et al., 2012; Hunter et al., 2018; Iliffe et al., 2014; Goyder et al., 2014; Van Dongen et al., 2013; Robertson et al., 2001a; Audrey et al., 2019) were deemed to be at low risk of bias. Eleven studies (Broekhuizen et al., 2018; Burn et al., 2015; Harris et al., 2018; Taylor et al., 2014; Larsen et al., 2017; Stevens et al., 1998; McEachan et al., 2011; Dzator et al., 2004; Dalziel, Segal and Elley, 2006; Haas, 2006; Tully et al., 2019) had some concerns, and four (Gray et al., 2018; Wilson and Datta, 2001; Robertson et al., 2001a; Golsteijn et al., 2014) were at high risk of bias. Most concerns were due to deviations from intended interventions, the randomisation process, or selection of the reported result. There were very few studies with concerns over missing outcome data or the measurement of the outcome

4.3.4 Behaviour change techniques and cost-effectiveness of interventions

Interventions were coded for BCTs: 54 BCTs were identified. Figure 4.8 displays the BCTs that appeared at least 3 times. The three most prevalent BCTs were problem-solving, self-monitoring of behaviour, and instruction on how to perform the behaviour. The most commonly-identified BCT clusters were (1) Goals and planning, (2) Feedback and monitoring, and (3) Social support. Figure 4.9 displays the prevalence of each BCT cluster coded in the interventions by their cost-effectiveness (ICERs <£1, £1-£15, and >£15). The most prevalent BCT clusters - used in at least 50% of interventions - in the most cost-effective studies (orange bars) were (1) Goals and planning; (2) Feedback and monitoring; (3) Social support; (4) Shaping knowledge; and (9) Comparison of outcomes. In the next category of cost-effectiveness (green bars), the most prevalent clusters were also clusters (1), (2), (3), (4) in addition to clusters (5) Natural consequences; (6) Comparison of behaviour; (7) Associations; and (8) Repetition and substitution, however not cluster (9). The least cost-effective category (purple bars) most frequently used clusters (1) – (6), (8), and (12) Antecedents. Studies which were not effective (red bars) most frequently used clusters (1) and (3) only. In summary, clusters (1) – (6), (8) and (9) are most frequently used in the most cost-effective interventions.

4.3.5 Complexity and cost-effectiveness of interventions

The complexity of the interventions was measured by the iCAT_SR tool (Lewin et al., 2017). All studies were complex in terms of the multiple components delivered in the interventions, whereas they were less complex concerning the level of skill required by those delivering the intervention.

Most interventions targeted only one or two behaviours, e.g., physical activity alone or combined with nutrition. Interventions varied concerning the iCAT_SR items 2-5: behaviours targeted by the intervention, organisational levels targeted by the intervention, degree of tailoring, and level of skill required by those delivering the intervention. In terms of organisation level, half of the interventions targeted only one level and the other half targeted several. For example, some interventions targeted both a patient and their doctor. Most interventions were moderately or highly tailored to the individuals receiving the interventions, e.g., by planning individual sessions with participants. Finally, most required those delivering the intervention to have intermediate or high-level training, e.g., dietitians or nurses.

The complexity of the interventions by their cost-effectiveness is presented as a spider diagram (Figure 4.10). Cost-effectiveness was split into four categories according to ICER: <£1, £1-15 and >£15 per MET-h/week and not effective. The ineffective interventions appeared to be more complex in terms of the number of behaviours they targeted. The most cost-effective interventions were less complex in terms of the skills required by the intervention trainer. Due to the higher costs of recruiting a highly-skilled team to deliver the intervention, this is a logical relationship.

The relationship between the overall complexity and cost-effectiveness was also assessed. Each intervention was given an arbitrary overall complexity score by summing the score for each component, which ranged from 9 to 13 points depending on the six items in the iCAT_SR tool. The summary scores were plotted against the cost-effectiveness of the interventions to identify any patterns between complexity and cost-effectiveness (Figure 4.11). There were no strong indications that complexity is correlated with cost-effectiveness in these studies, however, the most cost-effective interventions were on the less complex side of the scale. The relationship between overall complexity and cost-effectiveness was assessed using a Spearman's rank correlation (r = 0.46, p-value = 0.05). The results indicate a weak negative correlation between complexity and ICERs, i.e., higher complexity is slightly correlated with lower cost-effectiveness.

4.3.6 Intensity and cost-effectiveness of interventions

In figure 4.12, the relationships between each measure of intensity and the cost-effectiveness of the intervention were plotted. There is a weak negative trend between cost-effectiveness and engagement with the intervention (times/week). There were no apparent relationships in the other measures of intensity: contact points, contact hours, and duration of the intervention.

4.4 Discussion

4.4.1 Summary of results

Twenty-five economic evaluations of interventions with a focus on physical activity or sedentary behaviour in adults were included in the review. Nineteen of those interventions were effective at increasing levels of physical activity (mean increase of £0.92 per MET-h/week). ICERs were generated to compare the cost-effectiveness of the interventions, which ranged from £0.04 to £62.82 per MET-h/week gained. The included studies were high quality, with most meeting 9 or 10 points on the Drummond checklist, however, fifteen studies had some or high concerns regarding the risk of bias. Four studies were deemed to be at high risk of bias (Gray et al., 2018; Golsteijn et al., 2014; Wilson and Datta, 2001; Robertson et al., 2001b), mainly due to deviations from protocol or missing outcome data. Two of those (Golsteijn et al., 2014; Gray et al., 2018) were included in the quantitative analysis, which may bias the overall findings.

Fifty-four distinct BCTs were coded in the 25 interventions. The most commonly-used BCTs were 'problem-solving', 'self-monitoring of behaviour', and 'instruction on how to perform the behaviour'. Clusters (1) Goals and planning; (2) Feedback and monitoring; (3) Social support; (4) Shaping knowledge; and (9) Comparison of outcomes are most frequently used in the most cost-effective interventions, indicating that those clusters might be associated with greater cost-effectiveness. Interestingly, these results were very different to results in a previous analysis of cost-effectiveness and PHIs in the UK. Beard et al. (2019) reported that the BCT clusters (4) Shaping knowledge, (9) Comparison of outcomes, and (8) Repetition and substitution were associated with lower cost-effectiveness and the BCT cluster (10.) Reward and threat was more cost-effective: almost the opposite of what this study has found. This is may be due to the much wider range of studies assessed by Beard et al.

The assessment of complexity and cost-effectiveness suggested that the more cost-effective interventions were slightly less complex. Less complex interventions may incur lower costs, increasing the likelihood of cost-effectiveness. In terms of the intensity of the intervention, there was a weak negative trend between the number of times per week a participant engaged with the intervention and its cost-effectiveness. The rate of participant engagement could increase the effectiveness of the intervention, making cost-effectiveness more likely.

Only two studies (Audrey et al., 2019; Wyke et al., 2019) had included sedentary behaviour as a focus or outcome. There appears to be an evidence gap: high-quality research into sedentary behaviour interventions is needed in various settings, larger samples and over a longer follow-up period to assess effectiveness and cost-effectiveness. However, a notable strength of the sedentary behaviour interventions is the common use of objective measures, reducing bias in the outcomes. Sutherland *et al.* (2020) suggest that a framework of effective components for reducing sedentary behaviour may be a useful approach going forward. In the COM-B model, social and physical opportunities may be particularly important in sedentary behaviour interventions (Ojo et al., 2019)

4.4.2 Intervention setting

The characteristics of the interventions differed by their setting; they were split into three categories of community, healthcare or workplace settings. Community and healthcare-based interventions produced similar ICERs in studies where sufficient data were available, each having four studies with ICERs under £15 per MET-h/week. Only four workplace interventions were identified and only one had sufficient information to calculate an ICER. In terms of BCTs, the interventions in the community used 16 BCTs on average, almost twice as many as healthcare interventions. Workplace interventions used 13 BCTs on average. The most commonly used BCTs were problem-solving, information about health consequences, self-monitoring of behaviour, and social support (unspecified) which all feature in the top five most prevalent BCTs in interventions based in the workplace, community, and healthcare settings. 'Instruction on how to perform the behaviour' and 'goal-setting' were also common in both workplace and community settings, while 'feedback on behaviour' was common in both healthcare and workplace settings.

In terms of overall complexity scores, community interventions were the most complex, followed by those in healthcare settings and then workplace settings. The level of complexity has implications for scalability: the less complex interventions have greater potential to be scaled up at a more affordable cost. Community interventions were the least intense interventions by every intensity metric compared to those in healthcare and workplace settings. In this sample of interventions, the intensity did not necessarily align with complexity or number of BCTs.

4.4.3 Population subgroups

Subgroups in the population may need special consideration in intervention design. Interventions specifically aimed at pregnant women are effective at slightly increasing physical activity (Flannery et al., 2019), however, in the two interventions involving pregnant women, physical activity in the intervention group either decreased (Oostdam et al., 2012) or was not reported (Broekhuizen et al., 2018). Certain BCTs may be specifically helpful for pregnant women, such as: 'goals and planning', 'feedback and monitoring' and 'shaping knowledge' with 'social support', however, none were used in the two interventions in pregnant women. These interventions used fewer BCTs (5.5 on average compared to the overall average of 11.8) and fewer different BCT clusters (average 4.0 compared to overall average 7). Both studies had the same overall complexity score as the mean score for all included studies. The FitFor2 study was particularly intense in terms of contact points (50 hours overall, 2 hours per week).

Six studies were focused on older adults who were all over 60 years old. Two studies reported an increase in physical activity due to the intervention. The remaining four studies did not report physical activity and focused on other outcomes such as fear of falling. These studies also used fewer BCTs than average. Physical activity interventions in older adults most frequently used the BCTs 'goal-setting', 'action-planning' and 'credible source' (Senkowski, Gannon and Branscum, 2019). This did not reflect the BCTs used in the interventions identified here, of which only one intervention used 'goal-setting' and 'action planning'. The interventions had slightly more engagement per week (3 times) compared to the mean engagement (2 times) of the other studies.

Another important consideration is the long-term effectiveness of the intervention: feedback may be a particularly important BCT for maintaining physical activity in middle- and older-aged adults (O'Brien et al., 2015). Only one study had a follow-up point of more than 12 months after the intervention (Enhanced Green Prescription). Encouragingly, the participants maintained increased physical activity at one year and two years after baseline.

Adults with overweight or obesity may benefit from 'goal-setting' and 'self-monitoring of behaviour' (Samdal et al., 2017), both of which were used in the two interventions which included individuals with high BMIs (over 25kg/m2) (Gray et al., 2018; Wyke et al., 2019). Both studies were deemed to be relatively cost-effective, with both ICERs under £15 per MET-h/week. These interventions were shorter (12 days) than the mean length (17 days), which may have resulted in lower costs.

4.4.4 Strengths and Limitations

The review provides an overview of economic evaluations of physical activity and sedentary behaviour interventions in healthy adults. It summarizes complexity and intensity of these interventions and codes the BCTs used. The study was limited by a high risk of bias in some studies and the difficulty in comparing disparate outcomes. The differences in costs, methods of analysis and countries/settings restricted the possibility of a meta-analysis.

The study is limited by the heterogeneity of reporting of costs between and, possibly, within studies, therefore care is warranted when comparing costs across studies. Although costs have been standardised to the same year and currency for the purpose of this review, it should be acknowledged that there are differences in how costs have been described. The World Health Organization (2003) recommend that unit prices and quantities should be reported when estimating the programme costs, which most studies included. However, some studies included administration costs involved in the intervention development and others did not. In the case of healthcare costs, there are differences in what is normally covered by the healthcare service, e.g., prescription charges, or differences in how much services cost by country, which limits comparability. Therefore, the ICERs calculated here are indicative of cost-effectiveness within a specific context and are not intended to be guide decision-makers in other contexts. Rather they are intended to be used by researchers who are developing interventions and could benefit from considering the relative cost-effectiveness of an intervention characteristic.

There is also a high risk of publication bias: many studies assess the effectiveness of interventions but relatively few conduct an economic evaluation. Formal analysis for publication bias was not conducted since the included studies and the outcomes reported were heterogeneous. It is expected that some studies of interventions that were ineffective will be missing from this search. Although the articles included may have been restricted by language restrictions, all were conducted in high-income countries, indicating that little research on the cost-effectiveness of physical activity interventions is happening in low-middle income countries (LMICs).

Strategies that are deemed cost-effective in one context may not translate well in all contexts. Although the interventions in this review vary by setting, location and year, all were conducted in high-income countries. This has particular relevance if the strategies were to be replicated in a low-middle income setting, where external factors such as the local economy, politics, or societal norms may influence outcomes. Several studies also reported results of cost-utility analyses (CUAs) with ICERs expressed in cost per quality-adjusted life-years (QALYs), e.g., in the evaluations by Hunter et al. (2018) and Oostdam et al. (2012). However, most did not report their findings in costs per QALYs. CUAs may be interpreted as being more complicated than CEAs due to the additional estimation of QALYs that may be inappropriate for an outcome with a short follow-up time. For the sake of comparison this review has compared results in costs per change in physical activity (MET-hours). Wider use of QALYs would make the economic evaluation of physical activity interventions more comparable with other PHIs (Owen et al., 2018).

The type of cost-effectiveness focused on here is technical efficiency: how interventions can be developed to achieve the largest increase in physical activity (Palmer, 1999). Alternatively, the UK uses allocative efficiency to determine how the resources can be used that lead to better health, distributed among society. Therefore, they are related areas but deal with different types of cost-effectiveness in public health. When making decisions relating to health, the economics of the decisions and their cost-effectiveness is a key consideration of the EtD framework (Rehfuess et al., 2019). Decision-makers usually determine the cost-effectiveness of a PHI based on a cost effectiveness threshold. In the UK, the Department of Health makes decisions based on ICERS representing costs per QALY generated. The threshold ICER for determining the cost-effectiveness of PHIs was set at £15,000 by the Department of Health (£20,000 by NICE) using a discount rate of 1.5% for future health costs and benefits (Owen and Fischer, 2019). Since the determination of the ICER threshold can be somewhat arbitrary, Gafni and Birch (2006) argue the case for more flexibility in decisions. This is especially important when a PHI can offer improvements to health equity. The ICERs generated in this chapter are not suitable for medical decision making; they are intended to serve as a guide to researchers considering cost-effectiveness, complexity, and which BCTs to include in an intervention. This study may support researchers as they develop cost-effective PHIs.

Health equity was not the main focus of the systematic search and review. However, it was noted which interventions had specifically targeted socially disadvantaged and minority groups. Out of the 25 studies included, six had included women only in their samples. Of those studies, one specifically targeted Latina women living in the US (Larsen et al., 2017). The other women-only studies targeted menopausal women (Goranitis et al., 2017), pregnant women (Broekhuizen et al., 2018; Oostdam et al., 2012), mothers with young children (Burn et al., 2015) or older women (Robertson et al., 2001a). Two studies included in this review had specifically targeted individuals with low SES or living in socio-disadvantaged areas (Tully et al., 2019; Taylor et al., 2014). It is important that individually-targeted interventions consider equity issues and target interventions to groups who might benefit most. Furthermore, spill-over effects, where people in close proximity to the intervention participants may also experience benefits, should also be considered (Benjamin-Chung et al., 2018); this was not a focus of the interventions included in the review.

There are many challenges associated with the methodology of health economic evaluations. The time horizons here are relatively short, which only indicate the short-term effectiveness of the intervention. Only two studies included models with a lifetime horizon which indicated effectiveness and likely cost-effectiveness (Taylor et al., 2014; Dalziel, Segal and Elley, 2006). Network meta-analysis (NMA) for core-component analysis (Kabboul et al., 2018) was explored as a potential methodology to estimate the relative cost-effectiveness of the characteristics of the interventions. However, the heterogeneity of the studies, particularly the cost data, meant that NMA was not possible.

4.4.5 Public health interventions at the individual level

The interventions included in this review target inactive individuals. Inactive individuals are at elevated risk of several chronic diseases and premature mortality therefore the individual-level approach can bring substantial benefits to the participants (Howlett et al., 2019). Individual approaches are useful for high-risk individuals with low capability, opportunity, or motivation to change their behaviour. However, the benefits may not be long-lasting and the cost of the intervention per person can be very expensive. Behaviour change requires especially high levels of motivation in contexts, which promote physical inactivity due to prevailing social norms, the built environment or community values (Doyle, Furey and Flowers, 2006). Consequently, even interventions that are carefully tailored to an individual may not be effective at increasing physical activity. Radical changes at the population level may be needed to effect change in more people long-term.

Population-level interventions target communities or whole populations, e.g., water fluoridation and smoking bans. The initial investment of this approach is usually much more than the individual-level approach, but the return on investment can be considerably greater. In very large groups of people, a small per-person increase in physical activity level could bring large benefits to population health, the health care services, and the economy. In comparison, with an intense intervention involving a small group of participants, the population approach can be more cost-effective.

RCTs were the only study design that was included in the review to avoid selection bias and confounding. RCTs can provide good evidence regarding the effectiveness of an intervention, with high internal validity and are appropriate for simple interventions with individuals. In future, reviews in this research area could consider including other study designs to incorporate community-level interventions or other interventions which require more flexibility and cannot randomize participants such as a matched control group design or a cohort study. n-of-1 studies also present an opportunity to explore new interventions and technologies in behaviour change research, which has been so far underused in this field (McDonald et al., 2017). The behaviour of one individual, measured over time, could provide insights into personalised BCIs. In particular, researchers can assess behavioural patterns over time, 'intra-individual patterns', and how behaviour might be predicted by other factors. N-of-1 studies might be particularly useful in assessing digital health technologies (DHTs) such as mobile apps that can generate large amounts of data on one individual, although it would be challenging to conduct economic evaluations using data based on these studies. HeartSteps is an example of a digital health intervention to encourage users to walk regularly by sending tailored suggestions throughout the day. Klasnja et al. (2019) found that the intervention increased step count by 24%, although it decreased as the study went on. DHTs are a promising area for behaviour change.

4.4.6 Conclusion

The main objective of this review was to assess which characteristics of physical activity and sedentary behaviour interventions might be associated with greater cost-effectiveness. The results here suggest that the BCT clusters (1) Goals and planning; (2) Feedback and monitoring; (3) Social support; (4) Shaping knowledge; and (9) Comparison of outcomes are most frequently used in the most cost-effective interventions. A certain level of complexity may be necessary to achieve effectiveness in interventions, possibly because many of the included interventions targeted special populations that might require more support. However, overly complex interventions may lead to greater costs, which reduce the likelihood of cost-effectiveness. Finally, the intensity of the intervention did not appear to be associated with cost-effectiveness. These findings are useful for researchers designing potentially cost-effective interventions. Future economic evaluations of interventions should prioritise comprehensive reporting of the intervention content and all relevant costs including unit prices and quantities of programme costs.

Interventions can be effective and cost-effective at an individual-level, but there may be greater potential for public health benefits when interventions are aimed at a population-level. Abu-Omar *et al.* (2017) report that more economic evaluations of population-level physical activity interventions are needed. In particular, natural experiments on policies and environmental interventions deserve more attention due to their greater potential to reduce health inequalities.

Figure 4.1 The COM-B system – a framework for understanding behaviour (Michie et al. 2011)

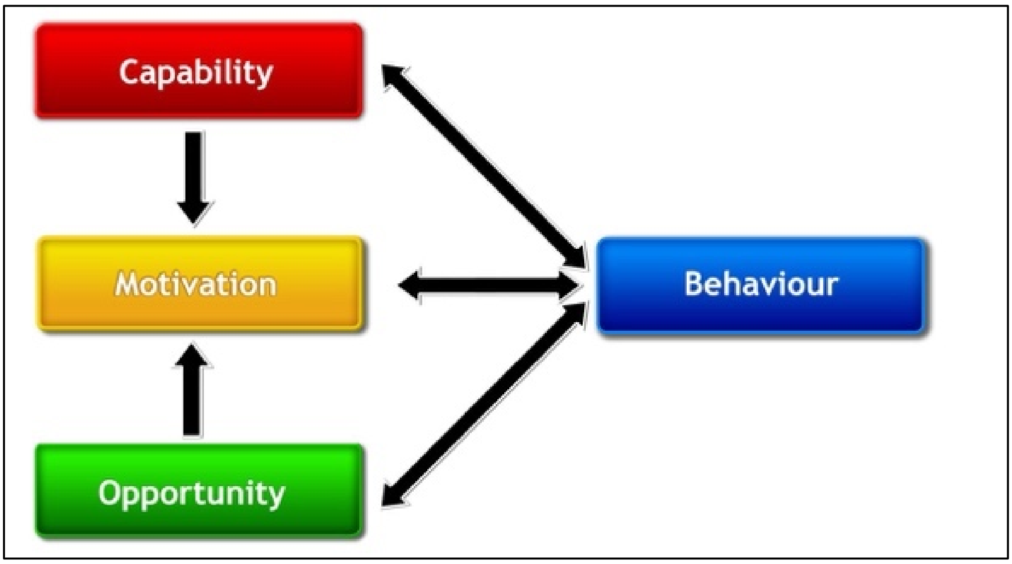


Figure 4.2 The behaviour change wheel (Michie et al. 2011)

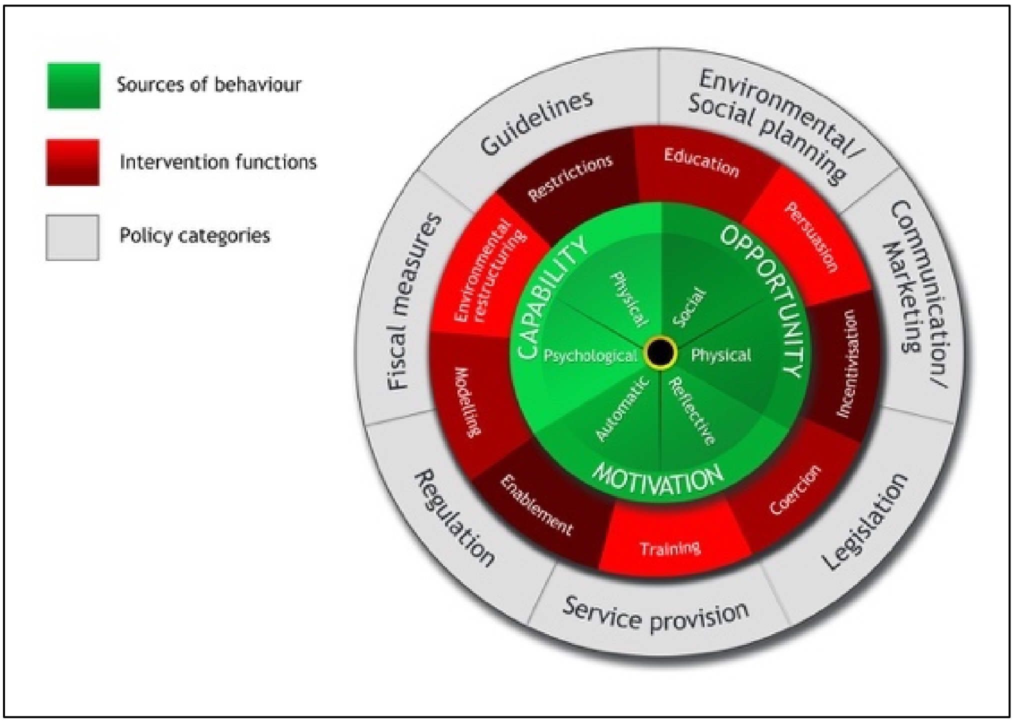


Figure 4.3 Electronic Search Strategy for Ovid Medline

1. exp Baseball/
2. exp Basketball/
3. exp Bicycling/
4. exp Boxing/
5. exp Dancing/
6. exp Football/
7. exp Gardening/
8. exp Golf/
9. exp Gymnastics/
10. exp Hockey/
11. exp Sports/
12. exp Swimming/
13. exp Tai Ji/
14. exp Walking/
15. exp Running/
16. exp Jogging/
17. (baseball OR basketball OR bicycling OR boxing OR dancing OR football OR gardening OR golf OR gymnastics OR hockey OR sports OR swimming OR "Tai Ji" OR walk* OR running OR jogging).ti,ab.
18. exp Sedentary lifestyle/
19. (sedentary adj (lifestyle* or behav* or time)).ti,ab.
20. exp Sitting position/
21. Sitting or lying.ti,ab.
22. exp Screen time/
23. ((screen or media) adj (us* or time)).ti,ab.
24. ((television or TV) adj (viewing or watching)).ti,ab.
25. ((computer or video) adj game*).ti,ab.
26. exp Physical Exertion/
27. (physical* adj (fit* or train* or activ* or endur* or exert* or educat* or inactiv*)).ti,ab.
28. MVPA.ti,ab.
29. exp Physical Fitness/
30. exp Exercise/
31. exercis*.ti,ab.
32. (active* adj (commut* or transport* or travel* or lifestyle*)).ti,ab.
33. exp Exercise Therapy/
34. 1-33
35. exp Economics/
36. (health adj (economics or expenditure or "technology assessment")).ti,ab.
37. exp "Costs and Cost Analysis"/
38. (cost* adj (benefit* or util* or minim* or estimat* or evaluat* or averted or analys*)).ti,ab
39. ("costeff*" OR "cost-eff*").ti,ab.
40. exp Models, Economic/
41. exp Cost-Benefit Analysis/
42. (economic* adj (evaluat* or analys*)).ti,ab
43. ("incremental cost-effectiveness ratio*" OR ICER*).ti,ab.
44. ("life-year gain*" OR LYG*).ti,ab.
45. "quality-adjusted life-year".ti,ab.
46. 35-45
47. exp Randomized

