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Physical Activity and the Environment

Final Report

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INVESTORS IN PEOPLE

Contents

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Abbreviations

CHD	Coronary heart disease
CPA	Compendium of Physical Activity
HRQOL	Health-related quality of life
HSE	Health Survey for England
ICER	Incremental cost-effectiveness ratio
MET	Metabolic equivalent time
ONS	Office for National Statistics
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NHB	Net health benefit
PSS	Personal Social Services
PSSRU	Personal Social Services Research Unit
QALY	Quality-adjusted life year
RR	Relative risks
WHO	World Health Organization

Plain Language Summary

In order to help the Public Health Advisory Committee (PHAC) to develop recommendations for the guidance on physical activity and the environment, we developed a cost-effectiveness model. The model was developed so that we could use the best-available information in order to understand how different interventions might affect the health of the general population, as well as the impact that the intervention might have on the costs to the National Health Service (NHS), local authorities and to society as a whole.

We used national health survey data to estimate the current level of physical activity in the UK population, and how these levels changed after an intervention was introduced. We also used information from other studies to estimate how the risk of developing five health conditions changed depending on physical activity level. The conditions we included were breast and colon cancer, diabetes, stroke and coronary heart disease. As we also know the costs associated with each of these complications, it was possible to calculate the overall costs for each group of people over their remaining lifetimes.

As well as estimating costs, we measured the health benefits that people would gain by increasing their physical activity. This was done by combining the increases in life expectancy with the increases in individual quality of life (by avoiding some of the conditions listed above). This allowed us to calculate a measure known as the *quality-adjusted life year* gain for a person that could potentially be achieved by increasing weekly physical activity.

For each intervention that we assessed, the health benefits were matched against the costs that would be incurred to deliver it. This was not an easy task, as many environmental interventions, such as installing cycle lanes or renovating parks, vary substantially from place to place. Due to this variability in costs, we calculated the maximum cost per person that each intervention could be in order for the benefits to outweigh the costs.

The results of the analysis showed that interventions could be cost effective if modest numbers of people increased their physical activity. If we consider a town with a population of 100,000 people, then an intervention that cost £10 per person would be beneficial to fund it if it motivated 1,000 people to cycle for an additional 30 minutes per week or 1,900 people to walk an extra 30 minutes per week. If the intervention cost £100 per person, a greater amount of additional physical activity would be required in order for it to be worthwhile: the equivalent of 5,100 people cycling an additional 30 minutes per week or 11,000 walking an additional 30 minutes per week.

When we looked at specific schemes previously undertaken in the UK that amended transport infrastructure, increased public transport and changed open spaces, we found the benefits outweighed the costs even up to costs of £100 per person. An intervention that completely renovated a local greenway, regenerated park land and added cycle and walking paths was even better and would be cost-effective up to an intervention cost of £190 per person.

However, one study looking specifically at park renovations (such as new fitness equipment and play areas) was not very cost-effective and would only be funded if the costs were less than £20 per person.

Our results did not substantially change when we changed parts of the model. For example, we looked at what would happen if people did not sustain the activity improvements they experienced from the intervention. We are therefore confident that our results are informative in determining the value of environmental interventions to promote physical activity.

Section 1: Introduction

1.1 BACKGROUND

The level of an individual's physical activity has a clear and strong association with physical and mental health status. Those with sedentary lifestyles or with low levels of physical activity are at a higher risk of a large number of conditions including coronary heart disease, stroke, cancer and depression [1]. There are also additional benefits to increasing physical activity such as walking and cycling through reducing the use of vehicles that present mortality risks and pollute the environment.

The World Health Organization's (WHO) 2010 report on physical activity identified it as the fourth leading risk factor in global mortality and liable for 6% of annual global mortality[2]. These figures do not include the quality of life reductions resulting from living with and being treated for the health conditions that physical inactivity has caused, making this health burden even greater. These health consequences translate into significant financial costs for the National Health Service (NHS) and society in England; direct costs to the NHS are estimated at £1.06bn and wider social costs at £6.5bn, stemming from lost productivity and premature death resulting from sickness [3] [4].

The benefits of increasing physical activity in the population are reflected in its prominence in public health campaigns. Since the National Institute for Health and Care Excellence (NICE) began developing public health guidance in 2005, five guidelines have been produced, covering numerous approaches to promoting physical activity including work place initiatives (PH13) and interventions targeting children and young adults (PH17), and have identified a number of cost-effective policies.

The work presented in this report contributes towards updating the guidance produced in 2008 on how the built and natural environment can be developed to improve physical activity levels in the population (PH8). A *de novo* model is produced using updated evidence linking physical activity to health outcomes and is able to evaluate the impact of interventions on low mobility populations in addition to the general population. The aim of the model will be to present a range of threshold analyses that will provide decision-makers with information on how cost-effective an intervention will be for given levels of cost and physical activity improvement. The cost-effectiveness of a number of case study interventions will also be evaluated to support the Public Health Advisory Committee's updated recommendations.

1.2 OBJECTIVES

The economic model outlined in this report will contribute toward the achievement of the objectives set out in the NICE scope. The key questions from the scope are as follows:

1. Which interventions in the built or natural environment are effective and cost-effective at increasing physical activity in the general population?
    - **1.1** Which transport interventions are effective and cost-effective?
    - **1.2** Which interventions related to the design and accessibility of public open spaces in the built and natural environment are effective and cost-effective?
2. Does the effectiveness and cost-effectiveness of these interventions vary for different population groups (particularly those less able to be physically active)?
3. Are there any adverse or unintended effects?
    - **3.1** How do these vary for different population groups (particularly those less able to be physically active)?
    - **3.2** How can they be minimised?
4. Who needs to be involved to ensure interventions are effective and cost-effective for everyone?
5. What factors ensure that interventions are acceptable to all groups?

Section 2: Methods

2.1 MODEL OVERVIEW

A cohort model was developed in line with the NICE methods manual and adopts a NHS and personal social services (PSS) perspective [5]. The model allows for various time horizons to be reported, and incorporates a lifetime time horizon in order to capture all relevant costs and benefits. Discount rates of 3.5% for both costs and benefits are applied to future costs and outcomes as stipulated in the NICE methods manual. The principal measure of cost-effectiveness is the incremental cost-effectiveness ratio (ICER), expressed as the incremental cost per quality-adjusted life year (QALY) of an intervention when compared with no intervention. This is defined as the ratio of the difference in cost and the difference in QALYs between the treatment, tx, and comparator, cx:

$$ICER = \frac{Cost_{tx} - Cost_{cx}}{QALY_{tx} - QALY_{cx}}$$

If the ICER is below the cost-effectiveness threshold, for which NICE uses a range of £20,000 to £30,000, then an intervention is deemed cost-effective. The cost-effectiveness threshold reflects the opportunity cost of lost health from areas as funds are moved to the new intervention that arises in fixed-budget health care systems. We also summarise results using net health benefit:

$$NHB = \left(QALY_{tx} - QALY_{cx}\right) - \frac{(Cost_{tx} - Cost_{cx})}{k}$$

Where k is an estimate of the cost-effectiveness threshold. NHB provides the net QALY per person QALY gain for a given level of the threshold: if NHB is greater than zero, the intervention will be cost-effective. We also provide disaggregated results that show both incremental costs and health-related quality of life (HRQOL) benefits.

The objective of the model is to identify the combinations of intervention cost and physical activity gain for which interventions will be cost-effective. These are summarised by determining a series of thresholds: the maximum intervention cost for it to be cost-effective for a given range of physical activity increases; and the minimum physical activity increase necessary for cost-effectiveness given the intervention cost. In addition, a number of case studies identified by the NICE evidence review and agreed with the Committee are modelled to assist with the recommendations.