Table 4.1 Data extracted from eligible studies

Participants at Baseline	**Intervention**	**Economic Evaluation**
Number of participants	Country	Perspective
Gender	Description of intervention	Included costs
Age	Main focus	Intervention cost per participant
Body mass index	Control/Comparison	Effectiveness of intervention
Activity level	Setting	Incremental cost-effectiveness ratio
Ethnicity	Number of arms	Currency
Chronic disease or limiting illness	Duration of intervention	Year
Other special characteristics	Time-points when outcomes measured	Time horizon
	Length of follow-up	Discount rate
	Intensity of intervention (hours and contact points)	Sensitivity analyses
	Proportion reaching final follow-up	
	Primary and secondary outcomes	
	Timepoint at which outcomes measured	
	Mean effect/change in outcome	
	Behaviour change techniques used in the intervention	
	Complexity measured by iCAT_SR tool	

Table 4.2 Translation Formula for Physical Activity Outcome

Original Outcome	Translation Formula*
Steps per day walking	MET-h = (steps/10,000) x 4.25 x (1/3) x 3 MET
30-min blocks in physical activity per day	MET-h = [(30-min block)/4] x MET assigned†
Minutes per day on physical activity	MET-h = [min/d) x MET assigned†]/60
People meeting guideline (%)	MET-h = (% people) x (1.5 MET-h for adults or 3.0 MET-h for children)
MET-minutes per week	MET-h = (MET-min/wk)/60/7
Active days (at least 3 MET-h) per week	MET-h = (active days) x (3.0 MET-h)/7

*MET indicates metabolic equivalent of task. †MET assigned depends on level of activity: moderate PA = 3 METs; MVPA = 4.5 METs; and vigorous PA = 6 METs.
Adapted from Wu et al. (2011) (Table 1)

Figure 4.4 Flowchart of the selection process

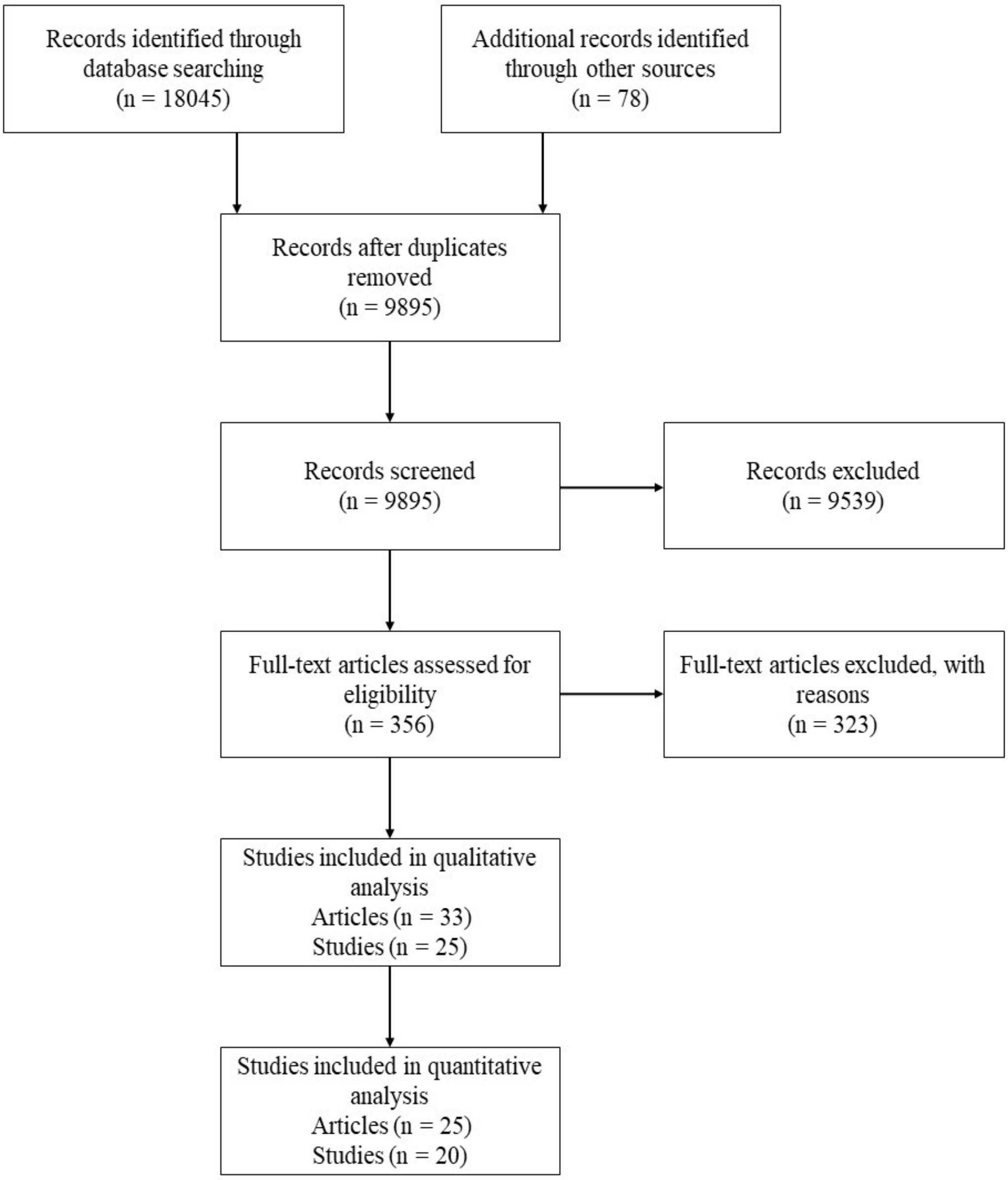


Table 4.3 Characteristics of included economic evaluations of physical activity and sedentary behaviour interventions

Study	Study population, location and setting	Interventions and Control Group content	Intervention and follow-up durations (weeks)	Outcome	
				Last time-point (weeks after baseline)	Incremental MET-h/week*
Interventions to increase physical activity					
1. Travel to Work (Audrey 2019)	654 employed adults in the UK; workplace setting	I1: trained workplace promoter giving employees written information and pedometers for commuting C: usual care	10, 42	52	I1: 0.00
2. Walk with Me (Tully 2019)	50 adults aged 60-70 years living in socioeconomically disadvantaged areas in the UK; community setting	I1: peer mentor programme which involved social meeting to discuss goal-setting, problem-solving, sign-posting physical activity opportunities, walking. C: information booklet on active ageing	12, 40	26	I1: 0.05
3. Active Plus (Golsteijn 2014, Peels 2014)	1248 adults aged over 50 years in the Netherlands; community setting	Tailored physical activity advice at three moments based on personal characteristics, motivational readiness and needs I1: printed I2: printed with environment component I3: web-based I4: web-based with an environmental component C: wait-list	15, 37	52	I1: 5.20 I2: 4.90 I3: 2.90 I4: 1.80
4. AME (McEachan 2011)	1260 adults in the UK, workplace setting	I1: physical activity toolkit including knowledge quiz, interactive leaflets, posters, team challenges, reminders, letters of management support, newsletters, and fridge magnets to allow self-monitoring of physical activity C: no intervention	12, 39	52	I1: 0.13

5. Enhanced Green Prescription (Elley, 2011)	1089 adults aged 40-79 years in New Zealand; healthcare setting	I1: Brief advice and written exercise prescription with telephone support C: usual care	39, 65	52	I1: 5.55
6. MobileMums (Burn, 2015)	263 mothers with children under 1 year in Australia; community setting	I1: physical activity counselling, tailored text messages, and other resources C: brief written feedback on physical activity	12, 27	39	I1: 0.03
7. PACE-UP (Anokye 2018, Harris, 2018)	1023 adults aged 45-75 years in the UK; healthcare setting	I1: 12-week walking programme with pedometers and diaries I2: same as I1 with additional nurse consultation C: usual care	12, 40	52	I1: 0.35 I2: 0.38
8. EuroFIT (Wyke 2019)	1113 male football fans aged 30-65 years with BMI over 27 kg/m2 in England, Netherlands, Norway, & Portugal; sports club setting	I1: Weekly exercise programme with a self-monitoring device C: wait-list	12, 40	52	I1: 0.25
9. Green Prescription (Dalziel 2006)	878 sedentary adults aged 40-79 in Australia; healthcare setting	I1: clinician discusses increasing physical activity and sets goals with patient C: usual care	13, 39	52	I1: 2.52
10. Pasos Hacia La Salud (Larsen 2017)	205 Latina women aged 18-65 years in the USA; healthcare setting	I1: Spanish-language website with tailored monthly physical activity reports C: website on other wellness topics	26, 26	52	I1: 0.02
11. PAL (Hunter 2018)	853 public sector employees in the UK; workplace setting	I1: high-street loyalty scheme rewarding participants for increased physical activity C: wait-list	26, 26	52	I1: -0.24
12. Prescription for Exercise (Stevens 1998)	714 adults aged 45-74 years in the UK; healthcare setting	I1: two consultations with an exercise development officer C: posted physical activity information	10, 25	35	I1: 0.04
13. ProAct65+ (Iliffe 2014, Iliffe 2015)	1256 adults aged over 65 years in the UK; healthcare setting	I1: weekly exercise classes in the community centre and at-home exercises. I2: at-home muscle strengthening and balance exercises and walking plan C: usual care	24, 28	52	I1: 0.13 I2: 0.02

14. Sheffield Physical Activity Booster Trial (Goyder 2014)	282 previously sedentary adults aged 40-65 years living in socio-economically disadvantaged areas in the UK who had increased their physical activity levels after receiving a brief intervention; community setting	Two physical activity consultations I1: face-to-face I2: telephone-based C: no intervention	8, 31	39	I1 + I2 average: 0.18
Interventions to increase physical activity and improve diet					
15. Dzator 2004	274 cohabiting couples in Australia; community setting	Six modules on nutrition and physical activity by mail I1: six modules only I2: additional group sessions with dietitian and exercise physiologist C: wait-list	16, 36	52	I1: 0.09 I2: 0.00
16. FFIT (Gray 2018, Hunt 2014, Wyke 2015)	747 adults aged 35-65 years with BMI over 28 kg/m2 in the UK; sports club setting	I1: weekly physical activity programme with healthy diet advice and email prompts C: wait-list and weight management booklet	12, 40	52	I1: 2.01
17. Vital@Work (van Dongen 2013)	730 hospital employees aged over 45 years in the Netherlands; workplace setting	I1: Exercise programme with personal coaching and free fruit C: written information on healthy lifestyles	24, 28	No physical activity outcome	
Interventions to improve medical condition or symptoms					
18. DALI (Broekhuizen, 2018)	435 pregnant women in 9 European countries; healthcare setting	Lifestyle coaching I1: healthy eating & physical activity I2: healthy eating I3: physical activity C: usual care	15, 0-5	No physical activity outcome	
19. FitFor2 (Oostdam 2012)	121 pregnant women at risk of gestational diabetes mellitus in the Netherlands; healthcare setting	I1: twice-weekly group exercise program C: usual care	15-26, 12	32	I1: -0.84
20. Active Women (Goranitis 2017)	261 inactive peri- or postmenopausal women aged 48-67 years in the UK; healthcare setting	Exercise intervention to improve symptoms of menopause I1: DVD	26, 26	52	I1: -1.69 I2: -1.80

		I2: social support C: one exercise consultation without intervention			
Interventions to reduce the risk of falling					
21. FICSIT study (Wilson 2001)	200 ambulatory adults aged over 70 years in the USA; healthcare setting	I1: weekly Tai Chi classes I2: balance training C: weekly meeting on age-related health	15, 17	No physical activity outcome	
22. Robertson et al. (2001a)	240 adults aged over 75 years in New Zealand; community setting	I1: exercise programme delivered in home visits and walking plan C: usual care	26, 26	No physical activity outcome	
23. Robertson et al. (2001b)	133 adults aged over 80 years in New Zealand; primary care setting	I1: exercise programme delivered in home visits and walking plan C: social home visits	8, 44	No physical activity outcome	
24. The Central Sydney tai chi Trial (Haas 2006)	702 adults aged 60-96 in Australia; community setting	I1: weekly Tai Chi classes C: wait-list	16, 8	No physical activity outcome	
Interventions to assist with smoking cessation					
25. EARS (Taylor 2014)	99 adult smokers in the UK; community setting	I1: one-to-one support from health trainer and subsidised physical activity opportunities C: brief advice on smoking cessation	8, 8	16	I1: -0.08

I = intervention arm; C = control arm; MET = metabolic equivalents of task.

Table 4.4 Economic evaluations of interventions

Study	Perspective; time horizon;	Currency and year	Costs included	Cost of intervention per participant	Cost-effectiveness ratio
1. Travel to Work (Audrey 2019)	Broad (employer, employee, healthcare costs and individual wellbeing), 1 year	GBP (£), 2016	Walk to Work promoter training (trainer time and travel costs, and promoter time) and intervention resources (e.g. booklets, pedometers)	I1: 24.19	I1: 109.57
2. Walk with Me (Tully 2019)	Public sector, <1 year	GBP (£), 2017	Intervention costs (not development) and health service resource use	I1: 210.61	I1: 48.62
3. Active Plus (Golsteijn 2014, Peels 2014)	Societal, 12 months	EUR (€), 2011	Intervention, healthcare, participant and family, and productivity costs	I1: 25.77 I2: 31.21 I3: 15.53 I4: 18.83	I1: 0.04 I2: 0.06 I3: 0.05 I4: 0.09
4. AME (Awareness, Motivation, Environment) for ACTIVITY (McEachan 2011)	Societal, 13 months	GBP (£), 2007-08	Intervention costs, productivity changes, opportunity costs to individual, healthcare costs	I1: 58.00	I1: 6.97
5. Enhanced Green Prescription (Elley, 2011)	Societal, 2 years	NZD ($), 2008	Intervention costs, participant costs, primary and secondary healthcare utilisation, allied health therapies, time off work	I1: 93.68	I1: 0.04
6. MobileMums (Burn, 2015)	Healthcare service, 2 years	AUD ($), 2014	Intervention costs and health system costs	I1: 62.64	I1: 17.5

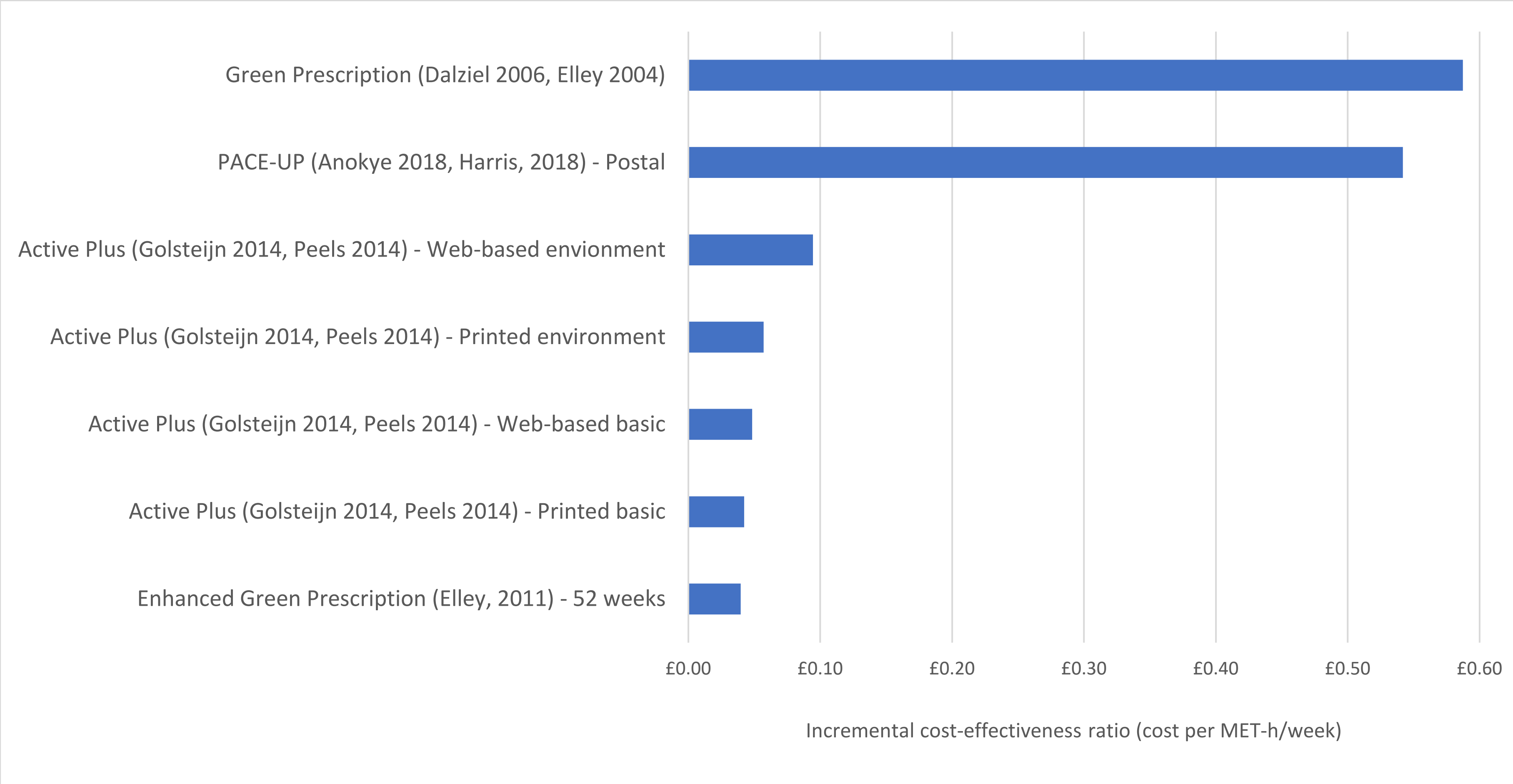
Study	Perspective; time horizon;	Currency and year	Costs included	Cost of intervention per participant	Cost-effectiveness ratio
7. PACE-UP (Anokye 2018, Harris, 2018)	NHS, 1 year	GBP (£), 2013-14	Intervention costs, health service use	I1: 55.00 I2: 157.00	I1: 0.54 I2: 4.54
8. European Fans In Training (EuroFIT) (Wyke 2019)	Societal, 1 year	GBP (£), 2016	Programme delivery, healthcare utilisation, medical utilisation, absenteeism	I1: 228.00	I1: 11.31
9. Green Prescription (Dalziel 2006)	Healthcare service, lifetime	NZD ($), 2001	Health care, productivity costs	I1: 170.43	I1: 0.59
10. Pasos Hacia La Salud (Larsen 2017)	Healthcare service, 1 year	USD ($), 2014	Personnel, website, hardware, materials	I1: 103.00	I1: 20.76
11. Physical Activity Loyalty Scheme (PAL) (Hunter 2018)	Public sector, 6 months	GBP (£), 2015-2016	Intervention costs (per participant) and health-care resource use	I1: 55.68	I1: -1.33
12. Prescription for Exercise (Stevens 1998)	NA, NA	GBP (£), 1998	Postage, stationery, labour, equipment	I1: 66.24	I1: 38.82
13. ProAct65+ (Iliffe 2014, Iliffe 2015)	NHS and private, 12 months	GBP (£), 2011	Cost of intervention programmes, out-of-pocket expenditures, productivity, hospital service utilisation	I1: 243.50 I2: 205.00	I1: 13.18 I2: 62.82
14. Sheffield Physical Activity Booster Trial (Goyder 2014)	Societal, 9 months	GBP (£), 2011	Cost of intervention; the cost of NHS resource use (primary care, emergency care, outpatient, inpatient); societal cost (opportunity cost of receiving care).	I1 & I2 mean: 108.80	I1: 12.35
15. Dzator 2004	Intervention payer, 1 year	AUD ($), 2003	Intervention costs	I1: 445.18 I2: 445.30	I1: 37.92

Study	Perspective; time horizon;	Currency and year	Costs included	Cost of intervention per participant	Cost-effectiveness ratio
16. Football Fans in Training (FFIT) (Gray 2018, Hunt 2014, Wyke 2015)	NHS and PSS, 12 months	GBP (£), 2011-12	Healthcare costs. Intervention costs, medication,	I1: 165.00	I1: 1.09
17. Vital@Work (van Dongen 2013)	Societal, 1 year	EUR (€), 2010	Intervention, healthcare, absenteeism, presenteeism, sports activities	I1: 149.00	NA
18. DALI (Broekhuizen, 2018)	Societal, <1 year	EUR (€), 2012	Intervention costs, medical, absenteeism, travel costs	I1: 436.00 I2: 430.00 I3: 426.00	NA
19. FitFor2 (Oostdam 2012)	Societal, 25 weeks	EUR (€), 2009	Direct costs: visits to healthcare providers, medication, and informal care. Indirect costs: sick leave	I1: 225.00	I1: -1.79
20. Active Women (Goranitis 2017)	NHS, PSS and societal, 12 months,	GBP (£), 2013-14	Healthcare; complementary and alternative medicine; time off work; out of pocket expenses	I1: 78.09 I2: 36.75	I1: -0.27 I2: -0.12
21. FICSIT study (Wilson 2001)	Societal, 1 year	USD ($), 2000	Healthcare costs	I1: 172.24	NA
22. Robertson 2001a	Societal, 1 year	NZD ($), 1998	Exercise programme, healthcare costs from falls	I1: 432.00	NA
23. Robertson 2001b	Societal, 2 years	NZD ($), 1995	Exercise programme, healthcare costs	I1: 173.00	NA
24. The Central Sydney tai chi Trial (Haas 2006)	Healthcare service, 24 weeks	AUD ($), 2002	Tai Chi trial costs and health service utilisation (including GP and specialist and other consultations, tests, hospitalisations and medications).	I1: 245.00	NA