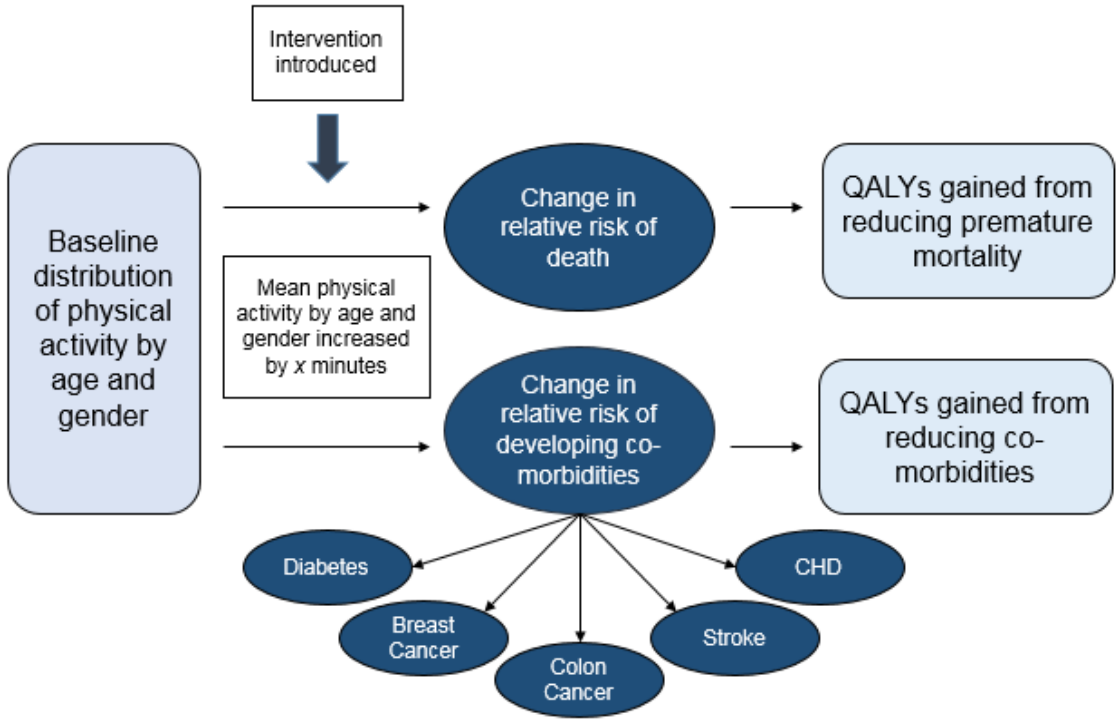
The first stage of the model is based on previous work that has been carried out in the development of previous NICE guidance on physical activity (PH41). This approach estimates the continuous relationship between physical activity and mortality risk; increases in physical activity generated by an intervention can, therefore, be translated into increases in length of

life. To account for health gains experienced whilst alive, we extend the analysis to model impacts on the risk of developing five major diseases associated with low physical activity. Combined with long-term epidemiological data, we capture the lifetime complications associated these diseases.

2.2 MODEL STRUCTURE

The model structure is shown in Figure 2.1. The population distribution of physical activity is estimated from Health Survey for England data from 2014, from which mean physical activity levels are calculated by age and gender. Metabolic equivalent time (MET) is used as the physical activity outcome measure, which adjusts the time spent on an activity according to its intensity. Successful interventions generate physical activity gains, for which a mean population gain is applied to the population, resulting in a post-intervention distribution of physical activity. Physical activity distributions are calculated for the general population and those with limited mobility using data from the 2014 Health Survey for England

Figure 2.1: Model structure



Note: CHD = coronary heart disease; QALY = quality-adjusted life year.

The pre- and post-intervention MET minutes for each subgroup are then plugged in to risk functions (see Sections 2.3.5 and 2.3.6) relating MET minutes per week with (i) mortality and (ii) five comorbidities linked to physical activity levels. From this we obtain the relative risk of death and disease from introducing the intervention for each age and gender subgroup. Since

these functions are continuous, the model allows for the impacts of even small changes in physical activity to be estimated. The five comorbidities included in the model, which were identified from the literature as being most commonly linked with physical activity levels [2], are:

- Breast cancer;
- Colon cancer;
- Diabetes;
- Stroke;
- Coronary heart disease (CHD).

Two cohorts (one for the intervention and another for the comparator) then progress through a simple Markov state-transition model, in which there are two states: alive or dead. In each annual cycle individuals have a probability of death and probabilities of developing each of the comorbidities, which are determined by the physical activity levels and risk functions described above.

Costs are determined by two factors: the initial intervention cost and the numbers experiencing comorbidities, for whom a yearly cost is applied. The lifetime health of the cohort is calculated by subtracting the expected QALYs lost due to experiencing disease from the expected QALYs experienced by all those alive.

Cohorts progressing through the model are all the same age by design. However, given that the kinds of interventions being considered are for the entire population, we run the model for every year of age from 16 to 100. The costs and QALYs for each age are then weighted by their relative population density and used to create weighted average estimates. These are then used to estimate cost-effectiveness of each intervention relative to the comparator.

The computational burden of this approach means that probabilistic sensitivity, which captures the combined uncertainty of all parameters simultaneously through Monte-Carlo simulation, was not deemed practical. Instead, a wide range of deterministic sensitivity analyses are conducted to establish the robustness of the results.

2.3 MODEL INPUTS

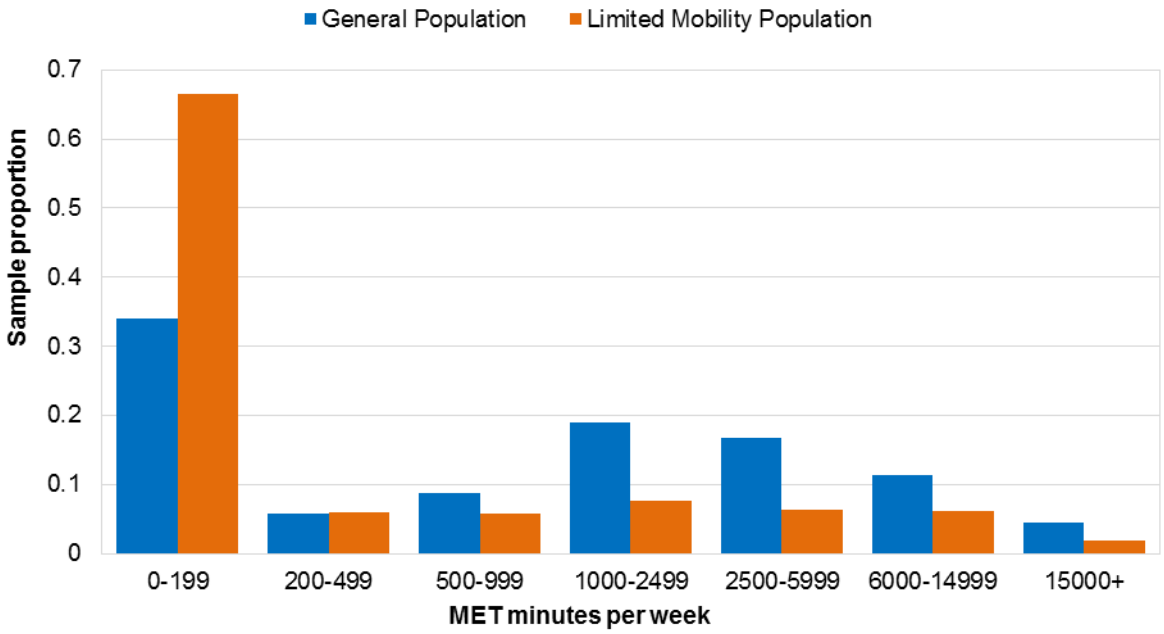
This section outlines the model inputs that have been used to populate the economic model and also highlights any areas in which there are data gaps.

2.3.1 Physical activity levels

The Health Survey for England (HSE) 2014 was used to create physical activity distributions for both the general population and those with limited mobility. The HSE is an annual series of surveys that randomly samples a cross-section of the population and contains information on a range of health, lifestyle and demographic factors.

In the 2014 survey this included the number of minutes per week spent by respondents on moderate and vigorous physical activity. Of the 10,080 survey participants, we extracted complete physical activity data for 6,452 individuals, as well as their age and gender. Of the 3,628 exclusions, 3,425 were due to missing physical activity information and 138 due to missing health-related quality of life data, the use of which is outlined in Section 2.3.4. An additional 65 were excluded because their total moderate and vigorous activity minutes exceeded 12 hours per day, indicating that the question was likely misunderstood and the answer incorrect. A second sample of 1,113 individuals was extracted to form our limited mobility population, where limited mobility was defined as having either 'Some problems in walking about' or 'Confined to bed' on the mobility component of the EQ-5D questionnaire.