Study	Perspective; time horizon;	Currency and year	Costs included	Cost of intervention per participant	Cost-effectiveness ratio
25. Exercise Assisted Reduction then Stop (EARS) (Taylor 2014)	NHS and PSS, lifetime	GBP (£), 2011	Training, recruitment, intervention delivery, HT supervision, exercise aids	I1: 192.00	I1: -52.83

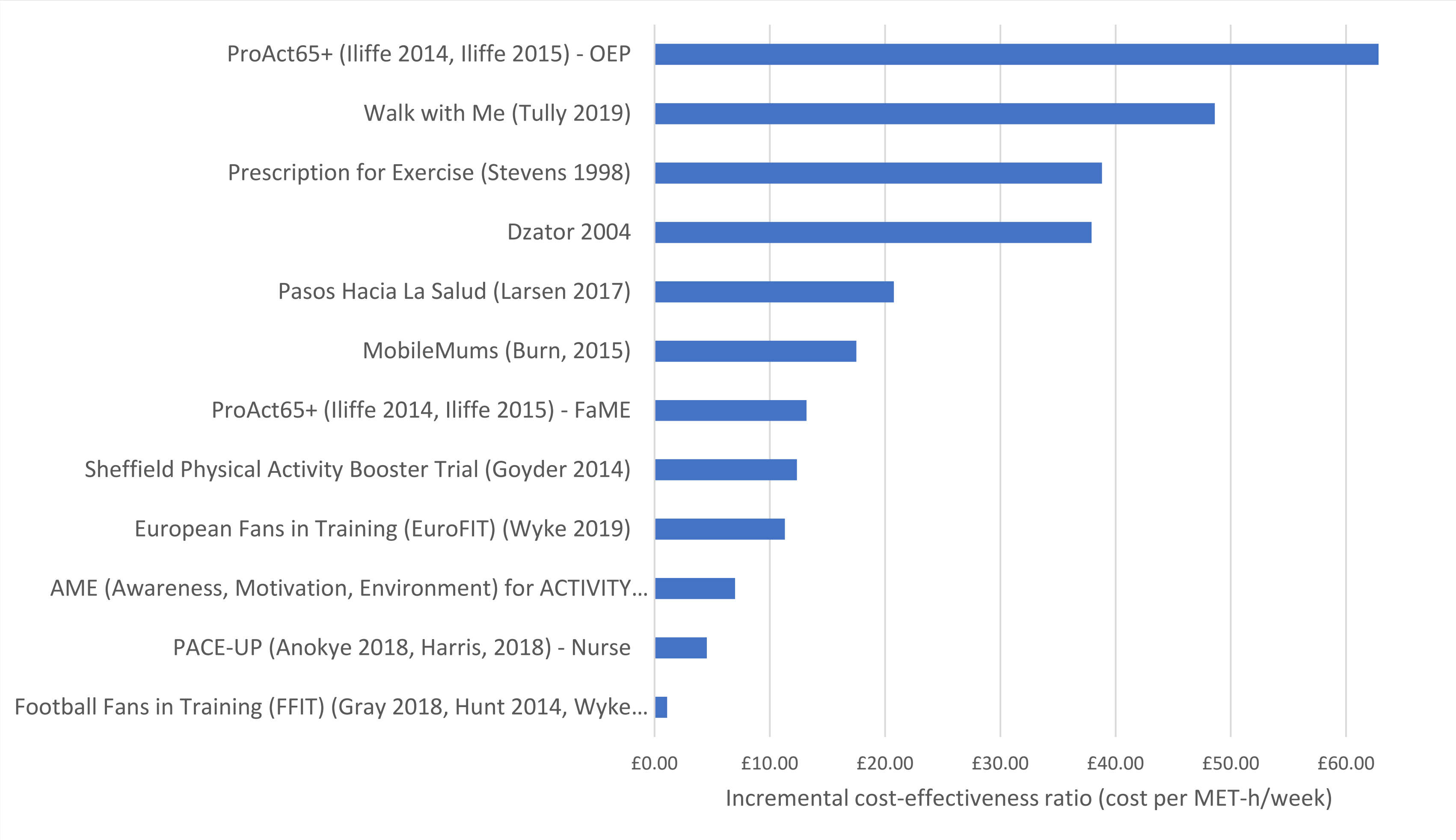
I = intervention arm; C = control arm; MET = metabolic equivalents of task; PA = physical activity

Figure 4.5 Incremental cost-effectiveness ratios for interventions using physical activity outcomes (<£1 per MET-h/week)



Only includes interventions which increased physical activity.

Figure 4.6 Incremental cost-effectiveness ratios for interventions using physical activity outcomes (>£1 per MET-h/week)



Only includes interventions which increased physical activity.

Table 4.5 Quality of included studies assessed by the Drummond Checklist

	Drummond checklist item									
	1	2	3	4	5	6	7	8	9	10
Active Plus (Golsteijn 2014, Peels 2014)	1	1	1	1	1	1	1	1	1	1
Active Women (Goranitis 2017)	1	1	1	1	1	1	1	1	1	1
AME for ACTIVITY (McEachan 2011)	1	1	1	1	1	1	1	1	0	1
DALI	1	1	1	1	1	1	1	1	1	1
Dzator 2004	1	1	1	0	1	0	0	1	1	1
Enhanced Green Prescription (Elley, 2011)	1	1	1	1	1	1	1	1	1	1
European Fans in Training (EuroFIT) (Wyke 2019)	1	1	1	1	1	1	1	1	1	1
FitFor2 (Oostdam 2012)	1	1	1	1	1	1	1	1	1	1
Football Fans in Training (FFIT) (Gray 2018, Hunt 2014, Wyke 2015)	1	1	1	1	1	1	1	1	1	1
MobileMums (Burn, 2015)	1	1	1	0	0	1	1	1	1	1
PACE-UP (Anokye 2018, Harris, 2018)	1	1	1	0	0	1	1	1	1	1
Exercise Assisted Reduction then Stop (EARS) (Taylor 2014)	1	1	1	1	1	1	1	1	1	1
Green Prescription (Dalziel 2006, Elley 2004)	1	1	1	1	1	1	1	1	1	1
Football Fans in Training (FFIT) (Gray 2018, Hunt 2014, Wyke 2015)	1	1	1	1	1	1	1	1	1	1
FICSIT study (Wilson 2001)	1	0	1	1	1	1	1	1	1	1
Prescription for Exercise (Stevens 1998)	0	1	1	0	1	1	0	1	1	1

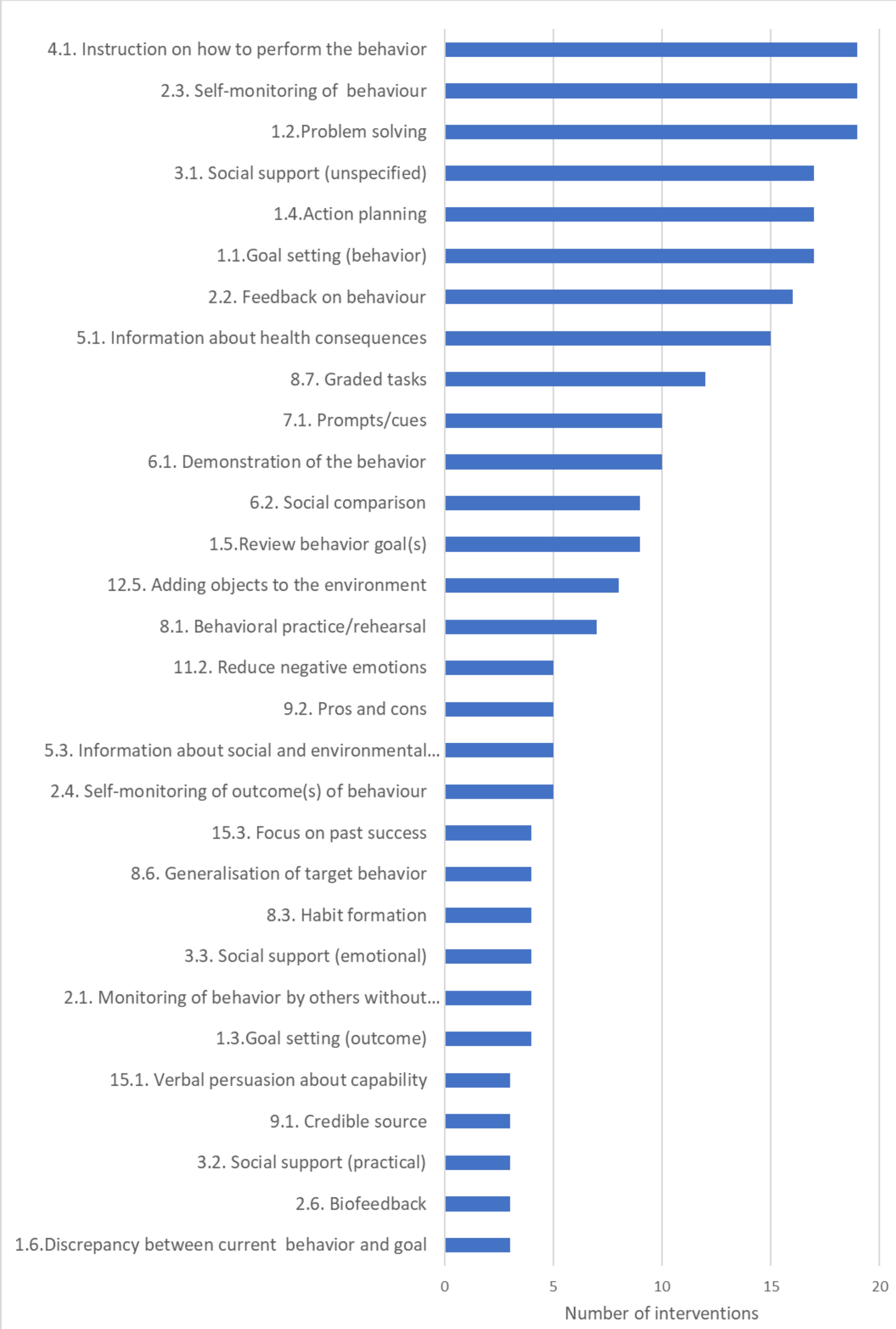
	Drummond checklist item									
	1	2	3	4	5	6	7	8	9	10
Pasos Hacia La Salud (Larsen 2017)	1	1	1	1	1	1	1	1	1	1
Physical Activity Loyalty Scheme (PAL) (Hunter 2018)	1	1	1	1	1	1	0	1	1	1
ProAct65+ (Iliffe 2014, Iliffe 2015)	1	1	1	1	1	1	1	1	0	1
Robertson 2001a	1	1	1	1	1	1	1	1	1	1
Robertson 2001b	1	1	1	1	1	1	0	1	1	1
Sheffield Physical Activity Booster Trial (Goyder 2014)	1	1	1	1	1	1	1	1	1	1
The Central Sydney tai chi Trial (Haas 2006)	1	1	1	1	1	1	1	1	1	1
Vital@Work (vanDongen 2013)	1	1	1	1	1	1	1	1	1	1
Travel to Work (Audrey 2019)	1	1	1	1	1	1	1	0	0	0
Walk with Me (Tully 2019)	1	1	1	0	1	1	1	0	0	0

Figure 4.7 Risk of bias of included studies assessed using ROB2 tool

	Study ID	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Studies with intention-to-treat	Active Women (Goranitis 2017)	+	+	+	+	+	+
	AME for ACTIVITY (McEachan 2011)	?	+	+	+	+	!
	DALI (Broekhuizen, 2018)	+	+	?	+	+	!
	Dzator 2004	?	?	+	+	?	!
	Enhanced Green Prescription (Elley, 2011)	+	+	+	+	+	+
	European Fans in Training (EuroFIT) (Wyke 2019)	+	+	+	+	+	+
	Exercise Assisted Reduction then Stop (EARS) (Taylor 2014)	+	?	+	+	+	!
	FitFor2 (Oostdam 2012)	+	+	+	+	+	+
	Football Fans in Training (FFIT) (Gray 2018, Hunt 2014, Wyke 2015)	+	–	+	+	+	–
	Green Prescription (Dalziel 2006)	+	?	+	+	?	!
	MobileMums (Burn, 2015)	?	+	+	+	+	!
	PACE-UP (Anokye 2018, Harris, 2018)	+	?	+	+	+	!
	Pasos Hacia La Salud (Larsen 2017)	?	+	+	+	?	!
	Physical Activity Loyalty Scheme (PAL) (Hunter 2018)	+	+	+	+	+	+
	Prescription for Exercise (Stevens 1998)	?	?	+	+	?	!
	ProAct65+ (Iliffe 2014, Iliffe 2015)	+	+	+	+	+	+
	Robertson 2001a	+	+	+	+	+	+
	Robertson 2001b	+	?	–	+	?	–
	Sheffield Physical Activity Booster Trial (Goyder 2014)	+	+	+	+	+	+
	The Central Sydney tai chi Trial (Haas 2006)	+	?	+	+	?	!
	Travel to Work (Audrey 2019)	+	+	+	+	+	+
	Vital@Work (vanDongen 2013)	+	+	+	+	+	+
Studies with pre-protocol	Active Plus (Golsteijn 2014, Peels 2014)	–	–	–	+	+	–
	FICSIT study (Wilson 2001)	?	–	+	–	?	–
	Walk with Me (Tully 2019)	+	–	+	+	+	!

+ Low risk
? Some concerns
– High risk

Figure 4.8 Individual behaviour change techniques used in interventions



Only BCTs used in at least three interventions were included in the figure.

Figure 4.9 Prevalence of behaviour change technique clusters in interventions by cost-effectiveness

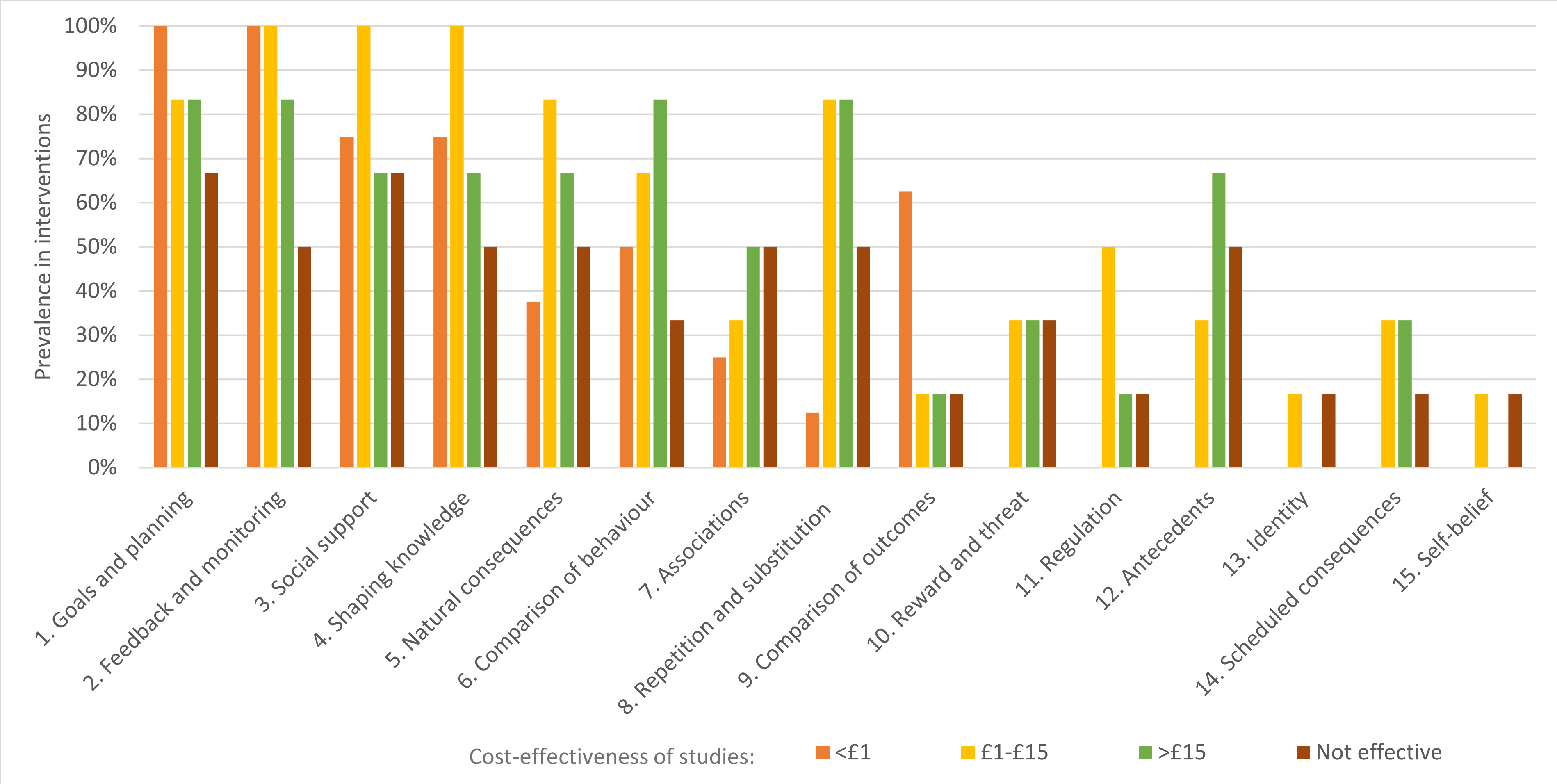


Figure 4.10 Complexity of interventions as measured by the iCAT_SR Tool by cost-effectiveness

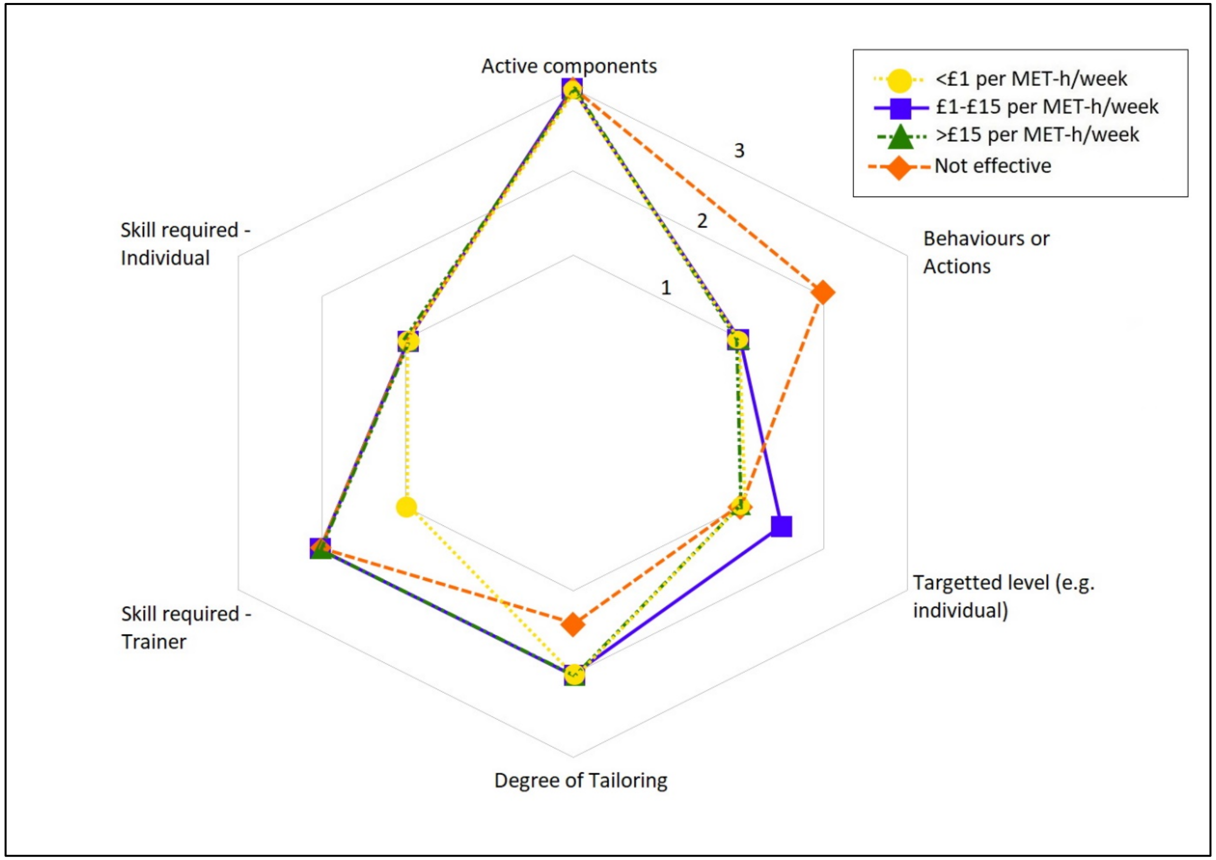


Figure 4.11 Relationship between overall complexity of the intervention and cost-effectiveness