Figure 2.2: Distribution of metabolic equivalent time (MET) minutes per week



Note: Includes only moderate and vigorous activities

Table 2.1: Light physical activity levels

		Minutes		MET Minutes	
Activity	**N**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Walking	1731	93	106	232	265
Gardening/Housework	1070	9	33	23	82
Total				**255**	**278**

Note: MET = metabolic equivalent time

Following this we converted the moderate and vigorous activity minutes into MET minutes. For this we used the Compendium of Physical Activity (CPA), a resource detailing the

conversion rate of one minute spent performing one of 821 activities into MET minutes [6]. Using WHO thresholds of 3-6 METs per minute for moderate activities and greater than six for vigorous activities, we calculated the average METs per minute of all relevant activities in the CPA as 4.1 and 8.7, respectively [7]. The subsequent population distribution of MET minutes per week for both the general and limited mobility population is shown in Figure 2.2.

Given that no data were available in the 2014 HSE on light activity, we used data on the time spent walking and performing housework and gardening from the 2012 survey as a proxy. The mid-point of the light activity range (2.5 METs per minute) was used to convert these minutes into MET minutes. We then assumed that light activity was a random variable with a gamma distribution and randomly drew values from it to assign individuals with additional METs per week. These light activity levels are reported in Table 2.1. The total mean MET minutes per week by age and gender are reported for our populations in Table 2.2 and Table 2.3.

Table 2.2: Mean metabolic equivalent time (MET) minutes per week

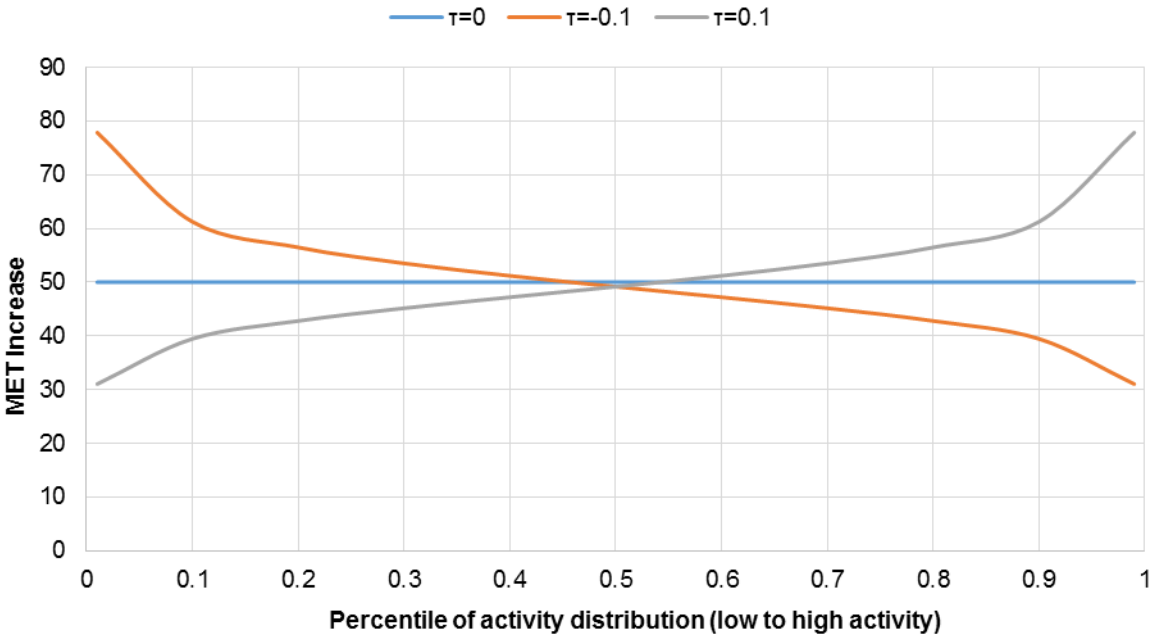
	General population		Limited mobility population	
Age	**Males**	**Females**	**Males**	**Females**
16 to 24	5396	2854	3313	2861
25 to 34	5159	2562	4366	2446
35 to 44	4827	2639	3445	1016
45 to 54	4709	2945	2860	1665
55 to 64	4146	2919	2319	1670
65 to 74	3352	2013	1483	1018
75+	1907	1054	1250	564

The physical activity outcome measure that is incorporated into the model is the mean increase in MET minutes per week. In the base case, this gain will be applied uniformly to the whole population, as agreed during discussions with the Committee. However, it is understood that this is a contentious assumption, and so we assigned every individual a weight based on their physical activity ranking, an approach previously used by Minton et al [8]. These weights were characterised by a Beta distribution of the form $Beta(1+\tau, 1-\tau)$, in which τ indicates how the gains are distributed: when $\tau = 0$ all individuals gain equally, for $\tau > 0$ the most active gain more and for $\tau < 0$ the least active gain more. This relationship between the weights and τ is demonstrated in Figure 2.3. This shows, for a hypothetical intervention increasing mean activity by 50 MET minutes per week, the difference in increase across the activity distribution when τ takes on the values -0.1, 0 and 0.1. Different values of τ are used in both scenario and sensitivity analyses to show how the distribution of MET gain impacts upon cost-effectiveness.

Our base case analysis assumes that the whole population maintains their increase in physical activity over their lifetimes. As this is another disputable assumption, we include in the model the option for the MET gain of a specified proportion of the population to decay. The decaying individuals are randomly selected and the decay rate can also be changed, so that anywhere between 0% and 100% of the gain is lost. When decay is factored into the model, it is applied

in the first cycle; for example, when decay is 100%, affected individuals lose all activity improvements and receive no incremental health benefits from the intervention.

Figure 2.3: Physical activity gain weighting function (for a mean increase of 50 MET minutes per week)



Note: MET = metabolic equivalent time

2.3.2 Effectiveness

Whilst the principal purpose of the model is to estimate which combinations of intervention cost and MET increase are cost-effective, a number of case studies were identified from the evidence review to be run through the model. Ideally, we would like the per person increase in physical activity to be estimated for the local authority population that decision-makers will operate in. However, only one of the seven studies modelled in this report recorded at the town or city level; the remaining studies all survey populations local to the intervention location, or, in one instance, survey route users only. The case studies were selected to represent five broad intervention types highlighted by the PHAC:

1. Increase active travel / total physical activity through changes to transport infrastructure (e.g. cycle lanes, traffic calming, busway);
2. Increase active travel / total physical activity through public transport frequency and access (e.g. frequency and number of buses, number of stops, improved routes including routes to green or blue space);
3. Increased active travel / incidental / total physical activity through reduction in vehicles and vehicle speed (e.g. congestion charge, cyclovia, speed reduction);

4. Increase incidental / total physical activity through changes to open space access and street design (e.g. including paths, trails, access/ signage, safe routes to schools);
5. Increased incidental / physical activity within existing green or blue space (woodlands, parks, canal paths, coastal path, including access and facilities).

The studies evaluating interventions that reduced vehicle numbers or speed provided a quantitative measure of physical activity that could not be converted into mean MET minutes per week. This intervention type was not therefore, represented in our case studies. Summaries of the included studies are provided below, alongside a description of how the mean MET increase was calculated from the outcomes reported in each study. The mean per person increases in MET minutes per week for each study are reported in Table 2.3

Four of the case studies were quality assessed by the evidence review team at NICE. Each was given a minus score, indicating that the study did not satisfy a sufficient number of quality criteria. In some instances, this was due to the observational, non-randomised nature of the studies that is unavoidable when evaluating environmental interventions. However, other sources of bias were identified, such as the risk of self-selection in the 'Smarter Choices, Smarter Places' programme that arose due to towns applying for grants. The poorest quality study we include is the park renovation evaluation conducted by Cohen et al., the methodology of which was not adequately explained. The full quality assessment reports are provided in the Effectiveness and Cost-Effectiveness Review documents: cycling demonstration towns, fitter for walking and the greenway renovation studies are in Review 2 ('Ciclovia' and Street Closures, Trails and Safe Routes to Schools), whilst Smarter Choices, Smarter Places and the park renovation study are included in Review 3 (Park, Neighbourhood and Multicomponent Interventions).