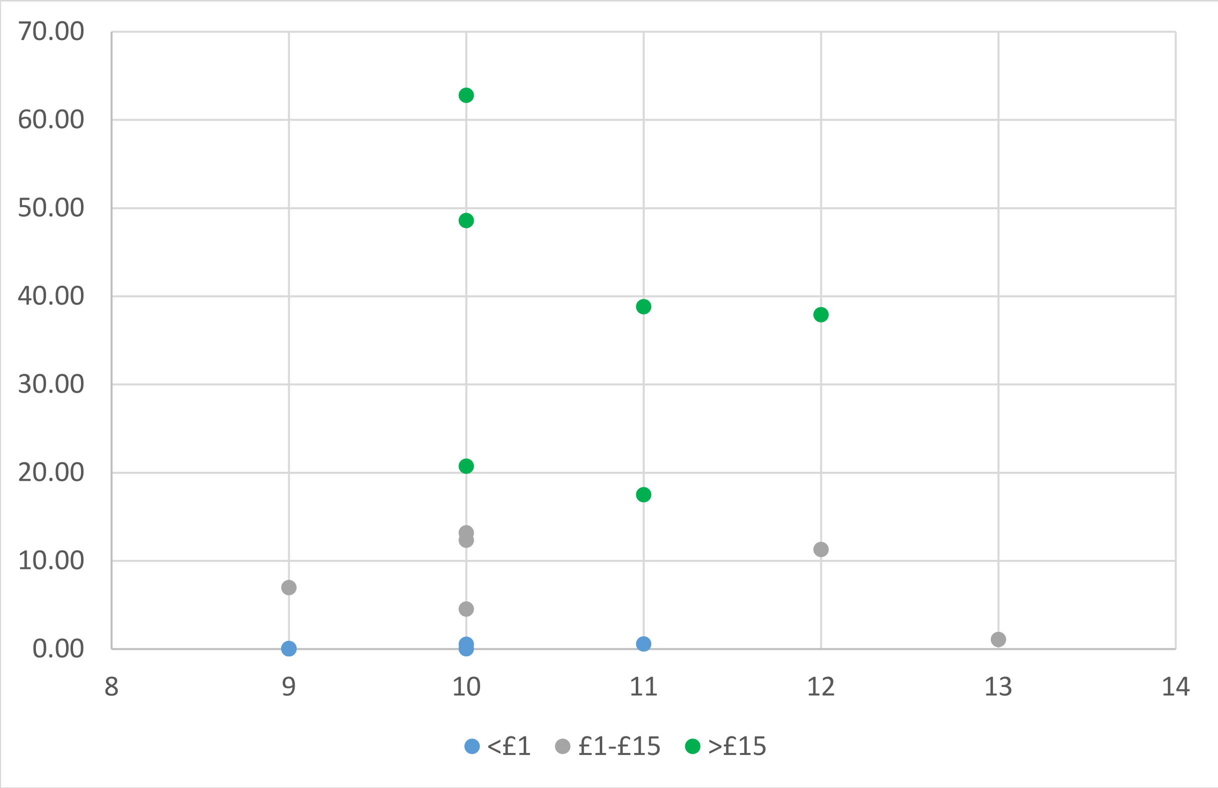
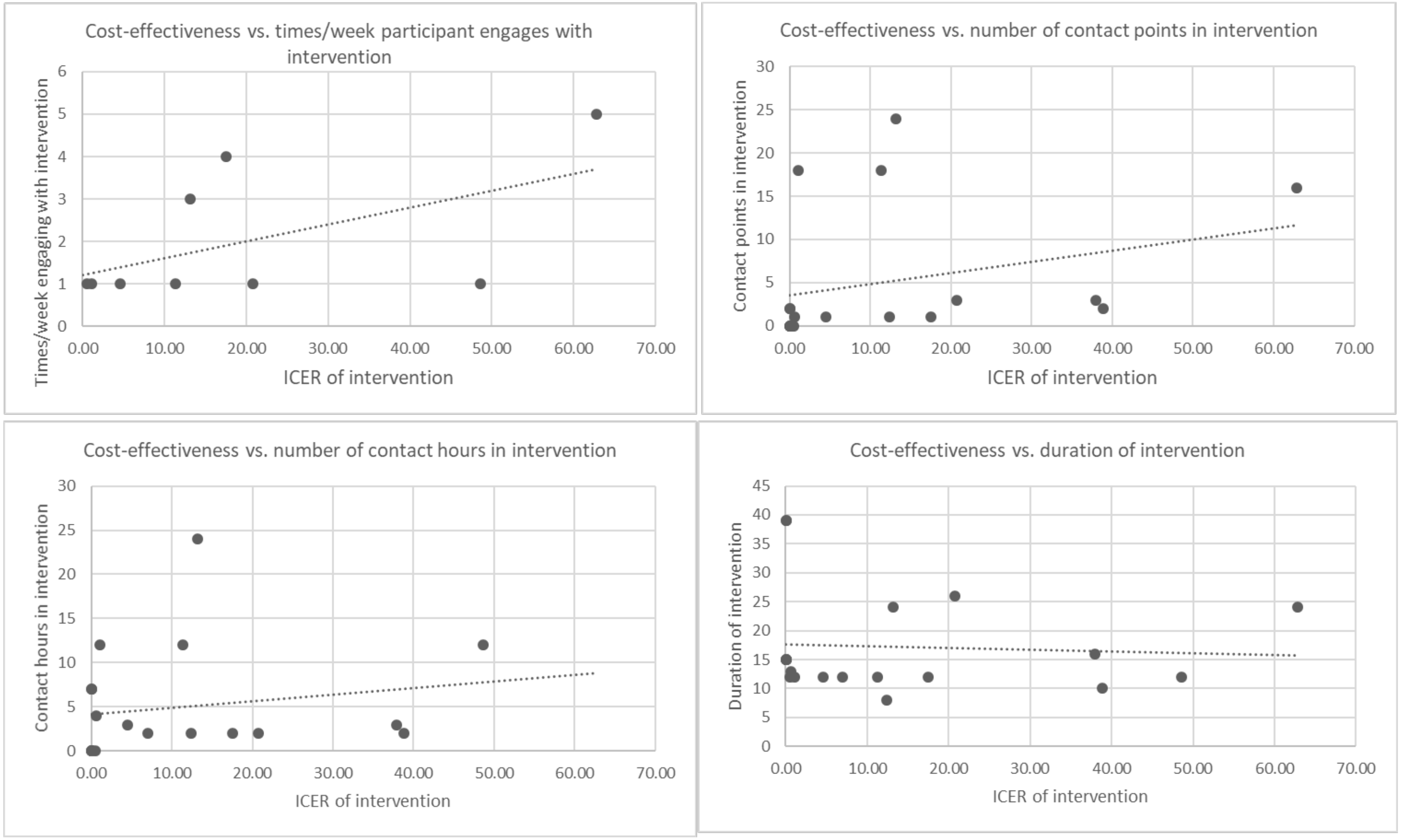


Figure 4.12 Incremental cost-effectiveness ratios for interventions using physical activity outcomes (<£1 per MET-h/week)



ICER = incremental cost-effectiveness ratio

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CHAPTER 5

UPDATED SOCIAL RETURN OF INVESTMENT ANALYSIS OF THE CONNSWATER COMMUNITY GREENWAY

5 UPDATED SOCIAL RETURN OF INVESTMENT ANALYSIS OF THE CONNSWATER COMMUNITY GREENWAY

5.1 Introduction

Population-level interventions can complement individual approaches by addressing the social, economic and environmental determinants of health on a large scale. They can involve radical changes to behavioural norms, which aim to shift the distribution of risk factors in a positive direction. Rose (1985) first proposed the idea that a population approach had greater potential than individual-level interventions targeting high-risk groups. The previous chapter explored interventions at an individual-level. Although an individual approach may reduce risk by a clinically-meaningful amount in one individual, a change in one person is negligible from a public health perspective. Targeting the whole population can reduce their overall risk profile, even if the difference to one individual may be small while reinforcing individual approaches through peer effects and adjusted social norms. Investment in new or improved urban green space (UGS) could be a worthwhile PHI for urban populations.

Permanent physical changes to the urban environment can be radical and expensive, but UGS can bring many health and social benefits to communities (Kondo et al., 2018; Zhou and Rana, 2012; Lee and Maheswaran, 2011; Hunter et al., 2015). UGS is defined as any urban space covered by vegetation, including large recreational green spaces such as parks and greenways but also small, roadside, or inaccessible green spaces (WHO Regional Office for Europe, 2016). Exposure to green space can significantly improve physical health by reducing stress levels, blood pressure, cholesterol, and the risk of T2D (Twohig-Bennett and Jones, 2018). Hunter, Cleary and Braubach (2019) reviewed international evidence and case studies of UGS to identify the most important considerations when designing or evaluating UGS interventions. There was strong evidence that park-based UGS interventions alongside marketing and promotion programmes increased physical activity and the greening of vacant lots had health, wellbeing, and social benefits such as improved perception of safety in the area. Furthermore, green infrastructure was associated with positive environmental outcomes such as increased biodiversity and improved air quality. Consequently, the United Nations (UN) and the WHO have called for more investment in UGS (United Nations (Habitat III), 2017; World Health Organization, 2017).

Investment in green space has the potential to reduce health inequalities (Public Health England, 2014). Individuals living in socioeconomically disadvantaged areas typically report poorer health and mental wellbeing and suffer from higher rates of chronic disease (Kontopantelis et al., 2018; Public Health England, 2017; NHS Health Scotland, 2018). Therefore, these areas stand the most to gain from investment in the local built environment. However, more socioeconomically disadvantaged neighbourhoods in the UK have less green space than wealthier areas, poorer air quality, and an increased risk of flooding (Public Health England, 2014). Therefore, the current distribution of UGS may increase health inequalities (Wolch, Byrne and Newell, 2014). Conducting UGS interventions in socioeconomically disadvantaged areas may be a means to both improve health and reduce health inequalities in the UK population.

Despite the existing evidence on the positive effects of UGS, economic evaluations of UGS are sparse. Hunter, Cleary and Braubach (2019) advocate that future studies should also include economic evaluations, which consider their wider economic impacts. The effects of UGS are potentially far-reaching; therefore, evaluations are needed that encompass environmental, and broader societal costs as well as those related to healthcare. Economic evaluations up to now have likely undervalued UGS interventions, as it is difficult to quantify and monetise many of the benefits e.g., improved air quality and mental wellbeing. However, many of the effects are undeniably important for society and should not be ignored. Deidda et al. (2019) recently published a framework for the economic evaluation of natural experiments. A natural experiment occurs when two population subgroups are exposed to different levels of some factor and the circumstances resemble a real experiment. Natural experiments are useful when it is not feasible or practical to randomise individuals to a group. Many UGS studies are natural experiments: one neighbourhood has access to UGS (the exposure) and a similar neighbourhood does not. Deidda's framework should be used to guide the development of a study from the early design phase to ensure sufficient data to perform an economic evaluation. More high-quality economic evaluations of UGS are needed to add to the limited current evidence base.

Two economic evaluations of the CCG in Belfast, NI were completed before its construction was complete. In the first, Dallat et al. (2014) used a macro-simulation PREVENT model to estimate that the CCG had the potential to reduce the burden from

CVD, T2D and cancer through increased physical activity. The reduction in morbidity and mortality, it was estimated, would lead to cost-savings for the NHS in the UK. In summary, the CCG would be cost-effective (£18,411 per disability-adjusted life-year [DALY]) even if it increased activity levels by just 2%. In the second evaluation, Hunter et al. (2020) conducted an expected SROI of the CCG. The benefit-cost ratio (BCR) was estimated at between 2.88 and 5.81, therefore the CCG was likely to be good value for money. Construction of the CCG was completed in 2017. The previous evaluations were based on several a priori assumptions, as the data were not yet available. Now that the CCG is open to the public, it is possible to revisit these evaluations now more information is available.

SROI analyses compare the costs of an investment with its benefits in monetary terms to produce a BCR (Edwards and McIntosh, 2019). This approach incorporates economic, social, and environmental benefits, which are determined by the relevant stakeholders: every person or organisation impacted by the intervention under study. SROI analyses aim to determine how the efficiency of an investment; in this case, the purpose was to evaluate the efficiency of the investment into the CCG.

The advantages of an SROI approach is that it is a more flexible approach that can incorporate a wider range of outcomes than traditional analyses which usually include QALYs (Edwards and McIntosh, 2019). SROIs can be useful in a public health context where economic, social, and environmental outcomes are particularly relevant. Since the outcomes are all estimated in monetary terms, it is accessible to non-experts such as policy-makers and local councils (Stone, 2005). Nevertheless, the SROI approach has not been standardised (Edwards and McIntosh, 2019). Outcomes can be valued using financial proxies, which can be WTP estimates, revealed preference, or well-being valuation (Edwards and McIntosh, 2019). The choice of which method to use depends on the stakeholders who dictate the perspective of the analysis. The flexibility of this approach can be useful, but some outcomes can be challenging to measure when appropriate data do not exist or the benefit has non-market value. The single ratio produced may be also misleading since it hides the complexity of the analysis and the various assumptions made. Furthermore, it is not advisable to compare SROI ratios since each analysis is designed based on its unique stakeholders.

An SROI analysis of the CCG was conducted as this method could incorporate a range of social, environmental and economic benefits and summarise the cost-effectiveness in monetary terms. The stakeholders were a key consideration as the East Belfast Partnership, a local community-based charity, and Belfast City Council were involved in the development, maintenance, and promotion of the CCG. Other stakeholders were Queen's University Belfast and local government.

This chapter describes an SROI analysis of the CCG (over an investment period of 40 years) based on before and after data. The methods section follows the framework by Deidda et al. (2019) and outlines the methodology used, in line with recommendations from the HM Treasury Green Book (HM Treasury, 2013). In the results section, I report the estimated economic benefits of the CCG compared to the total costs of the project. Then, I describe various sensitivity analyses to explore the robustness of the results. Finally, the discussion explores the societal impact of the CCG over its lifetime and the need for a consensus on the methodology for economic evaluations of UGS.

5.2 Methodology

As far as possible, this economic evaluation has been reported in line with the checklist for the economic evaluation of PHIs alongside natural experiments compiled by Deidda et al. (2019). The Treasury Green Book (HM Treasury, 2013) was also used to guide the analysis.

5.2.1 Population and Setting: The Connswater Community Greenway

The CCG is situated in East Belfast, NI, in an area of 29 electoral wards, with a population of 116,000 in 2017 (Northern Ireland Statistics and Research Agency, 2020). Twenty-two wards are within a one-mile (1.6km) radius of the greenway: containing approximately 87,500 residents. The area is socioeconomically disadvantaged: seven of the electoral wards are in the top 25% most deprived wards in NI according to the 2005 NI Multiple Deprivation Measure (Northern Ireland Statistics and Research Agency, 2005).

Previously, the area had not been well maintained and the Connswater River was polluted. Nine kilometres of linear parkway now provide a safe and accessible route from the outer city to the centre and connects existing parks and green space. The regeneration involved planting trees and shrubs, cleaning river water, and installing flood alleviation measures. CS Lewis Square, a new cultural and educational public space, was also constructed as part of the greenway. Closed-circuit television, 24-hour lighting, and park wardens were added to improve the public perception of safety in the area. The East Belfast Partnership advertised the greenway, promoted community engagement through volunteering and organised cultural and community events (www.communitygreenway.co.uk). In addition, the Centre for Public Health at Queen's University Belfast established the Physical Activity and the Rejuvenation of Connswater (PARC) study to evaluate the CCG.

5.2.2 Methodological Framework

In this SROI analysis, the net present social value (NPSV) and the BCR, the total benefits divided by the total costs, of the intervention were calculated from a societal perspective. The NPSV is the total value of the discounted benefits of the CCG, minus the discounted total costs and the BCR is a ratio of the total value of the discounted benefits and the total costs. The NPSV, the BCR, and other relevant considerations about the intervention help to determine its value for money.

Hunter et al. (2020) presented an SROI analysis of the CCG, which was completed in 2013 before construction was complete. The analysis used assumptions to produce an estimate of the expected value of the CCG to society. They estimated the NPSV of the CCG to be £33,633,037, discounted by 3.5%, over 40 years. At this stage, total costs were expected to be £35m. The BCR ranged from 2.88 (£100,741,873/£35,000,000) to 5.81 (£203,495,306/£35,000,000).

A logic model for the CCG, based on an example presented by Deidda et al. (2019), presents the inputs (costs of the interventions), the outputs (the CCG intervention), the context and the expected short-term and long-term outcomes of the CCG over its lifetime (Figure 5.1). It shows how the present values of the expected benefits of the CCG will each be estimated and used to calculate a BCR ratio.

The displacement and attribution were not estimated due to a lack of appropriate data. Displacement occurs when some or all of the apparent economic effects of the intervention are due to a reduction in economic activity elsewhere. Attribution is the extent to which the economic effects are due to the intervention and not something else. For example, did the CCG reduce car traffic in East Belfast or could this in part be caused by improvements to public transport? Drop-off refers to how long the effects will last, which were modelled in the analysis. The effects of the CCG are expected to last 40 years, but the strength of the effects may diminish or increase over that time.

The effect of drop-off on BCR and NPSV was addressed in sensitivity analyses, which used shorter expected lifetimes of the CCG.

5.2.3 Costs of the Connswater Community Greenway

The East Belfast Partnership, a local charitable organisation, obtained funding for the CCG from a Big Lottery Living Landmarks Award. The partnership developed the CCG project together with Belfast City Council (BCC). The total costs of its construction were £40m, higher than the initial estimate of £35m (Hunter et al., 2020). The BCC is responsible for maintenance of the CCG, estimated at a cost of £4m over 40 years. Other funders were the Department for Communities (£3.7m) and the Department for Infrastructure (£8.7m) in NI.

5.2.4 Time horizon and discounting

The time horizon of the analysis was 40 years, the expected lifetime of the CCG (Hunter et. al, 2020). Monetary benefits were assumed to be maintained over this time. All future monetary benefits were discounted from the base year of 2017 when construction of the CCG was completed. Discounting allows us to compare the costs and benefits of the CCG incurred differentially over time by converting them into present values, based on the assumption that we prefer to have goods and services now rather than in the future (time preference). The standard discount rate for UK governmental appraisal is 3.5%, also known as the 'social time preference rate' (STPR) (HM Treasury, 2013; NICE, 2008). The STPR consists of two components: 'time preference' and 'wealth effect'. 'Time preference' is the discount rate that assumes that there will be no change in future consumption. The 'wealth effect' assumes that consumption will grow in the future and consequently, its marginal utility will diminish (HM Treasury, 2013). The STPR can be expressed mathematically:

$$r = \rho + \mu g$$

Where r is the STPR; ρ is the time preference; and μg is the wealth effect (μ is the marginal utility of consumption multiplied by the expected growth rate of future consumption, g). The Treasury Green Book's preferred values for each component are as follows: $\rho = 1.5\%$; $\mu = 1.0$; and $g = 2\%$. Therefore, $0.015 + 1*0.02 = 3.5\%$.

The 'wealth effect' component of the STPR does not apply to health and life values. Instead, health and life values are discounted at 1.5%. The more appropriate discount rate was chosen for each of the elements of the analysis.

5.2.5 Costs of the Connswater Community Greenway

The Eastside Partnership was awarded a Big Lottery Living Landmarks Award that was used to fund the CCG. The total costs of its construction were £40m, higher than the initial estimate of £35m. The BCC is responsible for maintenance of the CCG, estimated at a cost of £4m over 40 years. Other funders were the Department for Communities (£3.7m) and the Department for Infrastructure (£8.7m).

5.2.6 Sensitivity Analyses

Discount rates that adjust for values changing over time could affect the overall estimates. Several sensitivity analyses explored various discount rates. Instead of 3.5%, a commonly-used alternative discount rate of 1.5% was applied to produce a final estimate. Furthermore discount rates of 0%, 1.5%, 3.5%, and 5% were applied to the present values to generate new BCRs. The lifetime of the CCG was expected to be 40 years. A shorter lifetime may reduce the return on investment of the intervention. Shorter lifetimes of 10, 20 and 30 years were also used to generate BCRs in alternative scenarios.

There is uncertainty in the value of tourism; spending in the CCG area may displace visitor spending elsewhere in NI and some of its value may overlap with biodiversity. A further sensitivity analysis re-estimated the BCR after removing the present value of tourism. To allow researchers to compare another green space intervention without flooding alleviation measures with the CCG, we removed the present value of those measures to generate a separate BCR. Finally, the ROI was tested to destruction by removing benefits in order of value from largest to smallest to evaluate when it no longer offered a positive NSPV.

5.2.7 Elements

Hunter et al. (2020) identified eight key areas that the CCG was likely to affect from previous literature and through consultations with the CCG Management Committee: (1) aesthetic benefits captured in property values; (2) flood alleviation; (3) tourism; (4) biodiversity; (5) climate change; (6) health and wellbeing; (7) crime; and (8) employment and productivity. For each element, the data sources and measurement were described, where available. The literature was summarised and if possible, the effect of the CCG on the element was quantified and monetised. The discounted present value of each benefit over the lifetime of the CCG was estimated. Uncertainty was included in the estimates where possible by choosing an appropriate lower and higher estimate for each element valued. Furthermore, sensitivity analyses addressed the uncertainty of the estimates in various ways (see section 5.2.6).

5.2.7.1 Element 1: Property values

Property prices may in part be influenced by proximity to green space. Hedonic pricing models can estimate the value of attributes for which the values are not directly observable by examining how prices vary with attribute levels. They are commonly used to assess the value of non-market goods such as air quality as reflected in property prices, as well as in other industries e.g., safety features of cars. The hedonic pricing approach has been subject to criticism (Chin and Chau, 2003) since it assumes that the market is competitive and in equilibrium, which is unlikely to be correct. It also assumes that the housing market is a single entity when in reality it may consist of many submarkets. Moreover, even after adjusting for income, ethnic background etc., the models may be unable to capture the true dynamics of the local market which may be subject to idiosyncratic shocks (Chin and Chau, 2003). Nevertheless, hedonic pricing models are particularly useful for estimating non-market values such as the perceived value of pleasant views, air quality, and proximity to UGS.

The Office for National Statistics (ONS) (2018) estimated the impact of UGS on property prices. The analysis was limited to properties in Great Britain, however, the analysis was high quality and relevant to our scenario. They used hedonic pricing methods and the following datasets: ACORN classification, which segments the UK geographically by significant behavioural and social factors; Zoopla, a UK property website; and Ordnance Survey, the UK mapping agency (Office for National Statistics, 2018). Urban space was categorised as either blue (inland bodies of water) or functional green space (green space with a specific function) and by size: functional green space (small [<100m^2], medium [100 m^2 - 200 m^2], large [200 m^2 - 500 m^2], very large [>500 m^2]) and blue space (small [<11 m^2], medium [11 m^2 - 200m^2], large [200m^2 -500m^2], very large [>500m^2]). Results showed that blue or green space within 200m had a positive effect on property prices, with similar effects for houses within 500m (Table 5.1).

At the time of writing (June 2020) property prices in NI are currently stable or rising slowly. But in recent decades, house prices have been more volatile. House price data were obtained from the Built Environment Research Institute at Ulster University (Built Environment Research Institute, 2019) for NI from 2007 to 2018. Figure 5.2

displays the average house prices in NI and East Belfast from 2007 to 2018. House prices have been adjusted to 2018 prices using the Retail Prices Index (King, 2020). The blue line represents the average house price in NI and the orange line is the average house price in East Belfast. The dashed lines represent their respective moving averages. The average price of terraced and semi-detached houses in East Belfast, which best represent houses in the CCG area, was £135,398 in 2009-2014

The estimated effect of the CCG on Property Values

Property prices capture the discounted present value of the positive and negative impact of the characteristics of the house and the neighbourhood, including local amenities such as UGS. Based on the ONS estimates, functional green space and blue space can increase house prices by up to 1.4% and 3.58% respectively (Table 5.1). The area of the CCG differs between medium to large-sized green spaces and smaller green spaces in the form of the linear park/pathway that connects the bigger parks. There are also small and medium blue spaces along the CCG. In line with the size of the functional green space and blue space in the CCG area, an increase of between 0.60% and 1.07% in property prices could be expected in houses within 500m of the greenway according to the aforementioned ONS analysis (Table 5.1) (Office for National Statistics, 2018). There were insufficient properties being traded to reliably estimate the increase in property price from the presence of the CCG over 40 years, therefore the ONS estimates were used to estimate the increase in property value.

Researchers in Queen's University Belfast planning department used geographic information system data to calculate the number of properties within 500m of the CCG with a standard Euclidean buffer using Ordnance Survey NI data. The ONS report stated that houses within these distances experienced approximately the same increase in value due to their proximity to green space.

The average property price of a house in the CCG area around the time of the CCG construction was £135,398. Based on the ONS analysis that used hedonic pricing methods to estimate the increase in house prices from green and blue spaces, the CCG was estimated to add 0.60% - 1.07% in net value to the properties in the CCG area over the lifetime of the greenway: £812-£1,449 to each property on average. The lower estimate of 0.60% was used to include uncertainty in the overall estimate. This is net added value in addition to any housing market effects. It is implied that a household is willing to pay £812-£1,449 in 2017 for the perceived discounted stream of benefits of the CCG over its estimated lifetime of 40 years. Over the lifetime of the greenway, the discounted aesthetic stream of benefits is estimated to be between £16,053,599 and £28,628,919 (Table 5.2). The increase represents the present value of the discounted stream of benefits that will come from the CCG and are captured in property values over its 40 year lifetime. It is expected that this approach is appropriate since a large dataset of UK property prices were used to estimate the ONS estimates, nevertheless, it may not be accurate in a Northern Irish context. Further research could perform a hedonic pricing analysis on property values in NI to provide more reliable estimates.

Properties situated in the CCG area will increase in value between £16,053,599 and £28,628,919 over 40 years. This monetary benefit is due to the perceived aesthetic value of green and blue urban space.

5.2.7.2 Element 2: Flood Alleviation

Parts of the CCG area were historically prone to flooding due to tidal flooding from the sea connected to the Connswater River, fluvial flooding from the river overflowing, or pluvial flooding from heavy rainfall. Heavy rains in 2007 and 2008 lead to flooding in hundreds of properties in the area. As well as the immediate problems faced by residents when flooding occurs, properties may be devalued or impossible to insure due to the risk. The local government must pay for services, accommodation, and emergency help when flooding occurs.

Due to the need for flooding alleviation measures, flooding defences were installed as part of the CCG regeneration project. Jacobs Engineering UK Ltd was commissioned by the NI Rivers Agency to explore options and develop an economic case for the East Belfast Flood Alleviation Scheme (Hunter et al., 2020). They designed options that would meet a design standard that protected against a 1% annual exceedance probability of a fluvial event (a 1 in 100 chance of fluvial flooding in any given year) or a 0.5% annual exceedance probability of a tidal event (a 1 in 200 chance of tidal flooding in any given year). The best option that met the appropriate standards and costs in a cost-benefit analysis (CBA) was a plan consisting of seven new culverts, 4.1km of floodwalls, and 1.2 km of flood embankments and 715m of river diversion works. The plan should prevent 1,741 properties along the greenway route from future flooding.

The present value of the flooding alleviation measures was previously estimated by Jacobs Engineering UK Ltd. They compared several possible options to alleviate flooding to a 'do nothing' approach. The cost of implementing each option was estimated using "Revision to Economic Appraisal Procedures arising from the new HM Treasury Green Book" from Department for Environment, Food and Rural Affairs (DEFRA, 2003), standardised to 2012 prices. They estimated the potential cost of damage due to flooding using 'The Benefits of Flood and Coastal Defence: Techniques and Data for 2003' (Penning-Rowsell et al., 2005) and adapted the costs to the market values of the CCG properties using valuation data from Land and Property Services provided valuation information. Damage costs included both structural damage, contents within the properties, and other costs such as healthcare services, temporary accommodation, and heating costs. They estimated that the new measures should avoid damage costs of £54.7m (variable discount rate of 2.5-3.5%) over an expected lifetime of 100 years. We adapted this estimate to the present analysis, by adjusting the estimate to 2017 prices using a consumer price inflation calculation [17]. The source data was unavailable for the flooding CBA, and the time horizon was longer than the 40-year expected lifetime of the other CCG elements. However, the benefits from the flooding alleviation measures are expected to last for 100 years and to artificially censor the benefits at 40 years would bias the estimates. In order to address the uncertainty in the value of flood alleviation measures, their value was removed in one of the sensitivity analysis (section 5.2.6).

Flood alleviation measures were included as part of the CCG regeneration project. The present value of flooding alleviation measured was estimated to be £61.4m over 100 years.

5.2.7.3 Element 3: Tourism

Tourism is a growing industry in NI. Revenue from overnight trips grew from £503m in 2005 to £926m in 2017 (Tourism Northern Ireland, 2017). Country parks, parks, or forests, such as the CCG, accounted for 42% of visits reported in 2018. The CCG is an amenity for both residents and external visitors. Increased property prices will capture the value of the CCG to residents but not to tourists or visitors more generally. External visitors who come from outside of the local area will bring additional economic benefit. The following analysis intended to capture the amenity value of the CCG site to external visitors from outside the CCG area.

Although there are no official visitor numbers recorded for the CCG, the Sustrans Intercept surveys were conducted before and after its completion. Researchers surveyed visitors in 2011 and 2018 in four locations adjacent to the CCG: Victoria Park, Orangefield Park, Flora Street Walkway, and the Holywood Arches, which would later become CS Lewis Square. In both 2011 and 2017, count data of park users were collected and members of the public were asked to complete a questionnaire about their journey.

Non-local residents must travel to visit the site, usually by public transport or car. Therefore, the cost of travelling can be used to estimate the willingness-to-pay (WTP) value for the amenity. The Environmental Value Look-Up Tool (DEFRA, 2015) gave indicative values of the economic benefits of recreation and tourism in UGS based on a study of moderate quality (Sen et al., 2014). A meta-analysis predicted per-visit values for different environmental sites using data from over 40,000 households in England, including socioeconomic and demographic factors. The authors estimated that costs-per-visit ranged from £1.54 for grasslands to £5.36 for greenbelt and urban fringe farmlands in Great Britain. Although data were unavailable for NI, the costs in Belfast are likely to be similar to average costs for England, Scotland and Wales. These costs are plausible estimates of WTP in terms of the face validity of the costs of travelling to the sites. The report does not explicitly name UGS as a type of site. However, the CCG may be most closely related to the categories 'freshwater and floodplains' or 'greenbelt and urban fringe farmlands'. The lowest and highest per person per trip values (£1.54 and £5.36) are used here to capture the true cost-per-visit for the CCG. We use these costs to assume that individuals from outside the CCG are WTP for the benefits of visiting the site at a cost approximately the same as the travel costs, assuming no shared journeys. All but one journey was from inside NI, therefore a multiplier effect was not applied to the estimate to account for tourist contributions to the NI economy.

Local visitors were individuals whose journeys originated from postcodes in the CCG area: BT4, BT5, BT6, and BT16. External, non-local visitors came from elsewhere in NI (only one visitor came from the outside NI, the Republic of Ireland). Only visitors whose purpose did not relate to work, education, or escorting someone to school were counted as external visitors for leisure or recreation purposes. In three out of the four areas where measurements were taken, the proportion of external visitors at the CCG for leisure or recreation increased in 2017 compared to 2011 (Table 5.3). CS Lewis Square had the biggest increase, from 5.6% in 2011 to 16.0% of users in 2017. The proportion almost doubled at Victoria Park from 5.7% to 10.4%. There was only a slight relative increase in external visitors for leisure or recreation at Orangefield Park, growing from 3.1% to 3.7%. Conversely, the proportion of external visitors for leisure or recreation decreased at the Flora Street Walkway, from 5.3% in 2011 to 2.1% in 2017. More external visitors (56,589) were recorded in the surveys than were initially expected in the benefits realization plan: 12,904 additional external visitors were expected by 2017.

The cost-per-visit values were multiplied by the number of additional external visitors in 2017 (Table 5.4). The value of external visits after one year was between £87,147 and £303,316. This was assumed not to be a public health benefit and a discount rate of 3.5% was used. Over the lifetime of the greenway, this would equate to £1,948,171.47 to £6,780,648.77 (3.5%, 40 years). It is unlikely that double counting has occurred in the analysis. The value of the site to external visitors does not overlap with other elements of the SROI analysis. However, some economic benefit from external visitors may be displaced from other amenity sites in NI, which was addressed in a sensitivity analysis.

More visitors have visited the CCG since its completion compared to initial predictions. There were 56,589 additional external visitors in 2017 compared to 2011. Based on a cost-per-visit study, the economic benefit totals £1,948,171.47 to £6,780,648.77 (3.5%, 40 years).

5.2.7.4 Element 4: Biodiversity

Biodiversity is the variation and diversity of species of living organisms in ecosystems. Globally, biodiversity has been decreasing over the past decades, mainly due to human activity (Secretariat of the Convention on Biological Diversity, 2000). It is difficult to assign a monetary value to biodiversity, although its importance to planetary health is clear. Environmental resources such as green space can have existence value, which is the benefit of knowing that the good exists. Some argue that attempting to place a monetary value to nature is crude or completely pointless (Spash and Vatn, 2006; Spangenberg and Settele, 2010). Although there are some valid points in this reasoning, it is ultimately very useful to translate the worth of an environmental good into monetary value if possible and appropriate.

Before the regeneration, the Connswater River and the surrounding areas were polluted, neglected and unattractive. Traffic-heavy roads separated the parks in East Belfast. Now, a linear green pathway joins the local parks. The CCG regeneration project cleaned five km of the river and added 7.84 hectares of various grasses, wildflowers, and shrubs, 498 trees and 352 linear metres of hedging, which is approximately equal to the size of a small farm.

In as much as biodiversity has a non-market value, stated preference estimates may be an appropriate method of evaluation. In order to value the biodiversity of the CCG, a relevant study was identified using the Environmental Value Look-Up Tool (DEFRA, 2015). Dallimer et al. used a choice experiment to find how much recreational visitors to UGS and rivers were willing to pay for an increase in biodiversity of freshwater in an urban context. The study of 1,035 participants was in Sheffield, England, which is larger than Belfast in both size and population. Nevertheless, the natural landscape, comprising several rivers in urban, suburban, and rural locations, is comparable to the CCG area in East Belfast. The measures can translate to another UK population, especially since the cities have similar socioeconomic and demographic characteristics. This is important as disposable income may vary considerably between areas in England and NI. Study respondents reported that they were willing to pay £11.99, £13.48, and £9.38 for a 10% increase in birds, plants, and aquatic macroinvertebrates. They would pay £16.51, £7.86, and £11.91 in additional annual tax for a 25% increase (Table 5.5). This was the only study identified in the literature that specifically valued the biodiversity of green space alongside rivers in the UK. Residents of the CCG area may be willing to pay additional tax for improvements in biodiversity, however the value may already be captured in the increased prices of local properties. Therefore, the biodiversity WTP estimates were multiplied by the total external visitors (whose journeys did not originate in the CCG area) to the CCG sites in 2017: 161,373. To include some uncertainty in the estimate, the preference values were used for both a 10% and 25% increase in biodiversity (Table 5.5).

The estimates indicate that the present value of biodiversity of the CCG is between £5,623,849 and £5,854,612 for the first year. Over the lifetime of the CCG, the estimate is between £125,721,552 and £130,880,285 (40 years, 3.5%). This is the first estimate of the monetary value of biodiversity in the CCG. A lack of appropriate WTP studies prevented any earlier estimates. The value of biodiversity may overlap into other areas such as property prices. A sensitivity analysis will address the potential double-counting of biodiversity and increased property value.

5.2.7.5 Element 5: Climate Change

The current rate of global warming due to human activity is 'unprecedented' and unlike the patterns of Earth's temperatures during the last 2,000 years (Neukom et al., 2019). Drastic changes could reduce the impact of climate change, mainly by decreasing greenhouse gas emissions. Urban environments have the potential to lessen the effects of climate change through their design (The Mersey Forest et al., 2010). Green space is beneficial for the climate. Trees and plants have a cooling effect on their environment and reduce air and surface temperature (The Mersey Forest et al., 2010). A study in Chicago found that increasing the amount of tree cover in a city by 10% can reduce the air temperature by 1°C (The Mersey Forest et al., 2010). Even in winter, the shelterbelt effect can slow winds, which decreases heat loss from buildings. The cooling effect of trees and green space is particularly useful in warmer climates where air conditioning is common. This does not apply to Belfast where air conditioning is less common, average temperatures are between 8°C and 19°C year-round and record temperatures have not exceeded 30 degrees (since 1960, measured at Stormont Castle, Belfast). Therefore, I will not consider the cooling effect of the UGS in Belfast as it is very unlikely to affect the use of air conditioning and subsequently energy consumption.

Trees and plants absorb carbon as they grow, removing it from the atmosphere. The carbon is released when the plants later die. Large urban trees can store significant amounts of carbon: up to 1,000 times more than small trees. As the trees mature in the CCG, the amount of sequestered carbon will increase. However, the benefits to the environment through carbon sequestration in the CCG will be relatively small. Although the number of trees and vegetation planted in the CCG area was substantial, the area was also formerly green and blue space. Consequently, we are unlikely to see a meaningful change in carbon sequestration and its economic implications in the CCG area.

Transport in the form of motor vehicles causes potentially avoidable greenhouse gas emissions, whereas walking or cycling poses no threat to the environment, promotes health and wellbeing, and is low-cost. Despite this, Belfast is extremely car-dependent and drivers spent on average more than an entire week (190 hours) per year in congestion, ranked second longest in the UK (INRIX, 2019). Although bicycle usage has been increasing steadily over recent years in NI, only 2% of journeys in Belfast were by bicycle in 2015-17. In NI overall, 0-1% of journeys were by bicycle. (Department for Infrastructure, 2019). Bicycle journeys only made up 0.6% of miles travelled in 2015-17 in NI. The reasons for high car dependency is likely due to the limited public transport system and cycling infrastructure, especially in more rural areas.

The CCG presents a rare opportunity to would-be cyclists in Belfast: 16km of protected cycling pathway. The CCG extends from suburban East Belfast to close to the city centre. It intersects with the Comber Greenway, 11km of a traffic-free pathway from East Belfast to Comber, County Down. Many citizens commute into the city centre for work or education and the CCG may encourage them to cycle as an alternative to a car journey, leading to lower greenhouse gas emissions. Although the CCG provides high-quality infrastructure for cycling, there has not been an intensive and sustained programme to encourage CCG residents to participate in active travel. Therefore, it may be overly ambitious to assume that the CCG could convert many local car journeys to cycling trips, especially given the gaps in cycling infrastructure elsewhere in Belfast.

To investigate if commuters are choosing active travel over car journeys, traffic count data were assessed. Traffic count data were available for three locations in the CCG area in 2012 and 2017 (Department for Infrastructure, 2018): Upper Newtownards Road (Outbound), Upper Newtownards Road (Inbound), and Knock Road Castlereagh (Table 5.6). These were the only locations in the CCG area for which traffic data was available in both 2012 (the most recent year for which data was available) and 2017, which are also main commuting routes from the east into the city. The volume of cars was recorded at peak commuting times on weekdays: 0800-0900 and 1700-1800 on the Upper Newtownards Road (Outbound) and Knock Road, Castlereagh and 0700-0800 and 1600-1700 on Upper Newtownards Road (Inbound). The volume of cars at peak times has fallen from 2012 to 2017 in two out of three locations: on the Upper Newtownards Road, in an outbound direction (decreased by 12%) and on Knock Road, Castlereagh (decreased by 8%). There has been no change in the volume of traffic at peak times on the Upper Newtownards Road, in an inbound direction. There are 734 fewer cars on the roads in the CCG area per day on average, a reduction of 1%.

However, this is limited to only two time points and this reduction could be part of a general trend, e.g., due to increased usage of public transport.

The proportion of park users has risen by 26% from 2011 to 2017. Table 5.7 shows the proportion of park users recorded as cyclists before and after the CCG intervention. Several of these people are likely to be cycling for recreation. It is assumed that the 1% reduction of car journeys is due to a switch to cycling, given the 405% increase in cyclists surveyed along the CCG . A reduction in 1% of cars commuting in the CCG area equates to approximately 116 cars, according to the traffic count data in Table 5.6. The average length of a car journey in NI in 2017 was 12.1km according to a travel survey (Department for Infrastructure, 2019). An average car emitted 0.29kg CO_2 per km in 2017 (Department for Business Energy & Industrial Strategy, 2017). Therefore, an average car journey would emit 412kg CO_2 per day. Allowing six weeks per year for holidays, it is assumed that people commute to work approximately 230 days per year. Over one year, commuting by car in NI would emit an estimated 95 tonnes CO_2. The UK government values carbon emissions as £4.13 per tonne CO_2 in policy evaluations (Department for Business Energy & Industrial Strategy, 2018). In one year, the present value of reduced carbon emissions from 116 fewer cars would equal £391.The present value of the CCG concerning reduced carbon emissions is £8,750 (3.5%, 40 years).

5.2.7.6 Element 6: Health and Wellbeing

Access to UGS can improve health and wellbeing and possibly reduce health inequalities. Extensive literature has established the associations between positive health outcomes and exposure to green space. Higher exposure to green space was significantly associated with better self-reported health, lower T2D, reduced all-cause and CVD mortality, diastolic blood pressure, salivary cortisol, heart rate, heart rate variability, and cholesterol in a systematic review and meta-analysis (Twohig-Bennett and Jones, 2018). People living closer to UGS have been found to have lower mental distress and higher wellbeing, even when controlling for SES, and other individual covariates (White et al., 2013).

Due to the health benefits, investment in UGS has the potential to bring economic benefits in terms of healthcare spending. Public parks in London were reported to have saved the economy £950m per year in health costs, £580m for physical health and £370m in mental health (Greater London Authority, 2017). Moreover, the WHO has called for ‘health-supporting urban environments’ as part of the European Strategy for the Prevention and Control of Noncommunicable Diseases in 2012−2016 (WHO Regional Office for Europe, 2016).

The PARC study measured levels of physical activity in CCG residents using the General Practice Assessment Questionnaire (GPAQ) (World Health Organization, 2005) in two surveys of different CCG residents before and after the construction of the CCG, in 2011 and 2017. The groups consisted of different residents each time but were similar in terms of age, gender, education level, income and marital status (Table 5.8). Contrary to expectations, the results indicated that residents reported a slight decrease in physical activity levels in 2017, the year the construction of the CCG had been completed (Table 5.8).

The PARC study was a natural experiment that surveyed CCG residents before and after the construction of the CCG. Researchers surveyed a random sample of 1209 residents in 2010 and a separate random sample of 1214 residents in 2017, the year construction of the CCG was complete. There are limitations to this approach. The second sample was surveyed on the year the CCG was completed, which could be too early to observe behavioural or health-related changes due to the CCG. Additionally, the PARC sample may have been insufficient to capture a relatively small increase in physical activity at a population level. Furthermore, the structure of the sample might have changed over time. Finally, comparable data taken from other Northern Irish samples were not available for all survey questions in those years. This meant that these results cannot be compared with other similar populations. Physical activity may have decreased in NI or Belfast during these six years and activity levels in the CCG area are higher than expected, but this cannot be determined with the data available. It is also possible that the CCG was not a sufficient intervention to meaningfully increase physical activity in the local population. The results are unexpected as the Sustrans Intercept surveys found an increase in visitor numbers including cyclists. However, these cyclists may not live within the CCG wards and therefore were not captured in the PARC survey. The analysis is limited by data available at only two time points. Data at more time points would have allowed a falsification test.

The PARC study also measured mental health and wellbeing in CCG area residents (Table 5.9). Specifically, they used the Warwick-Edinburgh Mental Wellbeing Scale

(WEMWBS), the Short Form-8 (SF8) physical and mental summary scores, and the EQ5D-5L summary index. In the EQ5D-5L questionnaire, participants reported significantly higher scores in the self-care domain and significantly lower scores in the Pain/Discomfort domain. On a scale from 0 to 100, participants rated their general health significantly worse in 2017 compared to 2010, by 12 points. Only the SF8 Physical summary score changed significantly; it increased by 1.2 points in 2017. Overall, the survey did not capture changes in the mental health and wellbeing of the local population.

Based on previous literature (WHO Regional Office for Europe, 2016; Twohig-Bennett and Jones, 2018), it is likely that the CCG brings health benefits to residents. However, the marginal health gains of the CCG are undetectable at a population level and it is not possible to translate them into economic savings. We have chosen to conservatively estimate the health gain at zero.

5.2.7.7 Element 7: Crime

UGS can affect levels of crime and violence in communities in both positive and negative ways. When communities do not share common values, residents experience less social capital, which can increase crime and violence, according to the theory of social disorganisation (Coleman, 1988). UGS can strengthen residents' emotional connection to their neighbourhood (McCunn and Gifford, 2014), foster feelings of community, encourage social cohesion, invoke feelings of safety and trust, and generate a reduction in crime, violence and aggression (Mason, 2010; Bogar and Beyer, 2016). Specific elements of green space design are associated with lower levels of crime. Recreational facilities for sport, adequate lighting and nearby public transport stops may discourage crime (Kimpton, Corcoran and Wickes, 2017).

Conversely, green space may also facilitate higher levels of crime (Bogar and Beyer, 2016; Kimpton, Corcoran and Wickes, 2017). More trees and vegetation can be beneficial for wellbeing, but can also create feelings of fear due to its potential to conceal criminal activity (Bogar and Beyer, 2015). Green space is particularly associated with antisocial behaviour in young people, drug use, pickpocketing, and more serious violent crimes (Kimpton, Corcoran and Wickes, 2017). The number of amenities that the green space might have, work- and school-day routines, and crucially, the surrounding neighbourhood's SES will all affect the timing and frequency of crimes committed (Kimpton, Corcoran and Wickes, 2017). The evidence for the relationship between UGS and crime remains mixed. (Bogar and Beyer (2015) conducted a systematic review of the relationship between green space, crime and violence in the US. They reported wide variation between studies, insufficient evidence and conflicting findings on the effects of green space. The relationship between street lighting and crime is also conflicted (Atkins, Husain and Storey, 1991; Farrington and Welsh, 2002; Pain et al., 2006). Although street lighting may improve residents' feelings of safety, reassurance and reduce the fear of crime, it does not appear to be associated with an actual reduction in crime. Nevertheless, the CCG area may experience reduced crime due to increased social capital from the community involvement with the CCG.

Crime levels have been decreasing in NI over the last 15 years, according to police statistics (NISRA, 2019). The CCG area consists of 29 electoral wards in East Belfast. Figure 5.3 displays the change in reported crimes per 1,000 inhabitants from 2012 to 2018 in NI, Belfast, and the CCG area overall. The rates of overall crime in NI overall, Belfast, and the CCG area have remained stable from 2012 to 2018. The social determinants of crime are complex and several wards in the CCG area are socioeconomically disadvantaged which is associated with higher crime rates.

It is difficult to determine if the 24-hour lighting or the improved green space has had any impact on crime without conducting a thorough study. The statistics appear to show no change, using NI overall and Belfast as comparisons.

Although other studies have estimated reductions in crime associated with UGS investment [24,25], we did not identify any discernible reduction in reported crimes rates in the short interval since the completion of the CCG. Therefore, we have taken the conservative approach of assuming these benefits were zero.

5.2.7.8 Element 8: Employment and Productivity

Urban regeneration has the potential to create new jobs and improve productivity. New opportunities for physical activity could improve the health of local employees. However, effective interventions that increased activity in a workplace setting are more likely to include both social and environmental components (To et al., 2013). Without a focussed intervention in place, employees are unlikely to increase their physical activity levels to a point where they reduce their absenteeism, increase productivity and subsequently benefit the local economy. Three large employers are located in the CCG area: the Holywood Arches Health Centre, Bombardier, and Allie Bakeries. They declined to release absenteeism data, therefore it is not possible to estimate the change before and after completion of the greenway.

Insufficient data exist to quantify the potential that the CCG has to reduce absenteeism and add value to the local economy's labour market. Productivity effects are changes that typically lead to higher wages, perhaps due to higher production levels. Unfortunately, no data are available to quantify any such change. Due to the lack of available evidence, we have conservatively estimated the benefits to be zero.

5.3 Results

Table 5.10 summarises the social present values of the CCG. It was possible to quantify and monetise five elements: property values; flood alleviation; tourism; biodiversity; and climate change. After combining all four elements, the total social present value was between £205,123,322 and £227,689,852. The net social present value (NSPV) was between £165,123,322 and £187,689,852.

5.3.1 Benefit-Cost Ratio

The BCR of the CCG is estimated to be between 5.13 and 5.69. This indicates that for each pound invested in the CCG, the local economy gains between £5.13 and £5.69. The CCG is likely to be good value for money (Table 5.10). It should be noted that the costs of the CCG were not discounted, therefore these estimates are likely to be an underestimate of the value for money of the CCG. However, there is the potential for double-counting of benefits; increased property values may be partly due to the reduced risk of flooding or improved biodiversity.

5.3.2 Sensitivity analyses

The social present values for tourism, biodiversity and climate change were estimated using an alternative discount rate of 1.5% (Table 5.11). The alternative present value of tourism is between £2,694,223 and £9,377,271 (40 years, 1.5%); biodiversity is between £173,866,047 and £181,000,292 (40 years, 1.5%); and climate change is £12,101 (40 years, 1.5%). BCRs for discount rates between 0% and 5% are presented in Table 5.12. They range from 3.27 to 8.56. BCRs also vary depending on the expected lifetime of the CCG. For an expected lifetime of ten years, the BCR would be 3.27 to 3.69. For lifetimes of 20 and 30 years, the BCRs are 4.11 to 4.59 and 4.71 to 5.24 respectively. Note that the flooding alleviation measures are expected to last for 100 years and the present social value was discounted using a variable rate of 2.5%-3.5%, which was not changed in the sensitivity analysis.

Further sensitivity analyses addressed uncertainty in the model and re-estimated the BCR after removing the present value of tourism due to the possibility of double-counting with biodiversity and the risk that external visitors to the CCG may displace tourism elsewhere in NI. Without the present value of tourism, the BCR was 5.08 to 5.52.