Included Studies

Sloman et al. (2009) – Cycling Demonstration Towns [9]

For this intervention, funding was provided for cycling promotion and cycling infrastructure improvements in six locations in the UK (Aylesbury, Brighton and Hove, Darlington, Derby, Exeter and Lancaster). The interventions varied considerably, from the construction of a pedestrian bridge to improved lighting and break areas for cyclists on existing trails, and falls under the 'changes to transport infrastructure' theme. Data were collected on a range of physical activity variables, with temporal trends controlled for by comparing each area with a 'matched' town not included in the scheme. Quota sampling was used to select approximately 1,500 individuals living in each town.

The study reports that there was a 2.6% decrease in the proportion of the population reporting physical activity levels that placed them in an 'inactive' group. As no formal definition was provided for 'inactive', we assumed it referred to WHO guidelines on minimum recommended levels of 150 minutes of moderate activity per week. To obtain the mean MET increase, two assumptions were made: (i) only 2.6% of the population increased activity and (ii) their post-intervention activity levels were equal to individuals whose activity levels were between 150 and 300 minutes of moderate activity per week. It is felt that the respective pessimistic and

optimistic nature of these assumptions will offset each other to some degree, limiting potential bias.

We then multiplied 150 and 300 by 4.5, the mid-point of the MET minutes range for moderate activity, to obtain the thresholds in MET minutes per week of 675 and 1350, respectively. The 2014 HSE is used the estimate the mean MET minutes for people with less than 675 (93) and between 675 and 1350 (1001), with the difference representing the improvement in MET minutes per week from moving from the inactive to active groups. Multiplying this by the proportion transitioning gives the population mean MET increase:

$$(1001 - 93) \times 0.026 = 23.6$$

Norwood et al. (2009) – Smarter Choices, Smarter Places [10]

This study evaluated a programme encompassing a series of interventions that aimed to increase uptake of walking, cycling and public transport in seven local areas in Scotland. Interventions included the introduction of new bus services, shelters and ticketing improvements, with the study representing the 'public transport frequency and access' theme. Temporal trends are once again controlled for by comparing each area with a 'matched' town outside of the scheme. Between 8% and 10% of each local area were randomly selected to be included in the pre- and post-intervention surveys. Physical activity is measured by the proportion meeting physical activity guideline levels – here explicitly given as 150 minutes of moderate exercise per week.

Compared with the control areas, the proportion meeting guidelines increased by 11.5%. As the activity thresholds are identical to the Cycling Demonstration Towns study, the same calculations and numbers can be used to obtain the mean MET increase for the general population, updating only the proportion transitioning to the active group:

$$(1001 - 93) \times 0.115 = 104.4$$

Adams and Cavill (2015) – Fitter for Walking [11]

The Fitter for Walking scheme involved infrastructural changes, community activities and promotional activities to increase walking in 12 locations in the UK. The study, which represents the 'open access and street design' theme, evaluated five of these sites and reported the relative increases in the number of pedestrians using affected trails and walkways. No control group is used to account for temporal changes, meaning that the results are more vulnerable to bias. Another source of bias is that activity gains are calculated by surveying route users rather than a random sample of a defined population. This is likely to overestimate the activity gains as it does not account for the local population not using the facilities.

The authors report a 14.9% increase in pedestrian activity on the monitored routes. To calculate the mean MET increase, we used data on the mean number of weekly walking trips and mean walking trip length from the National Transport Survey, as reported in Brennan *et*

al. This is used to estimate the average weekly time spent walking for an additional pedestrian. This is multiplied by 3.5, the MET minutes for one minute of brisk walking and 14.9%, the additional number of pedestrians to obtain the mean population increase in MET:

$$3.5 \times 44.7 \times 0.149 = 23.3$$

Cohen et al. (2015) – Park renovation [12]

This study investigated the impact of park renovations on moderate and vigorous activity in San Francisco in the USA and is included here as part of the 'green or blue space' theme. Six parks were included in this controlled before-and-after study: two that were renovated, two partially renovated and two not renovated. Improvements to the park included new outdoor fitness equipment and play areas and renovated recreational grounds.

The researchers monitored activity throughout the day for seven days a week and directly recorded the number of minutes of moderate and vigorous activity performed by park users. As with the Fitter for Walking intervention, this is likely to overestimate the activity gains as it does not account for local residents not using the park. The authors also note that one of the control parks decreased in observed activity at follow up due to more restrictive opening hours – we therefore assumed that the control parks saw no change to remove this factor. Activity time was converted into and reported as MET hours per person at baseline, with the effect of renovation reported as a percentage increase. This yielded a mean increase of 4.5 MET minutes per person.

Dallat et al. (2013) – Connswater Community Greenway [13]

The Connswater Community Greenway was a four year regeneration project that took place in Belfast, Northern Ireland, with the explicit objective of increasing physical activity. The intervention included the construction of nearly 20 kilometres of cycle paths and walkways and improved access to green space.

The study used a quasi-experimental survey to estimate physical activity changes, randomly sampling 1,209 households defined as being 'in the vicinity' of the greenway, compared to control group of individuals from the rest of Northern Ireland. It was found that the intervention increased the proportion of those achieving 150 minutes or more of exercise a week by 5%. We therefore convert the increase into MET minutes per week using the same method as that used for Cycling Demonstration Towns, resulting in the following calculation:

$$(1001 - 93) \times 0.05 = 45.4$$

West & Shores (2011) – New greenway [14]

This study evaluated the physical activity impacts of constructing five miles of greenway along a river in an unnamed city in United States. No further details are provided on the renovations by the authors.

A total of 1,168 households located within one mile of the greenway were randomly selected for pre- and post-intervention surveys, of which 168 (14.2%) responded to both. The authors then report matrix showing, both before and after the intervention, how many participants

partook in walking or moderate and vigorous exercise, and the respective frequency in the preceding week. From this we calculated the change in the mean number of days per participant that each activity was undertaken. Using data on average daily MET minutes of 33, 158 and 276 for walking, moderate exercise and vigorous exercise, respectively, the change in MET minutes per week could be estimated by the following calculation:

$$(0.38 \times 33.2) + (0.56 \times 158) + (0.46 \times 276) = 229$$

Chomitz et al. (2012) – Active Living By Design [15]

The Active Living By Design programme was a multicomponent intervention implemented in cities in the United States in 2007. However, we use only the results from the one city, Someville, which had a before and after component. The intervention included new signage, park renovations and the creation of new walking paths alongside a well-funded promotional campaign.

Two random samples of the Somerville population were surveyed in 2002 and 2008, totalling 1,725 adults. The physical activity measure reported by the authors is the proportion meeting moderate and/or/ vigorous physical activity guidelines, defined as 150 and 60 minutes, respectively. They found that there was a 22% increase in the number meeting these guidelines. Using the technique described for previously, we use this proportion to calculate the mean MET minutes per week increase:

$$(1001 - 93) \times 0.22 = 200$$

Table 2.3: Increases in mean metabolic equivalent time (MET) minutes per week for selected case studies

Intervention	Study	Mean MET increase
Cycling Demonstration Towns	Sloman *et al.* (2009) [9]	23.6
Smarter Choices, Smarter Places	Norwood *et al.* (2014) [10]	104.4
Fitter for Walking	Adams & Cavill (2015) [11]	23.3
Park renovation	Cohen *et al.* (2015) [12]	4.5
Connswater Community Greenway	Dallat et al. (2013) [13]	45
New greenway	West & Shores (2011) [14]	229
Active Living By Design	Chomitz et al. (2011) [15]	200

The consultation version of this document also contained an additional case study. This case study has been removed prior to final publication because the study it came from is currently unpublished and because further analysis of the data indicates that the intervention may not be effective at increasing overall levels of physical activity.