We explored an alternative scenario where the CCG had not included flooding alleviation measures. When the costs (£11,695,970) and the present value of flood alleviation measures were removed, the resulting BCR was 5.08 to 5.88.

Finally, the value of the investment was tested to destruction by removing specific benefits, ordered from largest to smallest in value, until the project no longer offered a positive NSPV. After removing the present values of biodiversity and aesthetic benefits captured in property value, the project no longer offered a positive NPSV.

5.4 Discussion

The CCG is likely to offer value for money both in the sense of a positive NSPV and BCR>1. The CCG will bring estimated social benefits of between £205m and £228m over its 40-year lifetime. In the base case analysis, the ratio of benefits to costs, the BCR, is between 5.13 to 5.69. For each pound invested in the CCG, NI will experience benefits equivalent to £5.13 to £5.69. The estimate includes increased value to local properties, protection from flooding, increased tourism, improved biodiversity, and a positive impact on climate change. In order of their estimated present value, the elements were flood alleviation (£61m), biodiversity (£126m to £131m), property (£16m to £29m), tourism (£2m to £7m) and climate change (£8,750). Other elements were considered but could not be quantified and/or monetised for this analysis: namely, health and wellbeing, employability and productivity, and crime.

Since some elements could not be included, the full benefits have likely been undervalued and the results are conservative. However, there is a risk of double-counting in the included elements. Flooding alleviation measures could increase property prices by reducing the risk of local flooding. Increased biodiversity could attract more buyers to the area. It is unlikely that these values overlap due to the methodology used to value the increased house prices. It specifically valued the increased aesthetic value of the nearby green space, whereas biodiversity was valued using WTP estimates for an increase in birds, plants, and aquatic life. Nevertheless, a sensitivity analysis addressed these concerns for robustness. The removal of biodiversity resulted in a new BCR of 1.99 to 2.42. Removing the present value of the flooding alleviation measures and their estimated cost, the new BCR was 5.08 to 5.88. The lower BCRs indicate the importance of biodiversity and flooding alleviation measures to the CCG's net value.

The CCG is likely to last for at least 40 years with appropriate maintenance. Still, sensitivity analyses addressed the possibility of shorter lifetimes. The BCRs were 3.27 to 3.69 for ten years, indicating that the CCG is likely to be a good investment even if its benefits last only ten years.

SROI methodology was used due to the need for a pragmatic approach to an economic evaluation of the CCG which could encompass more of the potential effects of the CCG than a more commonly used method, e.g., CUA. SROI studies are useful in public health research. In comparison to other types of economic evaluations such as CEA or CUA, SROI studies use a broader perspective. Outcomes are typically from the health, environmental, social and economic sectors. SROI analyses use BCRs to summarise the positive and negative effects of all outcomes in a helpful ratio. It is logical for public health research to include a wide range of outcomes because they are intrinsically linked. For example, a reduction in car journeys results in positive environmental outcomes such as better air quality. This, in turn, leads to improved health for citizens. Important considerations for SROI studies are transparency, using data from various sources to improve trustworthiness, and performing sensitivity analyses to improve the robustness of the results (Banke-Thomas et al., 2015; Masters et al., 2017; Ashton et al., 2020). The present study has attempted to produce robust results by following these suggestions. Nevertheless, it is challenging to perform an SROI analysis without a specific framework for UGS or PHIs generally.

This SROI analysis has attempted to identify and monetise the societal benefits of the CCG. The analysis it is contended produced conservative estimates. Each benefit was described, explored and monetised where possible. All decisions in the analysis were explained in the methodology section. Sensitivity analyses explored different lifetimes, alternative discount rates and removed benefits from the NSPV to account for double counting. The CCG remained a worthwhile investment even with a lifetime of ten years. A societal perspective was used to capture all relevant benefits from the CCG, as recommended by the Treasury Green Book and Deidda's framework for economic evaluations of natural experiments. The logic model (section 5.2) is a helpful tool to visualise the societal, environmental and economic changes associated with the CCG. However, it is a much-simplified version of a complex system of interactions. The present SROI analysis has attempted to model the system, but its limitations must be acknowledged.

The analysis had several limitations. Insufficient data for some elements and potential sources of bias have limited the study. The data used to generate estimates of the present values of tourism, biodiversity, and property values were derived from English studies, which may not be valid in NI. As far as possible, the estimates were chosen from areas in England that could reasonably represent a Northern Irish population. Ideally, studies would be conducted in NI to reflect local values and culture here. Furthermore, it was not possible to examine the potential future changes in physical activity in the CCG area. Ideally, a similar neighbourhood in Belfast could have been used as a comparison to investigate the changes in physical activity before and after the completion of the CCG in a difference-in-difference study. This had originally been included in the study plans but another organisation did not repeat their study, therefore no comparison was available. The limitations highlight the importance of integrating economic evaluation from the early stages of design in a study or project. Missing information may have biased the results of the study. The missing maintenance costs may have inflated the BCR. However, the benefits of the CCG have likely been undervalued as some elements could not be monetised. Therefore, BCR is expected to be a lower and more conservative estimate. Each element included data that are subject to measurement error, but it is expected that any errors would be in both directions and not result in an overall bias of the results. Given the limitations, the analysis is unable to fully capture the complexity of the societal, environmental and economic effects of the CCG but there is sufficient evidence to suggest that the CCG is a worthwhile investment.

In the previous evaluation, the CCG was expected to bring higher monetary benefits than the results of this SROI suggest. Hunter et al. monetised seven benefits due to the CCG: health and employment and productivity in addition to the five benefits monetised in the present study. The additional two benefits were explored in the methodology above but it was deemed inappropriate to add them to the NPSV. The present SROI produced a total monetary benefit with a lower maximum and smaller range (£165m to £188m) compared to the previous estimate (£101m to £203m). The estimated cost of the CCG was also initially lower: £35m compared to the updated total of £40m. Lower overall benefits and higher costs resulted in a new lower BCR of between 5.13 to 5.69, compared to the previous estimate of between 2.88 and 5.81. As expected, there was more uncertainty in the previous analysis before the CCG had been completed. The updated BCR should be a more reliable estimate.

There are several methodological approaches for the economic evaluation of public health interventions, including CEA, CUA, cost-consequence analysis (CCA), CBA, and SROI. CEAs aim to compare the costs and health benefits of alternative interventions. CUAs are a type of CEA, which compares costs with a specific health-related outcome: QALYs. Although clinical health benefits are straightforward to measure and compare, CEAs could miss other important non-health outcomes. Alternatively, CCAs take a much broader perspective; they report a wide range of costs and effects of an intervention. This provides a simple summary for decision-makers who can easily see which costs and benefits are most relevant to them. However, this more subjective method increases the risk of decision-makers 'cherry-picking' results and ignoring what is best for society overall.

CBA is another economic evaluation tool that compares the costs and benefits of alternative interventions in monetary terms, producing a summary measure of the NPV of an intervention (benefits minus costs in their present value) from a broad societal perspective. The benefits may be health or non-health and are estimated using preference-based approaches (Edwards and McIntosh, 2019). It is a useful approach in public health as it produces an easily understood summary measure in monetary terms, although estimating preferences for health benefits can be complex.

SROI is closely related to CBA as it also compares costs and health and/or non-health benefits in monetary terms but it is considered to be more pragmatic and less theoretical as the outcomes are usually allocated a financial value rather than preference-based (Edwards and McIntosh, 2019). While CBA is a well-established methodology, SROI is relatively new. A key element in SROI development is the involvement of the stakeholders who inform the outcomes included. Because of this, the SROI is not comparable with other SROI of other interventions since each analysis is subjective and unique.

The CCG is a community-based project, which arose from the East Belfast Partnership, a local charity, and Belfast City Council. Since almost all of the stakeholders of the CCG were non-experts, a pragmatic approach to evaluation was favoured. The elements that were most relevant to the stakeholders had been identified in a forecast SROI (Hunter et al., 2020). The data available for the elements also favoured using SROI as some elements had a financial value, e.g., the financial savings due to reduced risk of flooding and carbon values used to value the impact of vehicle emissions, and since several benefits had non-market values, the more pragmatic and flexible SROI methodology was deemed to be better suited.

There are several methodological challenges associated with SROI analyses. Fujiwara (2015) outlined some important limitations. Firstly, the social value that a SROI attempts to measures has not been clearly defined which limits its interpretability and comparability with other studies. Secondly, SROI does not consider how an intervention affects individuals differently, which may miss social and/or health inequalities present or even exacerbated by the intervention under study. This could lead to SROIs prioritising the needs of richer people over socio-economically disadvantaged groups. Thirdly, the reliance on stakeholders may be a limitation if the stakeholders are unable to engage fully with the process or are not well informed. Fourthly, the SROI ratio can be biased if negative outcomes are not included, inflating the results. Finally, the methodologies applied to value outcomes do not always follow guidelines and may not assess the causality of the associations. It is important to acknowledge these limitations and find ways to develop the methodology of SROI analysis for future studies.

Economic evaluations of PHIs present distinctive difficulties compared to those of RCTs (Weatherly et al., 2009). Weatherly et al. explored four of those challenges in a systematic review of PHIs. The first challenge, attribution of effects, is the difficulty of estimating the long-term effects of a PHI in a non-randomised, uncontrolled experiment. The present study addresses the issue of attribution in sensitivity analyses, by analysing various scenarios where one or more elements of the analysis may have been double-counted. Secondly, measuring and valuing outcomes is challenging. No studies in Weatherly et al.'s review attempted to value non-health-related outcomes. The present study was limited by the availability of data for each outcome and all analysis is subject to possible measurement error. However, it may inform future studies that attempt to evaluate and monetise similar outcomes. Thirdly, they presented intersectoral costs and consequences as a challenge. The PHIs in the review did not attempt to include costs from more than one sector. The current analysis explored seven areas where the CCG might have impacted society. A wider societal perspective is more appropriate to capture more of the potential benefits of a PHI, but it can be more difficult to obtain the necessary data. Converting the outcomes into monetary terms allows the results to be compared and summed more easily. The fourth and final challenge was the consideration of equity. Equity has not been given adequate attention in PHIs and unfortunately, it was not possible to include equity in this SROI analysis. The CCG area contains several socioeconomically disadvantaged wards and the effects may not have been equally distributed across all neighbourhoods. Displacement may also be an issue in the case of tourism. Visitors may come to the CCG in favour of another tourist site in NI, with no overall benefit to the economy. We have addressed this possibility in a sensitivity analysis which removes the value of tourism.

The present SROI did not specifically address social and health inequity, but it remains a relevant topic as many wards in the CCG are socioeconomically disadvantaged. In the UK, individuals living in these areas generally experience poorer health and stand to benefit more from health-promoting interventions than their affluent counterparts. UGS can bring benefits of physical and mental health, wellbeing, economic opportunities and, specifically in the CCG, reduced risk of flooding. Socioeconomically disadvantaged communities are more likely to live in areas with poor air quality (Pye, King and Sturman, 2006), have less access to green space and higher rates of crime (Balfour et al., 2014). Interventions which require less individual agency are more effective at reducing inequalities (White, Adams and Heywood, 2009). Since the CCG provides more accessible UGS to socioeconomically disadvantaged wards in East Belfast, it could reduce health inequalities in East Belfast.

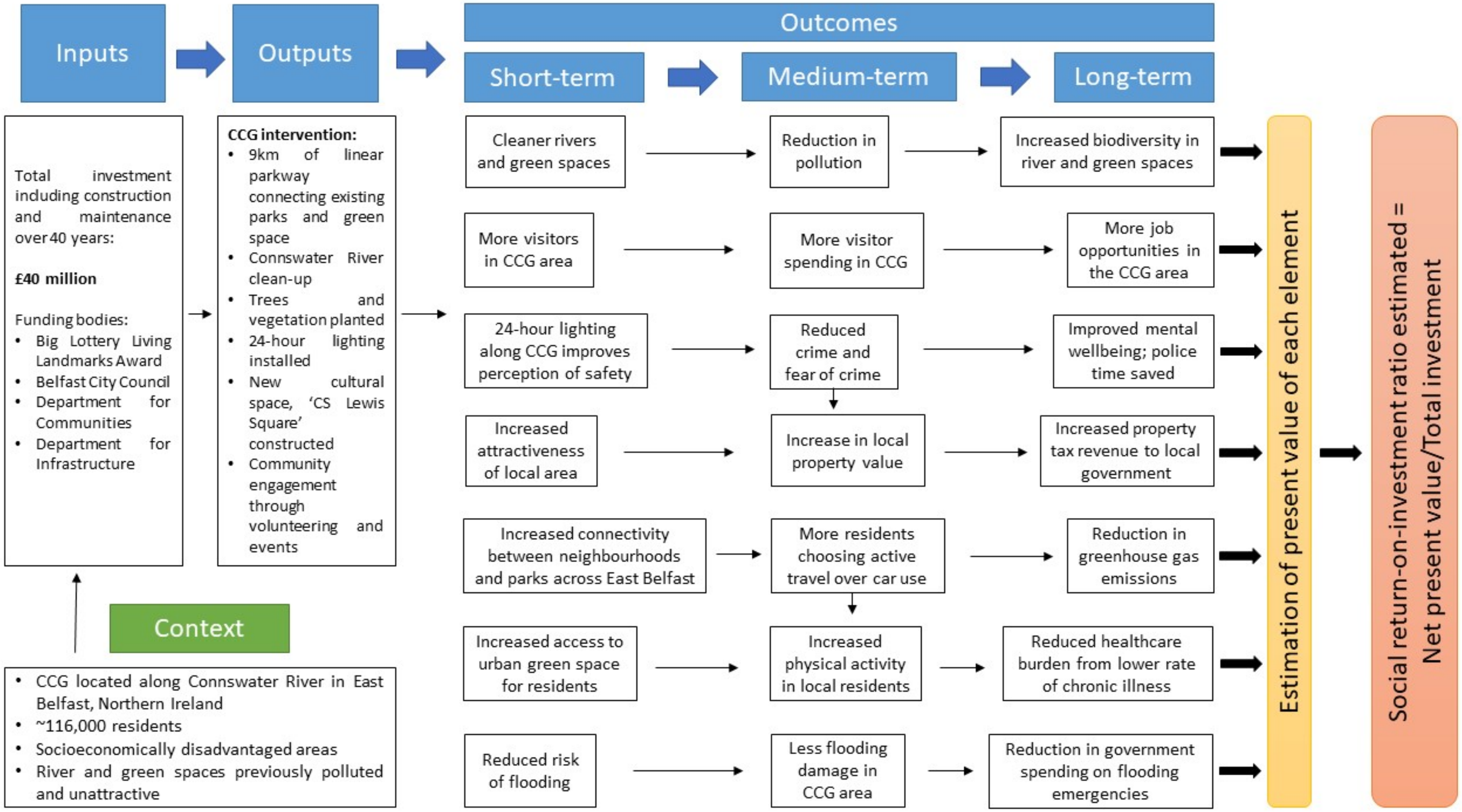
Although the regeneration aims to benefit the local community, there could potentially be negative unintended consequences. Gentrification is a process of social and economic changes to a neighbourhood associated with increased affluence. Increased house prices could reduce the affordability of living in the area and subsequently change the characteristics of the neighbourhood, i.e., increase its affluence. It is important to provide good quality green space for socioeconomically disadvantaged urban communities, as long as they can continue to access it in the long term. Ultimately, there is a risk that 'green gentrification' could increase social inequity in the long term. Gentrification can reinforce segregation, which would be detrimental in Belfast, a historically segregated city. Equity issues are complex and it is difficult to predict how a neighbourhood will change. Policymakers should be aware of these unintended consequences and ensure lower-income residents can continue to afford to live in the CCG area in future.

SROI analyses have several advantages: they can capture long-term social, environmental and economic effects of a PHI, the results are in straightforward monetary terms which makes them accessible to non-experts, and can be used to make an economic case for investment in cost-effective PHIs. However, they are not an appropriate evaluation tool for all PHIs and SROI methodology could be improved through standardisation and reporting guidelines. Banke-Thomas et al. (2015) make several useful points for SROI researchers and advocate an SROI reporting framework. They note that the quality of SROI studies has not improved over time. Reporting guidelines for SROI studies may improve the quality of new studies, make their results more robust and comparable, and advance the field of SROI research. They could incorporate the guidelines from the framework for conducting economic evaluations of natural experiments (Deidda et al., 2019) and the CHEERS checklist for reporting economic evaluations of health interventions (Husereau et al., 2013). SROI is suitable for the economic evaluation of PHIs and research although it is still not widely used. More guidance on SROI methodology could encourage more researchers to use this technique.

5.5 Conclusion

In conclusion, the CCG is likely to generate benefits whose value can be captured in various ways including increased local house prices, reduced risk of flooding, increased tourism, improved biodiversity, and reduced climate change. It is also expected to increase physical activity in residents and improve their mental health and wellbeing, but data could not capture health-related changes. The NSPV of the expected changes is estimated to be between £165m and £188m, resulting in a BCR of 5.13 to 5.69. Therefore, the CCG is likely to be a good investment.

Figure 5.1 Logic model of the short and long-term outcomes of the Connswater Community Greenway



CCG: Connswater Community Greenway

Figure 5.2 Average House Prices in Northern Ireland and East Belfast from 2007-2018, adjusted to 2018 prices

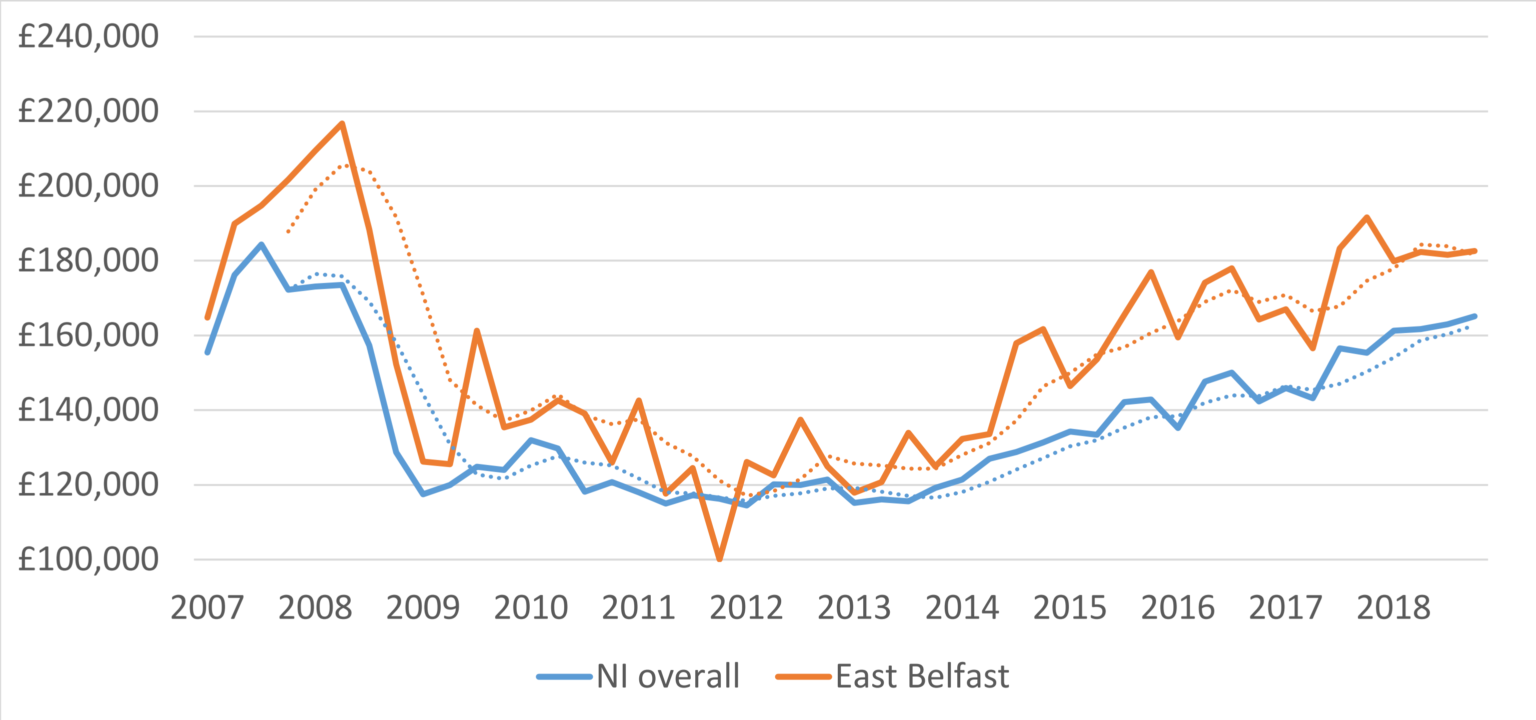


Table 5.1 Increase in property prices for houses within 200m of urban green or blue space

Area size	Functional green space	Blue space
Small	0.53%	0.93%
Medium	0.60%	1.02%
Large	1.07%	1.26%
Very large	1.40%	3.58%

Table adapted from a report by the Office for National Statistics, 2018.

Table 5.2 Additional property value due to the Connswater Community Greenway

Number of properties	Increase in property value of 0.60% increase	Increase in property value of 1.07% increase
1	£812	£1,449
19,761*	£16,053,599	£28,628,919

*Properties within 500m of the Connswater Community Greenway

Table 5.3 External visits to the Connswater Community Greenway in 2011 and 2017

	Total annual visits		External visits (%)*		Annual external visits		Additional external visits in 2017
	2011	2017	2011	2017	2011	2017	
Victoria Park	356,573	392,230	9.3%	12.8%	33,256	50,225	16,969
Orangefield Park	442,332	486,565	3.1%	4.8%	13,895	23,293	9,398
CS Lewis Square	357,160	392,876	9.6%	19.9%	34,447	78,072	43,625
Flora Street Walkway	269,357	296,293	7.2%	4.2%	19,425	12,432	-6,993
Total CCG	1,425,422	1,567,964	7.4%	10.3%	104,784	161,373	56,589

CCG = Connswater Community Greenway

*External visits are those recorded as coming from a postcode outside of the CCG area (BT4, BT5, BT6, BT16)

Table 5.4 The Economic Benefits of Tourism due to the Connswater Community Greenway

	Lower estimate	Higher estimate
Cost per visit	£1.54	£5.36
Cost after 1 year	£87,147	£303,316
Cost after 40 years, 1.5%	£2,694,215	£9,377,267
Sensitivity analysis: costs after 40 years, 3.5%	£1,948,171	£6,780,649

Table 5.5 Estimation of the value of biodiversity of the Connswater Community Greenway

Species	**WTP value for 10% increase**	**WTP value for 25% increase**	**Value of 10% increase in biodiversity***	**Value of 25% increase in biodiversity***
Birds	£11.99	£16.51	£1,934,862.27	£2,664,268.23
Plants	£13.48	£7.86	£2,175,308.04	£1,268,391.78
Macro-invertebrates	£9.38	£11.91	£1,513,678.74	£1,921,952.43
		Total, 1 year	£5,623,849	£5,854,612
		Total, 40 years, 3.5% discount	£125,721,552	£130,880,285
		Sensitivity analysis: Total, 40 years, 1.5% discount	£173,866,047	£181,000,292

WTP = willingness to pay.

*Calculated for the **161,373 external visitors** to the Connswater Community Greenway area in 2017.