2.3.3 Costs

Comorbidity costs

Comorbidities are incorporated into the model using the prevalent rather than the incident population. This is because we need to estimate the proportion of the cohort with each comorbidity in each cycle, rather than only new cases. However, the prevalent population can cover a wide variety of patient types and resource use, such as cancer patients with metastatic disease compared with those in remission. We therefore sought estimates of annual national-level expenditure for each comorbidity and divided this by the estimates of the prevalent population to generate the yearly costs for a hypothetical average patient.

The annual costs associated with each comorbidity and the data sources used to calculate them are provided in Table 2.4. The costs reflect the on-going annual costs and are multiplied by the number of people with each comorbidity each cycle.

The comorbidity cost sources were reviewed to identify if social care costs were included, and if so whether these costs could be disaggregated. However, given that not all cost sources reported the disaggregated costs it was not possible to report overall costs for social care separately and, therefore, results are reported for NHS and personal social services as a whole.

Table 2.4: On-going annual comorbidity costs per person (NHS)

Parameter	Cost	Source
Breast cancer	£2,363	**National expenditure:** Breast cancer expenditure by Programme Budgeting Category and Primary Care Trust. Department of Health [16] Inflated from 2013/14 to 2015/16 prices using PSSRU (2016) H&CHS indices [17] **Patient population:** Maddams *et al.* (2008) [18]
Colon cancer	£1,153	**National expenditure:** Trueman *et al.*(2007) [19] Inflated from 2006/07 to 2015/16 prices using PSSRU (2016) H&CHS indices [17] **Patient population:** Maddams *et al.* (2008) [18]
Diabetes	£2,338	**National expenditure:** Hex *et al* (2012). [20] Inflated from 2010/11 to 2015/16 prices using PSSRU (2016) H&CHS indices [17] **Patient population:** Public Health England [21]
Stroke	£5,653	NICE CG92 Full guideline [22]. Inflated from 2007/08 to 2015/16 prices using PSSRU (2016) H&CHS indices [17]
CHD	£1,394	**National expenditure:** British Heart Foundation. Cardiovascular Disease Statistics [23] Inflated from 2012/13 to 2015/16 prices using PSSRU (2016) H&CHS indices [17] **Patient population:** British Heart Foundation [23]

Note: PSSRU = Personal Social Services Research Unit

Intervention costs

Per person intervention costs for the selected case studies are provided in Table 2.5. These were extracted from the effectiveness studies and supporting documents where available. Maintenance costs were not specified in any of the studies and are not therefore included; the impact of these are therefore explored in a scenario analysis. For studies where only total intervention cost was provided, a per person intervention cost was only calculated when a population size was explicitly provided. Therefore, no intervention cost could be calculated for the 'Fitter for Walking' scheme. For the greenway intervention evaluated by West & Shores, no costs are provided at all. In all but one study where costs could be calculated, the population matched the one used to calculate effectiveness. However, in the park renovation evaluated by Cohen *et al.*, it is likely that park user surveys included those living outside of half a mile from the park, the population used to calculate the average cost. Lastly, as the park renovation study and Active Living by Design were conducted in the USA, the intervention costs were converted from dollars into pound sterling at an exchange rate of 0.77. This, along with the questionable transferability of US infrastructure cost to a UK setting, mean that these intervention costs should be treated with additional caution.

Table 2.5: Intervention costs for selected case studies

Intervention	Study	Cost per person
Cycling Demonstration Towns	Sloman et al (2009) [9]	£11.64
Smarter Choices, Smarter Places	Norwood et al. (2014) [10]	£96.59
Fitter for Walking	Adams and Cavill (2015) [11]	N/A
Park renovation	Cohen et al. (2015) [12]	£203.44
Connswater Community Greenway	Dallat et al. (2013) [13]	£71.87
New greenway	West & Shores (2011) [14]	N/A
Active Living By Design	Chomitz et al. (2011) [15]	£42.99

Furthermore, it was felt by the PHAC that intervention costs will have substantial variability across settings even within the UK. Therefore, for each intervention we conduct a threshold analysis to determine the maximum price at which it will be cost-effective. These are presented alongside the central estimate.

2.3.4 Utilities

We modelled health-related quality of life as a function of physical activity time as well as age and gender, as is normally done in cost-effectiveness analyses. This was done to capture the effects of physical activity on comorbidities not included in the model and on general health aspects not related to a particular condition, such as mental well-being.

Our HRQOL measure, as recommended in the NICE methods manual, is the EuroQol five dimension (EQ-5D) questionnaire and is included in the same HSE data from which we estimated the physical activity distribution. We are thus able to estimate the statistical relationship between EQ-5D score and age, gender and MET minutes per week using the following OLS regression model:

$$HRQOL_i = \beta_1 + \beta_2 age_i + \beta_3 gender_i + \beta_4 MET_i + \varepsilon_i$$

In which the β's are the estimated regression coefficients that quantify the impact of the variable on HRQOL and ε_i is the random error for each individual i. Prior to estimating the equations for each population (general and limited mobility), we first removed the individuals who have reported heart and circulatory conditions and diabetes. This is to strip out the impact of MET on HRQOL that would be associated with the five comorbidities included in the model, which are accounted for separately. The regression output is reported in Table 2.6. The EQ-5D scores were then calculated for age and gender groups by plugging their respective mean MET minutes per week from Table 2.2 into the equations. These predicted utility values are given in Table 2.7. For both populations, an additional MET minute per week increases utility, whilst being male is also associated with a higher score. In the general population, utility decreases monotonically from age 34 and above. Interestingly, older age groups in the limited mobility population have a higher predicted HRQOL. Whilst this could be due to random chance stemming from the small sample size or selection bias, it may also be due to the fact that limited mobility in older age is more commonly a result of attrition (for instance, joint deterioration), whereas for younger age groups, it is more likely to be the result of a debilitating chronic condition. Furthermore, elder populations may have also adapted better to limiting conditions and report higher HRQOL. It is therefore plausible that HRQOL could be lower for younger groups in this population.

In order to estimate the effect of developing a comorbidity on HRQOL, we undertook searches to identify estimates of the utility values associated with each of the five conditions contained in the model. These utility values, and their source are reported in Table 2.8. From these we calculate the disutility (the utility loss associated with living with the condition for one year). These are calculated by subtracting the disease-specific utility from that of someone in good health. For the latter, we use the utility value of the age group that matches the mean age of the sample from which the disease-specific utility is estimated to calculate the disutility. For example, the breast cancer utility of 0.77 provided in Hall *et al.* is calculated from a sample with a mean of 66. The disutility for females is then the difference between this and the healthy utility score for 65 to 74 year olds of 0.83, or 0.06. This disutility is then applied to anyone experiencing the condition, regardless of age, gender or whether they have limited mobility. Furthermore, we assume that the effect on HRQOL of experiencing multiple comorbidities, which some people invariably will, is additive. In other words, women who develop breast cancer and diabetes will have a yearly disutility of 0.063+0.165=0.228.

Table 2.6: Effect of age, gender and MET minutes per week

	EQ-5D Score (general population)	EQ-5D Score (limited mobility population)
N	5,429	715
Variable		
Constant	0.906*** (0.007)	0.528*** (0.049)
Male	0.024*** (0.005)	0.023 (0.021)
MET minutes per week	$0.03 \times 10^{-4***}$ (0.01×10^{-4})	$0.08 \times 10^{-4**}$ (0.03×10^{-4})
Age		
25 to 34	0.002 (0.008)	-0.028 (0.059)
35 to 44	-0.024** (0.009)	-0.016 (0.057)
45 to 54	-0.042*** (0.009)	0.002 (0.055)
55 to 64	-0.078*** (0.011)	-0.127* (0.056)
65 to 74	-0.080*** (0.011)	0.017 (0.052)
75+	-0.151*** (0.015)	0.022 (0.052)

Notes:

1. Standard errors in parentheses.
2. *** P<0.001 ** P<0.01 * P<0.05
3. MET = metabolic equivalent time

Table 2.7: Predicted EQ-5D utility scores for healthy individuals

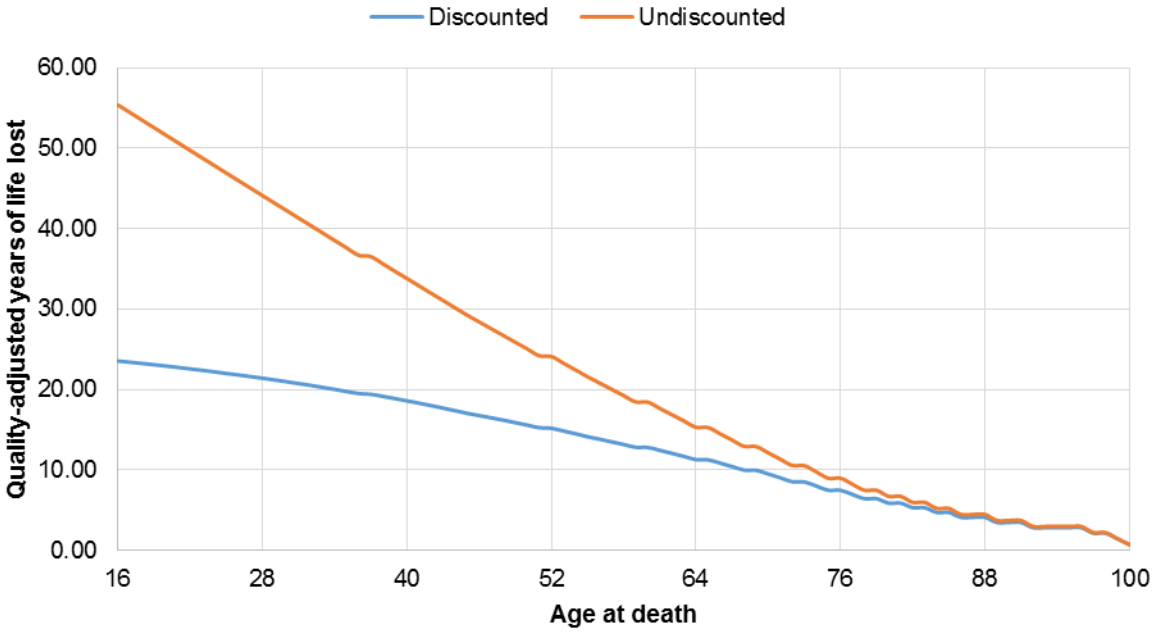
	General population		Limited mobility population	
Age	**Males**	**Females**	**Males**	**Females**
16 to 24	0.94	0.91	0.58	0.55
25 to 34	0.94	0.91	0.53	0.50
35 to 44	0.92	0.89	0.55	0.52
45 to 54	0.90	0.87	0.57	0.54
55 to 64	0.86	0.84	0.44	0.41
65 to 74	0.86	0.83	0.58	0.55
75+	0.78	0.76	0.58	0.55

Table 2.8: Comorbidity utility and disutility values

		Disutility		
Comorbidity	**Utility**	**Males**	**Females**	**Source**
Breast cancer	0.772	0.087	0.063	Hall *et al.* (2015) [24]
Colon cancer	0.793	0.066	0.042	Hall *et al.* (2015) [24]
Diabetes	0.670	0.191	0.165	Janssen *et al*. (2011) [25]
Stroke	0.440	0.419	0.393	Golicki *et al*. (2015) [26]
CHD	0.760	0.099	0.073	Stevanovic *et al.* (2016) [27]

Along with the QALY losses associated with living with diseases, we also wanted to capture the losses that result from premature death. This was done using estimates of life expectancy from Office for National Statistics (ONS) life tables [28] and the EQ-5D population norms calculated by Kind *et al* [29]. Firstly, life expectancy by single year of age was extracted to obtain the number of life years lost of a person dying at that age. Each year of life was then weighted by the EQ-5D score from the population norms by age and gender to adjust for quality of life. These were then discounted at a rate of 3.5% per year in accordance with the NICE methods manual. The resulting values, representing the total discounted QALYs lost from dying at any age, are subsequently applied to any deaths occurring in the cohort. The discounted and undiscounted QALY loss by age at death are shown in Figure 2.4.

Figure 2.4: Quality-adjusted years of life lost by age at death



Note: Discount rate of 3.5% was applied

2.3.5 Comorbidity Epidemiology

As the cohort progresses through the model and grows older, their risk of developing comorbidities will also change. These risks are also dependent upon an individual's level of physical activity. We therefore required information on the prevalence of each condition by age and gender and the dose-response relationship between risk and physical activity level, so that these changing risks could be incorporated into the model.

Table 2.9: Sources for prevalence of comorbidities

Comorbidity	Source for prevalence rates
Breast cancer	Maddams *et al.* (2009) [18]
Colon cancer	Maddams *et al.* (2009) [18]
Diabetes	Diabetes UK. 'Diabetes in the UK 2012: Key statistics on diabetes' [30]
Stroke	Bhatnagar *et al.* (2015) [31]
CHD	Liu *et al.* (2002) [32]

Note: Breast cancer prevalence was not reported for males. To calculate this, we multiplied the female rates by 0.007, as reported by Cancer Research UK [33].

Table **2.9** summarises the sources used to obtain the prevalence rates of each comorbidity. Where the age groups were aggregated at a higher level than the seven groups we use in the model, we assumed the rate was constant across contained age bands. For example, where cancer prevalence was given for 0 to 44 in Maddams *et al*., we applied this rate to the 16 to 24, 25 to 34 and 35 to 44 groups [18]. The prevalence rates by age and gender for all comorbidities are provided in Table 2.10 and Table 2.11.

Table 2.10: Prevalence of breast and colon cancer by age and gender

	Breast cancer		Colon cancer	
Age	**Males**	**Females**	**Males**	**Females**
16 to 24	0.01%	0.14%	0.01%	0.01%
25 to 34	0.01%	0.14%	0.01%	0.01%
35 to 44	0.01%	0.14%	0.01%	0.01%
45 to 54	0.19%	2.69%	0.34%	0.26%
55 to 64	0.19%	2.69%	0.34%	0.26%
65 to 74	0.40%	5.69%	2.24%	1.65%
75+	0.40%	5.69%	2.24%	1.65%

Note: Male breast cancer rates were assumed to 0.7% that of women at all age groups

To determine how these risks change following an increase in physical activity, we sought evidence that linked the relative risk of developing comorbidities to physical activity level. In the end, one study by Kyu *et al*. provided all the required evidence [34]. In this study the authors performed a systematic review and meta-analysis for each comorbidity that incorporated a total of 174 articles: 35 for breast cancer, 19 for colon cancer, 55 for diabetes, 43 for ischemic heart disease and 26 for stroke. Strong associations were found between physical activity and risk of each disease, with the largest reductions occurring when initial physical activity levels were low.

Table 2.11: Prevalence of type-2 diabetes, stroke and CHD by age and gender

	Diabetes		Stroke		CHD	
Age	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**
16 to 24	1.80%	2.10%	0.11%	0.11%	0.10%	0.00%
25 to 34	1.80%	2.10%	0.11%	0.11%	0.40%	0.30%
35 to 44	9.40%	6.60%	0.11%	0.11%	0.90%	0.60%
45 to 54	9.40%	6.60%	0.89%	0.79%	4.30%	1.80%
55 to 64	11.1%	8.00%	2.69%	1.96%	13.6%	6.30%
65 to 74	15.2%	12.2%	6.40%	4.39%	20.2%	12.5%
75+	15.9%	13.2%	14.9%	12.4%	23.4%	18.4%

Note: CHD = coronary heart disease

The authors, however, provide these relative risk reductions at 50 discrete intervals of MET minutes per week from 0 to 30,000, with each value being relative to 0 METs per week. This meant that we were required to fit curves to the reported data in order to obtain the continuous relationship between them. For each comorbidity, we therefore estimated the linear-log relationship in a regression model of the form:

$$RR_{cj} = \alpha_1 + \alpha_2 \log(MET_j) + \varepsilon_j$$

Where RR_{cj} is the relative risk for comorbidity c at interval j, ε_j is the random error and α_2 relates the relative risk to MET minutes per week. For each model, we set the reference MET value to 1 instead of 0 to avoid estimation errors when using $\log(0)$.