Table 5.6 The average volume of cars during peak commuting times on workdays on roads in the Connswater Commuting Greenway area in 2012 and 2017

Location	**Average volume of cars during peak commuting times on workdays**			**Average car count in 24 hours***		
	2012	**2017**	**Change from 2012 to 2017**	**2012**	**2017**	**Change from 2012 to 2017**
Upper Newtownards Road (Outbound)†	2495	2189	-306 (-12%)	15746	15216	-530 (-3%)
Upper Newtownards Road (Inbound)‡	2670	2673	3 (0%)	16339	16194	-145 (-1%)
Knock Road, Castlereagh*	6417	5882	-535 (-8%)	34237	34296	-59 (0%)
All locations	11582	10744	-838 (-7%)	66322	65706	-734 (-1%)

*The average 24-hour period includes weekdays and weekends.
†Peak commuting time was 0800-0900 and 1700-1800, Monday-Friday.
‡Peak commuting time was 0700-0800 and 1600-1700, Monday-Friday.

Table 5.7 The proportion of Connswater Community Greenway park users recorded as cyclists

	2011		2018		Change from 2011 to 2018, % (N)
	Respondents, N	**Cyclists, % (N)**	**Respondents, N**	**Cyclists, % (N)**	
Victoria Park	193	22 (11%)	164	62 (38%)	40 (182%)
Flora Street Walkway/Avoniel	208	6 (3%)	143	60 (42%)	54 (900%)
CS Lewis Square/Holywood Arches	197	8 (4%)	156	74 (47%)	66 (825%)
Orangefield	191	4 (2%)	188	6 (3%)	2 (50%)
All locations	789	40 (5%)	651	202 (31%)	162 (405%)

Table 5.8 Descriptive statistics and physical activity level in the PARC surveys

Variable	Level	Year	
		2010	2017
		n = 1209	n = 1214
Age, mean (SD)		50.4 (18.9)	51.7 (19.1)
Gender	Male	490 (40.5%)	531 (43.7%)
	Female	719 (59.5%)	683 (56.3%)
Marital status	Married/civil partnership/cohabiting	604 (50.0%)	571 (47.2%)
	Single	323 (26.8%)	356 (29.4%)
	Widowed/divorced/separated	280 (23.2%)	283 (23.4%)
Education	Tertiary/higher education	420 (34.8%)	516 (42.5%)
	GCSE/A-Level/RSA/apprenticeship	505 (41.8%)	472 (38.9%)
	None/other	282 (23.4%)	226 (18.6%)
Income	£60-£230 per week	370 (35.4%)	244 (25.1%)
	£231-£580 per week	391 (37.5%)	441 (45.4%)
	>£581 per week	283 (27.1%)	286 (29.5%)
Meeting physical activity recommendations (>= 500 METs/week*)		69.6%	64.3%
Physical activity level	No activity (0 mins)	19.2%	24.8%
	Some activity (1-29 mins)	19.2%	26.1%
	Sufficient activity (>30 mins)	61.0%	49.1%

Table 5.9 Mental health and wellbeing in CCG residents measured using the PARC study in 2011 and 2017

	2010 (n=1209)	2017 (n=1214)	p value
WEMWBS Summary Score	50.84	51.21	0.305
SF8 Mental Summary Score	48.31	48.75	0.288
SF8 Physical Summary Score	46.96	48.18	0.006
EQ5D Summary Index	0.80	0.82	0.113

WEMWBS = Warwick-Edinburgh Mental Wellbeing Scale. SF8 = Short Form-8

Figure 5.3 Reported Crime per 1,000 Inhabitants in Northern Ireland, Belfast and the Connswater Community Greenway, 2012-2018

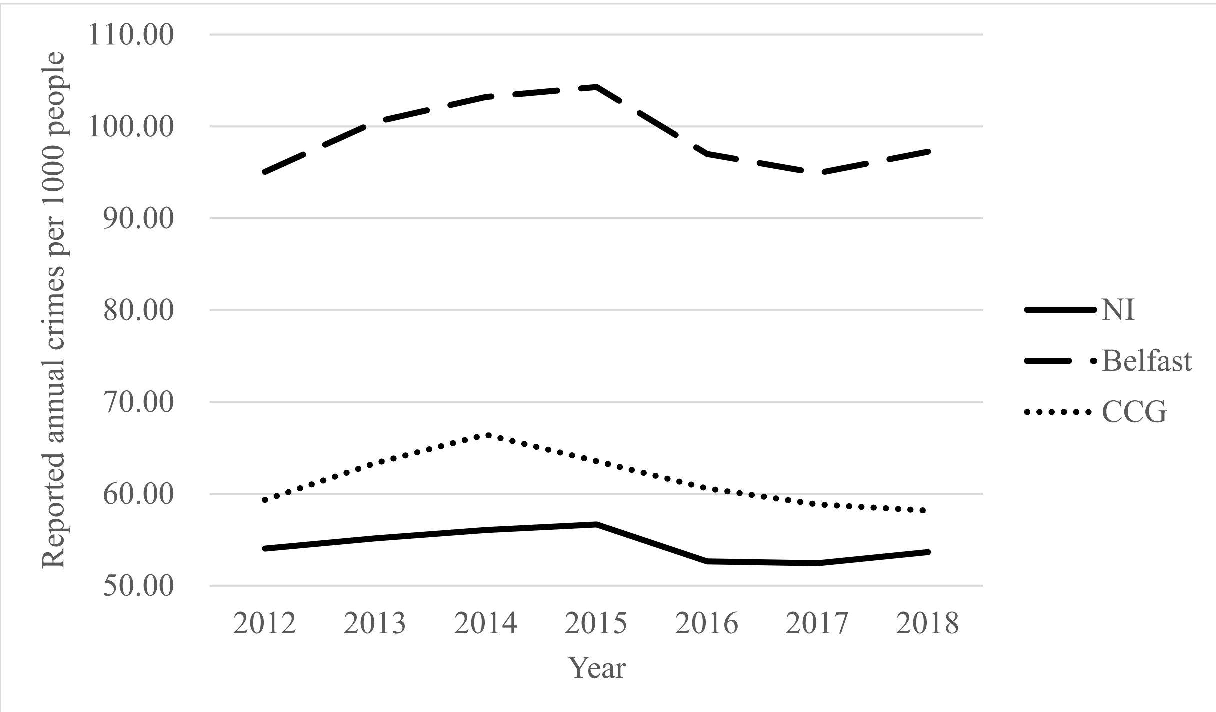


Table 5.10 Costs and Social Present Values of the Connswater Community Greenway

	Discount rate	Lower estimates	Higher estimates
Construction and maintenance costs	NA	£40,000,000	£40,000,000
Social Present Values			
Land & Property Values	NA	£16,053,599	£28,628,919
Flood Alleviation	2.5% - 3.5%	£61,400,000	£61,400,000
Tourism	3.5%	£1,948,171	£6,780,648
Biodiversity	3.5%	£125,721,552	£130,880,285
Climate change	3.5%	£8,750	£8,750
Total Social Present Value		£205,123,322	£227,689,852
Net Social Present Value		£165,123,322	£187,689,852
Benefit-Cost Ratio		5.13	5.69

NA = not applicable

Table 5.11 BCRs for various discount rates and lifetimes of the greenway

	BCR	
	Lowest estimates	**Highest estimates**
Discount Rate*		
0.0%	7.79	8.56
1.5%	6.35	7.01
3.5%	5.13	5.69
5.0%	4.53	5.05
Lifetime of the CCG		
10 years	3.27	3.69
20 years	4.11	4.59
30 years	4.71	5.24

BCR = benefit-cost ratio; CCG = Connswater Community Greenway.

The flooding alleviation estimate remained unchanged in the various scenarios.

*The various discount rates were applied to all estimates over 40 years.

†The various lifetimes were calculated using a discount rate of 3.5%, as in the main results (see Table 5.10).†The various lifetimes were calculated using a discount rate of 3.5%, as in the main results (see Table 5.10).

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CHAPTER 6

DISCUSSION

6 DISCUSSION

6.1 Background to the thesis

Physical inactivity is increasing across the world (Ding et al., 2016) which increases the risk of several chronic diseases, premature mortality (Physical Activity Guidelines Advisory Committee, 2018), and this costs the global economy an estimated $67.5bn per year (Ding et al., 2016). Sedentary behaviour is a related risk factor, defined as expending very low amounts of energy while sitting or lying during waking hours. Prolonged sedentary behaviour also increases the risk of poor health (Physical Activity Guidelines Advisory Committee, 2018). Around two in five adults in the UK are not meeting physical activity recommendations (British Heart Foundation, 2017b) which has implications for overall population health and the UK economy. Economic evaluation is an important aspect of physical inactivity and sedentary behaviour research. The health consequences of physical inactivity and sedentary behaviour have economic consequences through direct healthcare costs, indirect costs from reduced productivity and absenteeism, and other out-of-pocket costs. Cost of illness studies produce estimates of the economic burden due to physical inactivity and sedentary behaviour, helping researchers and policymakers understand their impact on society. Coupled with economic evaluations, they may help policy makers and practitioners prioritise interventions and inform decisions regarding implementation on a larger scale.

The GAPPA from the WHO has set out ambitious targets to reduce physical inactivity by 15% by 2030. However, we are not on course to meet those goals. Urgent action is needed and more evidence on the economic burden of physical inactivity and sedentary behaviour could be used to build a financial case to persuade policymakers to prioritise interventions that can reduce these risky behaviours. Importantly, the interventions to reduce physical inactivity and sedentary behaviour should be both cost-effective overall and help to reduce health inequalities in the population. This thesis has assessed the economic burden of physical inactivity and sedentary behaviour in terms of direct healthcare costs and explored the cost-effectiveness of interventions, both at an individual- and a population-level. This chapter will discuss how the findings fit with the existing literature on physical activity, how the studies could be developed further, and future directions for this area of research.

6.2 Summary of findings

In summary, the studies found that sedentary behaviour and physical inactivity generate higher healthcare costs in the UK, that cost-effective interventions to reduce physical inactivity may require a certain level of complexity and that regeneration of urban green space in Belfast, Northern Ireland, was a worthwhile social investment. The economic evaluations of sedentary behaviour and physical inactivity in the first two studies used both individual-level and population-level data to find that both risk factors have an impact on the economy. In a similar vein, the next two studies used both individual- and population-level perspectives to explore the cost-effectiveness of public health investment in reducing physical inactivity.

6.2.1 The economic cost of physical inactivity and sedentary behaviour

6.2.1.1 The direct healthcare costs associated with sedentary behaviour in the UK

Chapter 2 presented an analysis of the healthcare costs associated with prolonged sedentary behaviour in the UK. After adjustment for double-counting due to comorbidities, prolonged sedentary behaviour was estimated to cost the NHS £0.7bn annually, at 2016-17 prices. The study used a prevalence-based approach where PAFs were calculated for each of the five diseases associated with sedentary behaviour. All RR estimates had been adjusted for physical activity level. The PAFs were then applied to NHS budgetary data to estimate expenditure attributable to prolonged sedentary behaviour. The majority of costs came from T2D and CVD, due to their relatively high prevalence in the UK. This is the first known study of healthcare costs associated with prolonged sedentary behaviour. The findings may be useful for policymakers to help understand the economic impact of sedentary behaviour in UK adults. Specifically, they can compare these findings with other economic evaluations of sedentary behaviour and other risk factors to build a picture of its impact on the UK economy. They may be used to make a financial case for investment in interventions to reduce sedentary behaviour in the UK. Sedentary behaviour is not as costly as other risk factors such as smoking, poor diet, alcohol and obesity (Scarborough, 2011). But it remains an important health issue that may have worsened during long periods of lockdowns during the Coronavirus -19 pandemic.

6.2.1.2 The inpatient hospital costs associated with physical inactivity in the UK Biobank cohort

Chapter 3 assessed the relationship between physical activity level and inpatient healthcare use and costs in a large sample (n = 86,067) of the UK Biobank cohort.

Adults aged 43-79 years at baseline provided objectively measured physical activity data by wearing accelerometers for one week. Their data were linked with the NHS inpatient hospital records between 2013 and 2017, with a mean follow-up time of two years and four months. The sample was divided into tertiles according to accelerometer data; these were approximately equivalent to (1) achieving sufficient physical activity levels, (2) inadequate physical activity, and (3) low physical activity levels. Econometric models, adjusted for sociodemographic factors including health status and BMI, assessed the relationship between physical activity level and inpatient days and costs. Adults who were more active at baseline spent less time as an inpatient in hospital and incurred lower inpatient costs during follow-up. The individual differences were small but statistically significant: the more active groups spent on average 0.3 and 0.5 fewer days per year as an inpatient than the least active group. The two more active tertiles incurred on average £3.09 and £3.81 less in inpatient costs per month than the least active tertile. At a population level, the effects amount to hundreds of millions of pounds in inpatient costs alone. Furthermore, these are likely to be the lower bounds for population impact since the participants of the UK Biobank cohort are healthier and wealthier than the average UK citizen. Several sensitivity analyses confirmed that the main results were robust and revealed differences between subgroups. The effect of physical activity level on inpatient costs appeared to be stronger in women and the lowest income groups and there was an interaction effect with income. In the highest income groups, there was very little effect of physical activity on inpatient hospital use, indicating that lower-income groups may be driving the association. The findings indicate that policymakers should aim to reduce physical inactivity in the UK population overall and specifically target women and lower-income groups, which may improve health inequalities.

6.2.1.3 Comparison of approaches

The PAF-based and econometric approaches are two different methods of exploring the same topic. The PAF approach is a population-based, 'top-down' approach. The PAF-based approach was explored in detail in section 2.1. The advantages of this approach over the econometric approach are that it is possible to conduct an evaluation using population-level data when individual data is unavailable and it typically generates more conservative estimates than econometric approaches since it is based only on diseases for which sufficient evidence already exists. It is limited as it is usually unable to explore the association in population subgroups, unlike in econometric methods. Building a PAF-based model also requires data from several sources, whereas an econometric model can be created from one dataset.

Conversely, the alternative econometric approach usually leads to higher estimates as it captures more health outcomes that are associated with the risk factor in question. It benefits from the flexibility of regression models: they can adjust for confounding factors such as body weight, prior disability or illness and sociodemographic factors although the results may be biased by confounding factors that are difficult to measure such as health-seeking behaviour (or by the means and choices about controlling them). The regression models also allow for the exploration of subgroups: the UK Biobank dataset provided the opportunity to explore subgroups by household income level and sex, important measures of SES. The UK Biobank dataset consisted of middle-aged and older adults, which is common in econometric studies in this area. Older adults may bias the results since they are generally sicker than the overall population, require more healthcare, and generate more healthcare costs than other age groups.

Ultimately, the choice between using a PAF-based or econometric approach depends on data availability. A PAF-based approach can be faster as the data is easier to obtain and the methodology is relatively more straightforward. A considerable advantage of using econometric methods is the possibility of exploring subgroup effects in the data. In the UK Biobank analysis, we explored the results by gender and by income level. That would not have been possible with most PAF methodology.

Another main difference in the two studies was the use of self-reported (in Chapter 2) and objectively measured (in Chapter 3) physical activity/sedentary behaviour data. Although self-reported questionnaires on activity behaviours are usually cheaper and have been found to be acceptable in terms of reliability and validity for measuring sedentary behaviour, there is a risk of recall and social desirability bias with self-reported tools (Healy et al., 2011). Accelerometer-measured physical activity is objective and can provide much more precise information on activity. As a result, it was possible to identify small differences in healthcare costs between groups depending on their activity in Chapter 3. Nevertheless, accelerometers can be more costly, require more practical considerations such as charging the devices, and calibration of the data into meaningful activity states can be challenging (de Almeida Mendes et al., 2018).

6.2.1.4 Equity considerations and implications for policy

In the econometric study of physical activity and inpatient hospital use and costs, the sensitivity analyses revealed an interaction effect with household income. Exploratory subgroup analysis has been criticised as being unreliable" and susceptible to higher risks of Type 1 error (Lipkovich et al., 2018). Therefore, it is difficult to make conclusive statements on the interaction effect of income on the relationship between physical activity and inpatient healthcare use and costs based on a post-hoc analysis. Nevertheless, since the sample is large, the results suggest that the effect of physical activity may differ by income level. It is crucial that PHIs reduce health inequalities as well as improve overall health. The most radical intervention to public health would likely be to decrease the growing wealth inequality in the UK. Wealth inequality has many adverse implications for public health. People in a higher socioeconomic position have more choices in life, healthier living and working conditions, more education, and greater access to healthcare. Greater privilege associated with higher SES means that there is a social gradient in health and life expectancy (Marmot, 2010). Physical activity appeared to have less of an effect on the healthcare use of those with higher household incomes. This is probably due to their generally better health status, meaning that doing more physical activity will only improve health marginally (health production in other words is subject to diminishing returns). Whereas those on lower incomes have poorer health status as a baseline so that being more active has greater potential to improve health. Reducing health inequalities is a long-term process, therefore it will require governments to adopt a long-term approach and adequately fund PHIs.

The high prevalence of physical inactivity and sedentary behaviour in the UK presents a large burden on the NHS and the economy. These studies have added new evidence to the understanding of economic costs of physical inactivity and sedentary behaviour. Economic analysis is a vital component of public health research. In section 6.3 below, the future directions of economic analysis in this field of research are considered.

6.2.2 Interventions to decrease physical inactivity and sedentary behaviour

6.2.2.1 Characteristics of physical activity interventions associated with greater cost-effectiveness

Chapter 4 assesses which characteristics of physical activity and sedentary behaviour interventions are associated with cost-effectiveness in healthy adults in a systematic review. Interventions to increase physical activity or decrease sedentary behaviour were compared against usual care or an appropriate control group not receiving any intervention. The characteristics of interest were BCTs; complexity measured by the iCAT_SR tool; and intensity of the interventions measured by intervention duration, number of contact points, and number of contact hours. Thirty-three eligible studies, which described 25 interventions, were included in the review. ICERs were calculated for the interventions where possible. Cost-effectiveness ranged from £0.04 to £62.82 per MET-h/week gained. Fifty-four individual BCTs were identified in the 25 interventions: the most common were 'problem-solving', 'self-monitoring of behaviour', and 'instruction on how to perform the behaviour'. The following BCT clusters were used more frequently in the more cost-effective interventions: (1) Goals and planning; (2) Feedback and monitoring; (3) Social support; (4) Shaping knowledge; and (9) Comparison of outcomes. In terms of complexity, the more cost-effective interventions were slightly less complex than the less cost-effective interventions. It was apparent that a certain level of complexity might be necessary to achieve effectiveness; however, increasing complexity may lead to high costs that risk reduced cost-effectiveness. There was no obvious relationship between intervention intensity and cost-effectiveness.

This review examined the relationship between the characteristics of physical activity interventions and their cost-effectiveness. These findings are useful for researchers designing interventions and highlight the importance of comprehensive adequate reporting of interventions (Hoffmann et al., 2014) and of how their evaluations should take account of complexity and intensity. Future economic evaluations of physical activity interventions should report with greater transparency all relevant resource inputs and costs. This would be especially helpful if the intervention was scaled up for larger groups or included in a review. It is important to note that the evaluation of cost-effectiveness here is focused on comparing interventions and identifying the best option. Although it would not be appropriate in medical decision making, it may be informative to researchers developing interventions.

6.2.2.2 The social return on investment of urban green space regeneration

In Chapter 5, a social return on investment (SROI) of the CCG was conducted. The CCG regenerated UGS and created 9km of safe and accessible greenway for walking and cycling. The project included building a new cultural square, cleaning the Connswater River, installing flooding alleviation measures and establishing community engagement programs. The SROI identified several benefits due to the CCG including the increased value of land and property, reduced risk of flooding, increased tourism, improved biodiversity, and increased active transport. It is expected that the CCG will bring other benefits such as increased physical activity in the local community, though the before and after survey indicates that these have not yet materialised. Nevertheless, the net social present value of the CCG over its expected lifetime of 40 years is between £165m and £188m, resulting in a positive BCR of 5.13 to 5.69. A complex systems approach might have been useful in the economic evaluation of the CCG, given the inherent complexity of the interactions between the CCG residents, their physical environment, local socio-cultural norms, the CCG intervention, etc. The complex systems approach is discussed in greater detail in section 6.3.6.

6.2.2.3 Comparison of individual- and population-level interventions

Chapters 3 and 4 both explore interventions with a focus on physical activity or sedentary behaviour. The main difference between the interventions is the level at which they operate. The systematic review (Chapter 3) includes individual-level interventions, which attempt to increase an individual's physical activity level in a relatively intense programme, usually in a small sample. By contrast, the SROI study (Chapter 4) evaluates a community-wide project, which was built in a community of 110,000 people and changed the environment for visitors from further afield.

Individual approaches can be useful for high-risk individuals who have the most agency and motivation to change. They are usually not the most appropriate approach for socioeconomically disadvantaged individuals with less agency (White, Adams and Heywood, 2009). The interventions included in the review (Chapter 3) targeted inactive individuals, who are at elevated risk of several chronic diseases and premature mortality. In this way, the individual-level approach can bring substantial benefits to the participants (Howlett et al., 2019). However, the benefits may not be long-lasting and the cost of the intervention per person can be very expensive. Behaviour change requires especially high levels of motivation in certain contexts that discourage physical activity due to prevailing social norms, the built environment or community values (Doyle, Furey and Flowers, 2006). Consequently, even interventions that are carefully tailored to an individual may not be effective at increasing physical activity. Radical changes at the population level may be needed to effect sustainable change in more people.

Population-level interventions target communities or whole populations, e.g., in PHIs such as water fluoridation and smoking bans. The initial investment of this approach is usually much more costly than the individual-level approach, but the return on investment can be considerably greater. In large groups, a small per-person increase in physical activity level could bring substantial benefits to population health, the health care services, and the economy. In comparison with an intensive intervention involving a small group of participants, the population approach can be more cost-effective (Adams et al., 2016).

Interventions to increase physical activity need a certain level of complexity to improve a complex public health problem. The whole systems approach in public health has been gaining more interest recently (Bagnall et al., 2019). The whole systems approach involves a flexible way of thinking to involve all stakeholders and consider all of the factors that contribute to the risk factor or disease in question (Bagnall et al., 2019). This approach addresses the complex and multifactorial nature of health and behaviour and employing systems theory to intervention design may be a more realistic way to reduce growing inactivity levels (Rutter et al., 2019). The whole systems approach will require the cooperation of many sectors of government (i.e., health, planning, environment, economy) as well as community groups, private companies and individuals to instigate change. Increased coordination between many sectors of society should increase the likelihood of sustained behaviour change with wider impact. There are ten key features of a whole systems approach (Garside et al., 2010), including a complex adaptive system, explicit support for the groups within the system, engagement, and communication. There is also an emphasis on sustainable action, building relationships within the system and evaluation. Strong leadership, engagement and taking time to build relationships and trust are considered important features of successful whole systems approaches (Bagnall et al., 2019). Insufficient resources and funds were identified as barriers to the implementation of a whole systems approach. The evidence on the cost-effectiveness of whole systems approaches is scarce and this is an important next step in this research area (Bagnall et al., 2019). PHIs will need to use all three approaches to improve physical activity: individual-level, population-level, and whole systems approach.

6.2.2.4 Equity considerations and implications for policy

Interventions have the potential to improve or worsen existing health inequities. Two of the interventions included in the review in Chapter 3 specifically targeted socioeconomically disadvantaged adults although health inequity was not a major focus across the included studies. Literature is growing on how to integrate health inequality considerations in the development of PHIs. The WHO-INTEGRATE EtD framework encourages researchers to address complexity in the context of health inequity, equality and financial and economic considerations among other important issues (Rehfuess et al., 2019).