Table 2.12: Effect of log(MET minutes per week) on the relative risk of developing comorbidities

	Breast Cancer	Colon Cancer	Diabetes	Stroke	CHD
Constant	1.110	1.088	1.108	1.073	1.016
ln(MET)	-0.024	-0.031	-0.040	-0.037	-0.030
Lower 95% CI					
Constant	1.095	1.092	1.114	1.140	1.043
ln(MET)	-0.017	-0.024	-0.035	-0.033	-0.026
Upper 95% CI					
Constant	1.120	1.076	1.108	1.026	0.985
ln(MET)	-0.031	-0.036	-0.045	-0.043	-0.034

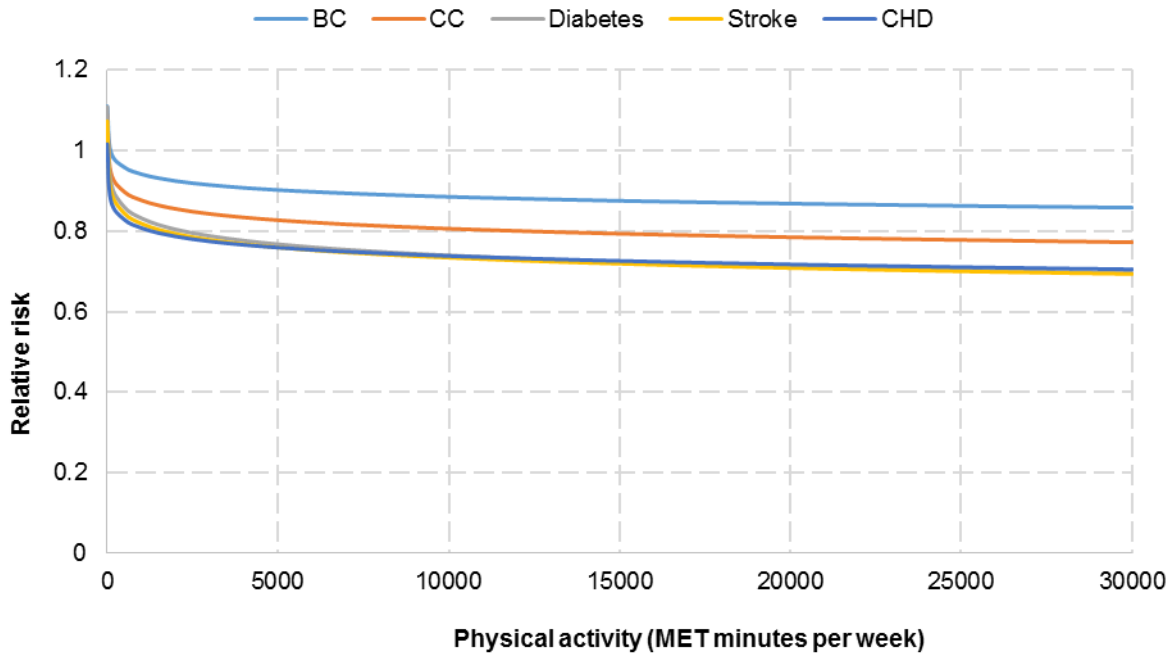
Note: MET = metabolic equivalent time

We estimate two further sets of equations for each comorbidity, using the upper and lower confidence intervals of the relative risks at each interval reported by Kyu *et al.* These provide an upper and lower estimate of the impact of $\log(MET)$ on relative risk, which we then use in sensitivity analyses. The results of all of these regression models are provided in Table 2.12.

These equations then allowed us to create continuous functions, from which the relative risk reduction of any increase in physical activity can be calculated. These are shown in Figure 2.5. It is assumed that the change in comorbidity risk is transferred instantaneously and that the same relative risk reductions occur for the limited mobility population. From here, the process of calculating the relative risk reduction of increase in MET from any starting level of MET is straightforward:

(i) Calculate the relative risk of the baseline MET relative to the reference level (1 MET minute);
(ii) Calculate the relative risk of the post-intervention MET relative to the reference level;
(iii) Divide (ii) by (i) to obtain the relative risk of the intervention MET compared with the baseline level.

Figure 2.5: Effect of MET minutes per week on relative comorbidity risk



Note:

1. BC = breast cancer; CC = colon cancer; CHD = coronary heart disease.
2. Metabolic equivalent time (MET) minutes per week adjusts time spent being active by the relative intensity. For instance, 700 METs are equivalent to 200 minutes each week of leisurely walking.
3. Risks relative to a reference level of 1 MET minute per week

2.3.6 Mortality Epidemiology

This section describes how the reduced mortality risk associated with additional physical activity is handled in the analysis.

As with comorbidity risk, mortality risk will increase as individuals' age and progress through the model. We were therefore tasked with finding data on the current mortality risks in the population and to identify evidence linking these risks to physical activity levels. For baseline mortality risks, we used Office for National Statistics (ONS) data on mortality rate by gender and single year of age [28].

Since the mortality impact of comorbidities is not explicitly modelled, we analyse mortality from all causes. This was advantageous as we were not required to strip out disease-specific mortality from the baseline mortality rates and could utilise the study by Anderson *et al*. that links physical activity to all-cause mortality [35]. This has been used previously in both the WHO's health economic assessment tool for walking and cycling interventions, and the analysis in PH41 by Brennan *et al [36].*

Table 2.13: Conversion of activity thresholds from Anderson *et al.* (2000) into MET minutes per week

Activity threshold	Study definition	MET threshold	Assumptions
Low	Entirely sedantary / less than two hours light activity per week	150	Mid-point of light activity range (2.5) multiplied by mid-point of activity range (60 minutes)
Moderate	Light activity 2-4 hours per week	630	CPA estimate of 3.5 METs for leisure cycling and walking multiplied by mid-point of activity range (180 minutes)
High	Greater than 2 hours vigorous activity per week	Varied by age and gender	Average vigorous minutes per week for those doing more than 120

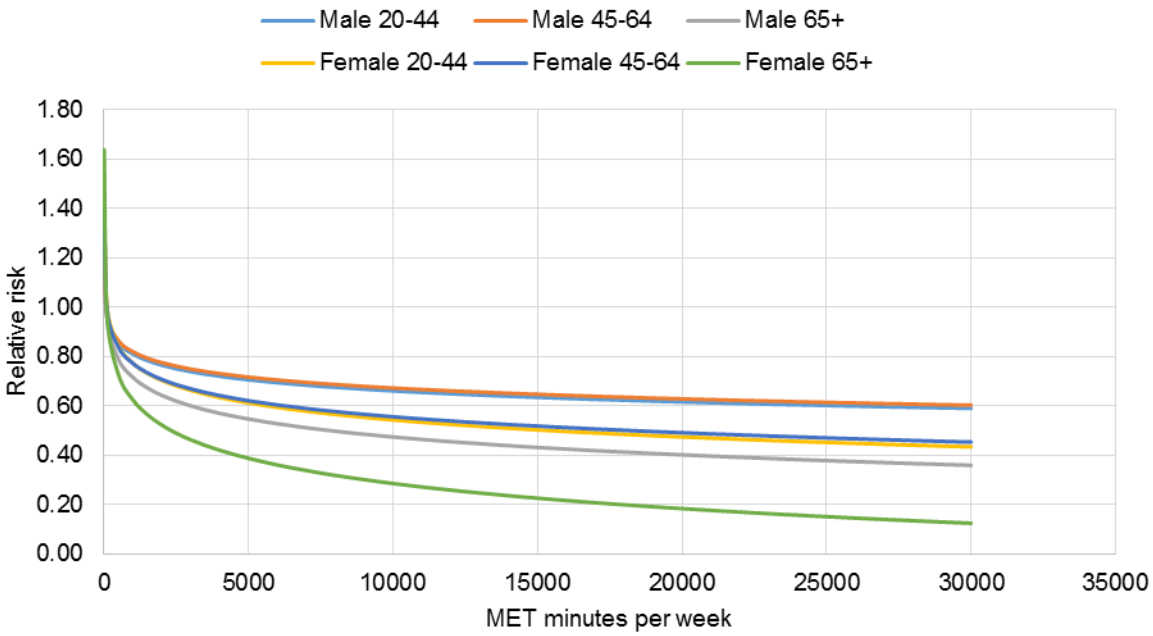
The Anderson *et al*. study followed a sample of 30,640 individuals for an average of 14.5 years and estimated the relative risk of death by physical activity level for six age and gender subgroups in a multivariate analysis to adjust for potential confounders. Individuals were grouped into one of three physical levels – low, moderate and high. These were based on loose threshold descriptions of weekly activity that required us to make several assumptions when converting them into MET minutes per week. The study thresholds, assumptions and our MET thresholds are provided in Table 2.13.