It is also important to consider the context, setting and population when implementing an intervention, as the socioeconomic position of the participants may influence its effectiveness. The SROI in chapter 4 did not specifically address social and health inequity although the CCG is located in an area of East Belfast where many of the wards are socioeconomically disadvantaged. Socioeconomically disadvantaged areas in the UK typically have less access to quality green space in their communities and at home (Mears et al., 2019) which can negatively impact health. A recent review confirmed that community-based interventions could reduce health inequalities of disadvantaged groups but the evidence is still growing (Nickel and von dem Knesebeck, 2020). Public Health England intends to prioritise and promote green space, especially in communities with deprivation (Public Health England, 2020b). For these reasons, investments such as the CCG are valuable ways to improve health inequalities. Individual-level and population-level interventions may each have distinct implications for health inequalities, which should be incorporated in health policies. The issue of intervention-generated inequality is explored in further detail below in section 6.3.4.

Decision-makers should also consider the transferability of PHIs since an effective intervention in one context may not translate well in another. This issue has been addressed both from an epidemiological and a public health or prevention science perspective, each discipline anchoring their perspectives using slightly different language. Speaking to the issue of the "transportability" of causal effects (either from a trial or an observational study) epidemiologists like Westreich et al, and others, highlight the key factors that affect the external validity of an effect estimate and whether it is valid or "transports" from one setting to another (Westreich et al., 2017; Stuart, Bradshaw and Leaf, 2015). Transportability is affected when the sample is not representative of the target population, e.g., the underrepresentation of minority groups is a common occurrence (Stuart, Bradshaw and Leaf, 2015). This issue can arise when the sample is not appropriately specified at the design stage of the intervention. Westreich et al. (2017) advise researchers to avoid claiming unconditional transportability; instead, the transportability of results should depend on how well certain characteristics of the sample and target population match. These differences can be explored using "selection diagrams", a graphical solution to deciding whether it is sensible to draw causal inferences in the target population based on trial results (Pearl and Bareinboim, 2014).

By contrast, from a broader prevention science perspective, in the PIET-T model, Schloemer and Schröder-Bäck (2018) offer criteria for assessing the *transferability* of a health intervention. They include the population (its characteristics, perceptions and attitudes), the intervention (content and evidence for its effectiveness), the environment (the setting, policies, healthcare system etc.) and the transfer process (communication between stakeholders etc). The TRANSFER Approach is another model which was developed to support collaboration between researchers and stakeholders and consider the transferability of interventions when conducting a review (Munthe-Kaas et al., 2020).

There are several interesting opportunities for the development of physical activity research, specifically related to the findings of this PhD thesis. Researchers will continue to explore the associations between physical activity, sedentary behaviour and health while benefitting from more objective measurement of activity behaviours from greater availability of affordable technology (section 6.3.2). They can use recent developments in statistical methodologies which may elucidate the causal pathways from behaviour to health outcomes, such as mediation analysis with PAFs (section 6.3.3). When developing and implementing physical activity and sedentary behaviour interventions, more emphasis will need to be given to reducing inequalities. PHIs risk increasing health inequalities therefore steps must be taken to avoid that scenario (section 6.3.4). In terms of economic evaluation, researchers can model the cost-effectiveness of different scenarios while assessing the distribution of health in the population using distributional CEA (DCEA), discussed in section 6.3.5. Furthermore, moving to a complex systems approach to interventions will be necessary to effectively evaluate PHIs (section 6.3.6). The next steps should shift the focus of physical activity research to a more population-based approach and in LMICs where physical activity research is at an earlier stage (section 6.3.7).

6.2.3 The physical activity continuum and its relationship with health

Extensive research has confirmed that spending more time in MVPA and less time in sedentary behaviour is beneficial for health (Stamatakis et al., 2019b) but there has been some debate on whether sedentary behaviour can be described as an independent risk factor (van der Ploeg and Hillsdon, 2017; Stamatakis et al., 2019a). sedentary behaviour can be modelled as independent in statistical models, which adjust for physical activity level, as was done to produce the RRs used in calculating the healthcare costs attributable to sedentary behaviour in chapter 1. However, the research suggests that there is a significant interaction between sedentary behaviour and MVPA (Matthews, 2019). Achieving high levels of MVPA may eliminate risk from sedentary behaviour, which is a particularly relevant message to individuals in sedentary occupations who spend much of the day sitting. New analytical methods have been proposed to address the interdependent relationship between sedentary behaviour and MVPA.

Traditional multivariate analysis may not be the most suitable model to explore activity behaviours. Activity behaviours are interrelated; time in one behaviour must displace time that could be spent in another behaviour. Compositional data analysis (CoDA) has been proposed as a methodology to assess these behaviours as compositions of activity over 24 hours, including sleep, sedentary behaviour, light-intensity physical activity, and MVPA (Dumuid et al., 2018). Isotemporal substitution uses the same idea of a 24h composition of time to investigate the effects of replacing one activity behaviour with another. Using this technique, researchers have demonstrated that replacing sedentary behaviour with low-intensity physical activity is beneficial to health, thus confirming that the public health message should be to sit less (Chastin et al., 2015). Objective measurement of activity behaviours will be useful for this area of physical activity research, especially now that new technology is more affordable and accessible.

6.2.4 Digital health technologies

DHTs present an exciting opportunity for public health, especially in research focused on physical activity and sedentary behaviour. DHTs can be apps, software, or medical devices used in healthcare or health promotion. In the field of physical inactivity and sedentary behaviour, accelerometers are now a common tool for objectively measuring movement. Apps can provide feedback on activity level as well as encourage behaviour change in interventions. Although technology may be partially responsible for modern sedentary lifestyles, it can also offer opportunities to increase physical activity and ensuring accessibility to DHTs could be a way to reduce health inequalities. DHT could be useful in prevalence studies, BCIs or clinical trials. Now it is feasible to continuously collect large amounts of high-quality data with mobile DHTs such as wearable accelerometers. For example, a recent study of sedentary time and physical activity surveillance pooled accelerometry data across four countries to estimate the activity levels of Europeans (Loyen et al., 2017). Repeated measures of physical activity could explore the impact of changing physical activity levels over the life course. Portable sensors and mobile phone apps can provide real-time feedback to participants in BCIs to encourage more physical activity. Machine learning could be used to learn more about an individual's behaviour patterns and use the information to design personalised interventions (Ryan, Dockray and Linehan, 2019; Barata et al.; Yardley et al., 2016). While there is value in real-life interaction with patients and participants, technology can use data to improve their experiences in healthcare and offer tailored interventions to increase health. Given the wide potential and availability of DHTs, it might be surprising that they are not more widely used in clinical trials, research studies and everyday life, but there have been several challenges.

Researchers may struggle to choose the most appropriate new DHT or may have difficulties with data collection, analysis and storage. The development of new DHT can be expensive and must be verified and validated. Feasibility studies are an important step for understanding the suitability and acceptability of new technology. They offer an opportunity to detect and remedy any practical challenges. Furthermore, in a regulatory setting, the authorities should be involved in the development process to ensure the DHT is suitable. The Clinical Trials Transformation Initiative (CTTI) provides recommendations on the use of DHT in clinical trials. For all of these reasons, it will take time to integrate new DHTs into research and everyday use. As new DHTs become more popular, it is imperative that they are safe for use and based on high-quality evidence. NICE published an evidence standards framework for DHT in 2019 (NICE, 2019). New technology could produce more high-quality data for analysis, which researchers can use to explore the causal pathways of physical activity and health. New methodologies such as mediation analysis with PAFs, discussed in the section below, presents a way to develop the PAF methodology used to produce the findings in chapter 2 of this thesis.

6.2.5 Mediation analysis with PAFs

PAFs are a common epidemiological measure and were calculated in the study described in chapter 2. Moderate to strong evidence exists for an association between sedentary behaviour and the five chronic diseases. The PAFs were calculated based on RRs and the prevalence of prolonged sedentary behaviour in the UK population, representing the proportion of cases of disease that are attributable to prolonged sedentary behaviour. Calculations of PAFs using these methods essentially ignore other risk factors and are indifferent to any specific causal pathways. However, Sjölander (2018) suggest that since the causal pathway from a risk factor to disease commonly involves another factor, the PAF should be decomposed into a direct component and a mediated component.

Sjölander (2018) proposes exploring risk through PAFs using this new methodology. The direct and mediated components of the PAF sum to produce the overall PAF. In Sjolander's worked example, they show the mediation effect of overweight on the causal pathway from physical inactivity to CVD. The author produces natural direct and natural indirect attributable fractions using data from cross-sectional, cohort, and case-control studies and demonstrates that both the direct and mediated components of the AF can be calculated using maximum likelihood or doubly robust methods. Out of 1000 incident CVD cases, 4.07 would be eliminated from the direct effect of physical activity. A further 0.48 cases would be eliminated from the indirect effect of overweight. These results used the doubly robust methods, found to be less biased than the maximum likelihood alternative. Further research could incorporate these techniques when calculating PAFs to explore the causal pathway involved with physical inactivity and sedentary behaviour. More information on how physical inactivity and sedentary behaviour cause disease and other factors involved in the causal pathway may be informative to researchers in the development of interventions to reduce these risk factors.

6.2.6 Intervention-generated inequality

PHIs should improve overall population health while reducing health inequalities (NICE, 2019). However many interventions have resulted in widening existing health inequalities. There are socioeconomic differences in the uptake of public health initiatives by SES. For example, people with lower SES benefited less from PHIs to encourage wearing a bicycle helmet, participated less in cancer screening, and were less likely to consume folic acid during pregnancy (White, Adams and Heywood, 2009). These PHIs mainly involve generating public awareness and education. The uptake of healthier behaviours ultimately requires voluntary behaviour change, which can lead to SE disparities. Voluntary behaviour change may appear to be reliant on an individual's free will but in reality, it is dependent on many factors. The choice could be influenced by the individual's socioeconomic position. PHIs which do not require any voluntary behaviour changes avoid increasing health inequalities. White et al. (2009) uses the example of water fluoridation, which was effective at increasing fluoride in the diet of the whole population and improving dental health, likely because no voluntary behaviour change was required. There is a need for health inequalities to be routinely considered in the development, implementation and evaluation of PHIs.

There are several other reasons that people with lower socioeconomic position do not benefit from PHIs. The resources involved may be less accessible, lower educational attainment or language barriers may result in lost information, and poorly funded public services in disadvantaged areas may slow the rollout of a PHI. Therefore, it is useful to assess PHIs at multiple stages of their development to assess their differential impact on health inequalities. Individually small factors which increase health inequalities can sum to create serious imbalances (White, Adams and Heywood, 2009). Furthermore, research must be representative where possible and appropriate to generate evidence that is not only relevant to the majority groups in society. If a community survey is not representative of the population at large, e.g., by not appropriately representing ethnic minorities or certain age groups, policies based on the survey results could be biased. In terms of the findings reported in this thesis, we should interpret the results with caution since the UK Biobank cohort is not fully representative of the UK. Researchers can also consider how the health impact of interventions is distributed across the population using DCEA instead of more traditional methods that focus on overall population health only.

6.2.7 Distributional cost-effectiveness analysis

There are serious health inequalities in the UK which are likely to grow as a result of the severe socioeconomic disruption caused by the COVID-19 pandemic (Public Health England, 2020a). Health inequality and inequity must be prioritised in health policies and PHIs. Traditional economic evaluations typically focus on overall population health as an outcome, which risks increasing existing inequalities. DCEA is a framework which can be used to prioritise concerns of health inequalities in economic evaluations of PHIs (Asaria, Griffin and Cookson, 2016). The DCEA comprises two main stages. In the first stage, the steps estimate how health is distributed, modelling how the intervention could improve health including opportunity costs and adjusting for alternative social value judgements. In the second evaluation stage, the steps involve quantifying overall change and any health inequalities, ranking the interventions and analysing any trade-offs between overall health inequalities. To achieve this, researchers involved in the development stages of PHIs must be aware of the data requirements to analyse these topics. DCEA could have great utility in the context of interventions to decrease physical inactivity and sedentary behaviour at both individual and population levels. Yang et al. (2020) demonstrated the consequences of not considering health inequalities in two PHIs targeting smoking and alcohol use. Although the overall health impact of the PHIs may be similar, there can be large differences in the impact on health inequalities. Since the direction and strength of effect on health inequalities cannot be easily predicted, all interventions should be evaluated with SES considerations in future. The next steps in physical activity and sedentary behaviour research must involve increasing physical activity in the population overall while reducing inequalities and supporting disadvantaged groups and regions.

6.2.8 Evaluation of interventions within a complex system

There is a need for more research on better methods of evaluating interventions within complex systems. Complexity can refer to either the intervention itself or the complexity of the systems in which the intervention is working (Shiell, Hawe and Gold, 2008) and a system is defined as “an interconnected set of elements that is coherently organised in a way that achieves something” (Meadows, 2009). Complex systems are adaptive, composed of other complex systems, and behave in a non-linear fashion, i.e., the output may not be proportionate to the input (Shiell, Hawe and Gold, 2008). Interventions work within complex systems such as hospitals, schools, or communities, and research must shift its perspective to take the context of the intervention into account. Complex systems have implications for researchers designing, implementing and evaluating interventions as they must consider how the intervention and components of the system might interact. The systems approach should involve all relevant stakeholders and promote good communication between them. If successful, this approach can provide policymakers with evidence to inform decisions, encourage intervention adaptability, assess potential barriers, and consider the political implications (Egan and McGill, 2020).

Economic evaluations are particularly challenging in these contexts because of the difficulty in specifying what the components of the intervention are, the costs of the intervention, and the potential spill-over effects. Due to the non-linear behaviour of a complex system, outcomes should be measured at multiple levels over a long time period. There is a risk of missing relevant outcomes and the value placed on the intervention could change over time, therefore, researchers should be adaptable to change and be sensitive to ecological theory (Shiell, Hawe and Gold, 2008).

Theorization in evaluation design could be a way to understand complex systems better and evaluate interventions more effectively (Cambon, Terral and Alla, 2019). Theorization would involve building an ‘intervention theory’ linking activities, mechanisms, outcomes and the context, allowing researchers to analyse interventions more effectively. Researchers could use a theory of change as an evaluation aid. A theory of change is an idea of how an intervention is working, explaining the connection between the activities and the outcomes, usually outlined by a diagram (Davies, 2018). Caffrey and Munro (2017) encourage researchers to not only ask ‘is the policy working?’ but also how it works and how it interacts with other systems. Policy evaluation frameworks must address complexity and its unpredictability and researchers should be open to adapting the evaluation process as they learn more about the system (Caffrey and Munro, 2017).

6.2.9 Next steps in research

Researchers are advocating for a shift in the distribution of investment into physical activity interventions to more population-based approaches since they have greater potential to improve health (World Health Organisation, 2013; Ding et al., 2020). Ideally, this process would involve collaboration with many stakeholders in a systems approach to increasing physical activity and reducing sedentary behaviour. ProPASS is an example of a collaborative research platform, set up to bring together physical activity research using thigh-worn accelerometer data (Stamatakis et al., 2020). Radical changes to the economy, environment, society, and national policies offer more opportunities for sustainable change. In order to achieve this, we need to further understand the determinants of physical activity at a macro-level. Research has been conducted in cross-sectional studies, but they do not provide sufficient evidence to understand the likely determinants (Ding et al., 2020). Macro-level research in physical activity may also have better outcomes for disadvantaged groups. The study would ask the research question, 'What are the policy determinants of physical activity?'. Researchers could gather evidence from various countries looking at policies that may affect physical activity and the level of activity in that country or region.

Economic evaluation will be a key part of this process to ensure efficient and equitable use of public funds. This shift in perspective will involve the use of alternative or new methodologies such as DCEA, discussed above. For example, what is the cost-effectiveness of a PHI, including the distribution of its effects on society? The study would follow the steps outlined above: first, establish how the health element is distributed across society and model how the intervention could improve health; second, quantify the overall change produced and any inequalities generated. Models should be able to capture all relevant costs and benefits, not only relating to physical activity but also to other important health outcomes. The SROI model used in chapter 5 is an example of an under-used method of gaining a wider view of the societal and economic impact of an intervention compared to traditional economic evaluations. It will be necessary to standardise these methods to ensure consistent reporting and implementation (Masters et al., 2017).

The next steps in physical activity research should also shift focus to LMICs. Although the relative economic burden of physical inactivity in LMICs in 2016 was low (19% of global healthcare costs), the disease burden is much higher (75% of global DALYs) (Ding et al., 2016). Despite the greater need, the vast majority of research on physical activity is based in high-income countries (Pratt et al., 2014). Poor health due to physical inactivity can be especially burdensome to households in LMICs where there is greater unmet health need. Out-of-pocket healthcare costs are more common and there is less financial support available to households in times of reduced productivity or absenteeism due to illness or death, exacerbating the economic burden. If levels of physical inactivity grow as LMICs develop their economies, the disease and economic burden of physical inactivity will worsen.

Since physical inactivity affects health worldwide, it is appropriate to create globally coordinated responses. The WHO published the GAPPA which sets out goals to achieve by 2030 (World Health Organisation, 2013). The evidence available on physical activity and sedentary behaviour can be applied to populations and individuals in LMICs, after making appropriate adjustments for distinct socio-cultural settings and other practical differences. There could be an economic case made for global coordination against physical inactivity. Higher-income countries could support policies to increase physical activity levels in LMICs to avoid the potential economic and health consequences (Ding et al., 2016). It is important to make research, epidemiological tools, and collaboration opportunities widely available for physical activity researchers in LMICs to support work in these regions.

When identifying the best way to spend research funding, researchers should first communicate with stakeholders: the individuals, organisations and governments who will be ultimately impacted by the research. They should conduct scoping reviews to identify where there are clear research gaps. Furthermore, the research should have a positive outcome that will improve our understanding of health and ultimately benefit society. For large investments, pilot studies can be conducted to determine whether the study is feasible. In the areas for future research above, the priority should be to establish the various societal and individual determinants of physical inactivity in order to guide interventions to increase activity levels.

6.3 Conclusion

Physical inactivity and sedentary behaviour are associated with a large burden of illness, premature mortality, and economic consequences. Prolonged sedentary behaviour costs the NHS in the UK £0.7bn annually, after adjusting for confounders including physical activity and BMI (see section 6.2.1.1 and Chapter 2). Physical inactivity leads to more days spent in hospital as an inpatient and higher inpatient costs, indicating that physical inactivity is costing the NHS hundreds of millions of pounds annually in inpatient costs alone (see section 6.2.1.2 and Chapter 3). Together, these findings add evidence to the understanding of the economic burden of physical inactivity and sedentary behaviour. The results indicated that income and gender had an interactive effect on physical activity level, making a case for physical activity interventions to target women and socioeconomically disadvantaged groups.

The solution to the current levels of physical inactivity could be well-designed interventions working at the individual-level, population-level and using a whole systems approach to effect sustainable change. The systematic review of the characteristics of physical activity interventions in Chapter 4 found that cost-effective individual-level interventions are likely to require a certain level of complexity. The theories of behaviour change can be used to inform intervention development; certain BCT clusters were found to be associated with cost-effectiveness. Population-level interventions such as the CCG in Belfast are an opportunity to promote healthy behaviour and reduce health inequalities by investing in socioeconomically disadvantaged communities. The urban regeneration project is likely to be good value for money, with a return of £5.1 to £5.69 for each pound invested (see section 6.2.2.2 and Chapter 5).

Future research in physical inactivity and sedentary behaviour can benefit from new digital technology to collect data faster and explore new ways to encourage activity. Researchers should be open to adopting new methodology to increase understanding of the causal pathways involved both in how physical inactivity negatively impacts health and how interventions can initiate behaviour change. Since interventions are usually working in a complex system, research should take a whole systems approach. The development of interventions should be based on a theory of change to aid evaluation. More research is needed to understand health interventions in complex systems and how to evaluate them effectively. Reducing health inequalities and must remain a key priority of physical activity research and public health research in general. Economic evaluation can help researchers achieve this through new methods such as DCEA. This will be central to evidence-based decisions in public health to ensure fair and equitable use of resources. More research is also needed in LMICs. As new technologies and methodologies are developed to deal with the complex challenges in public health, researchers must adapt to improve population health and reduce health inequalities.

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APPENDICES

Appendix 1. Drummond's Checklist for Assessing Economic Evaluations

(Drummond M et al. Methods for the economic evaluation of health care programmes. 2nd ed. Oxford. Oxford University Press. 1997)

1. Was a well-defined question posed in answerable form?
    1.1. Did the study examine both costs and effects of the service(s) or programme(s)?
    1.2. Did the study involve a comparison of alternatives?
    1.3. Was a viewpoint for the analysis stated and was the study placed in any particular decision-making context?
2. Was a comprehensive description of the competing alternatives given (i.e. can you tell who did what to whom, where, and how often)?
    2.1. Were there any important alternatives omitted?
    2.2. Was (should) a do-nothing alternative be considered?
3. Was the effectiveness of the programme or services established?
    3.1. Was this done through a randomised, controlled clinical trial? If so, did the trial protocol reflect what would happen in regular practice?
    3.2. Was effectiveness established through an overview of clinical studies?
    3.3. Were observational data or assumptions used to establish effectiveness? If so, what are the potential biases in results?
4. Were all the important and relevant costs and consequences for each alternative identified?
    4.1. Was the range wide enough for the research question at hand?
    4.2. Did it cover all relevant viewpoints? (Possible viewpoints include the community or social viewpoint, and those of patients and third-party payers. Other viewpoints may also be relevant depending upon the particular analysis.)
    4.3. Were the capital costs, as well as operating costs, included?
5. Were costs and consequences measured accurately in appropriate physical units (e.g. hours of nursing time, number of physician visits, lost work-days, gained life years)?
    5.1. Were any of the identified items omitted from measurement? If so, does this mean that they carried no weight in the subsequent analysis?

5.2. Were there any special circumstances (e.g., joint use of resources) that made measurement difficult? Were these circumstances handled appropriately?

6. Were the cost and consequences valued credibly?

   6.1. Were the sources of all values clearly identified? (Possible sources include market values, patient or client preferences and views, policy-makers' views and health professionals' judgements)
   6.2. Were market values employed for changes involving resources gained or depleted?
   6.3. Where market values were absent (e.g. volunteer labour), or market values did not reflect actual values (such as clinic space donated at a reduced rate), were adjustments made to approximate market values?
   6.4. Was the valuation of consequences appropriate for the question posed (i.e. has the appropriate type or types of analysis – cost-effectiveness, cost-benefit, cost-utility – been selected)?
7. Were costs and consequences adjusted for differential timing?
   7.1. Were costs and consequences that occur in the future 'discounted' to their present values?
   7.2. Was there any justification given for the discount rate used?
8. Was an incremental analysis of costs and consequences of alternatives performed?
   8.1. Were the additional (incremental) costs generated by one alternative over another compared to the additional effects, benefits, or utilities generated?
9. Was allowance made for uncertainty in the estimates of costs and consequences?
   9.1. If data on costs and consequences were stochastic (randomly determined sequence of observations), were appropriate statistical analyses performed?
   9.2. If a sensitivity analysis was employed, was justification provided for the range of values (or for key study parameters)?
   9.3. Were the study results sensitive to changes in the values (within the assumed range for sensitivity analysis, or within the confidence interval around the ratio of costs to consequences)?
10. Did the presentation and discussion of study results include all issues of concern to users?

10.1. Were the conclusions of the analysis based on some overall index or ratio of costs to consequences (e.g. cost-effectiveness ratio)? If so, was the index interpreted intelligently or in a mechanistic fashion?

10.2. Were the results compared with those of others who have investigated the same question? If so, were allowances made for potential differences in study methodology?

10.3. Did the study discuss the generalisability of the results to other settings and patient/client groups?

10.4. Did the study allude to, or take account of, other important factors in the choice or decision under consideration (e.g. distribution of costs and consequences, or relevant ethical issues)?

10.5. Did the study discuss issues of implementation, such as the feasibility of adopting the 'preferred' programme given existing financial or other constraints, and whether any freed resources could be redeployed to other worthwhile programmes.