These provided three data points for each of the age and gender groups, from which we estimated regression equations in the same way as was done for comorbidity risk in the previous section. Anderson *et al*. also provide 95% confidence intervals for their relative risk estimates, which we use to re-estimate the risk equations to provide the lower and upper bounds on the impact of MET minutes on mortality risk for each group. The results from all these regressions are reported in Table 2.14, with the continuous functions estimated from the equations plotted in Figure 2.6. The same process for estimating the risk of death at the intervention-level MET relative to the comparator is used as for comorbidity risk. As with the relative risks for the comorbidities, it is assumed that the change in risk happens in the first cycle and that the same curves apply to the limited mobility population.

Table 2.14: Mortality by smoking status

	Males			Females		
	20 to 44	**45 to 64**	**65+**	**20 to 44**	**45 to 64**	**65+**
Constant	1.257	1.259	1.438	1.459	1.419	1.638
ln(MET)	-0.065	-0.064	-0.105	-0.099	-0.094	-0.147
Lower 95% CI						
Constant	1.040	1.150	1.304	1	1.290	1.476
ln(MET)	-0.010	-0.038	-0.073	0	-0.064	-0.112
Upper 95% CI						
Constant	1.461	1.342	1.551	1.766	1.542	1.775
ln(MET)	-0.113	-0.084	-0.131	-0.169	-0.121	-0.176

Figure 2.6: Effect of MET minutes per week on relative mortality risk



Note: Risks relative to a reference level of 150 MET minutes per week

Section 3: Results

The results in this section are representative of the average age and gender in the general population, unless stated otherwise and are reported for a lifetime time horizon from the perspective of the NHS. The principal results are a series of scenario and threshold analyses that determine what combinations of MET improvement and intervention cost represent cost-effective use of resources. Our scenarios also show how cost-effectiveness is affected by the distribution of MET increases in the population, the value of the cost-effectiveness threshold and the proportion of the population for whom MET increases decay. The results of our case study evaluations are also shown. Throughout the results, net health benefit is calculated using a threshold of £20,000 per QALY, except during the threshold scenario analysis.

3.1 SCENARIO ANALYSIS

3.1.1 Intervention cost and activity gain

The following scenario analysis varies the mean MET improvement associated with an intervention, the cost of the intervention. This allows a variety of scenarios to be assessed and to observe their effect on the results. The following scenario analyses, shown in full in Table 3.1, assume that the comparator is no intervention (i.e. baseline levels of MET minutes per week.) Our analysis also varied the distribution of activity gain between favouring the less active (τ=-0.1), uniform (τ=0) and favouring the more active (τ=0.1). However, this had minimal effect and did not substantively alter the points at which interventions became cost effective.

Figure 3.1 shows that when the cost of an intervention increases, or when the effectiveness decreases, the NHB becomes lower. It is clear that, when the cost per person of the intervention is low, only modest gains in MET minutes per week are required in order for it be cost-effective. For an intervention cost of £10 per person for instance, an intervention need only increase activity by an average of 2 MET minutes per week – the equivalent of an additional one minute of light strolling per week. This increases to 23 and 59 MET minutes per week for interventions costing £100 and £250 per person, respectively.

The same analysis is conducted for low mobility populations and is shown in Figure 3.2. At low intervention costs, the required MET gain for cost-effectiveness is similar at around 1.5 MET minute per week. At higher intervention costs however, cost-effectiveness is achieved at far lower mean MET minute increases: when the cost is £100 the required MET increase falls from 23 for general population to 16; at intervention costs of £250 the respective fall is from 59 to 41.

Figure 3.1: MET gain and cost scenario analysis (general population)

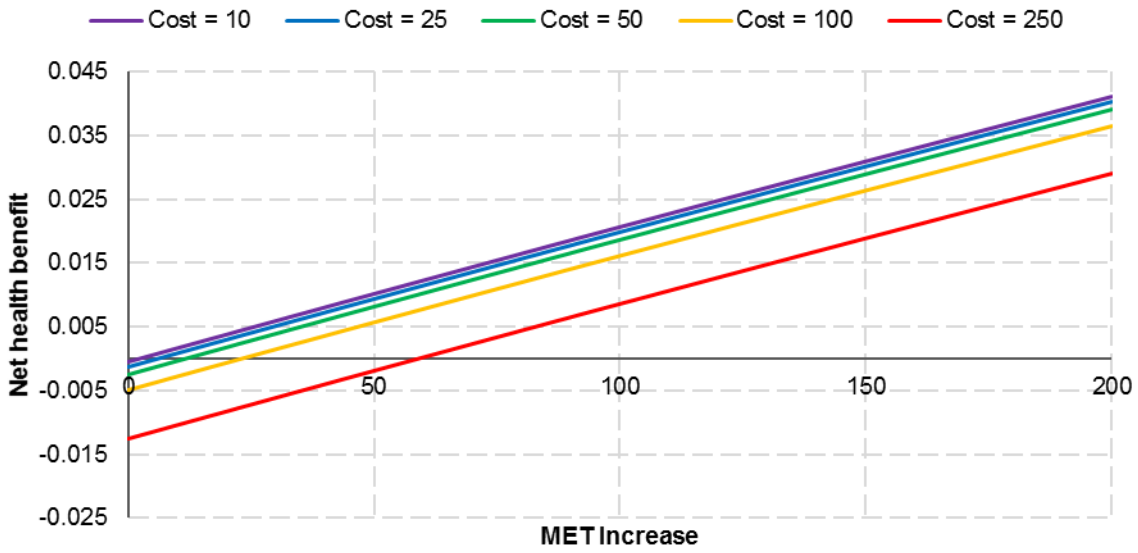
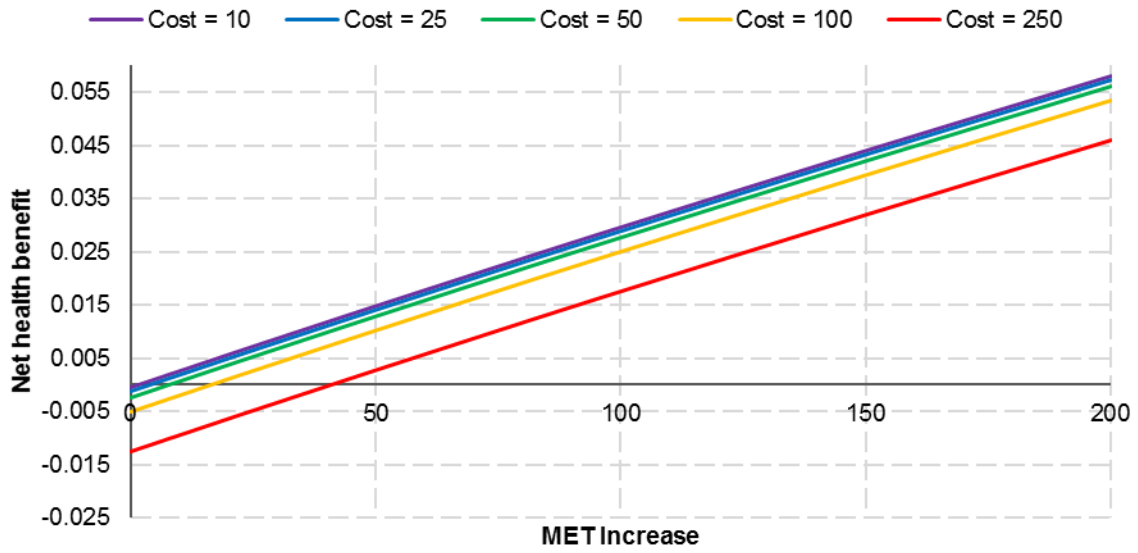


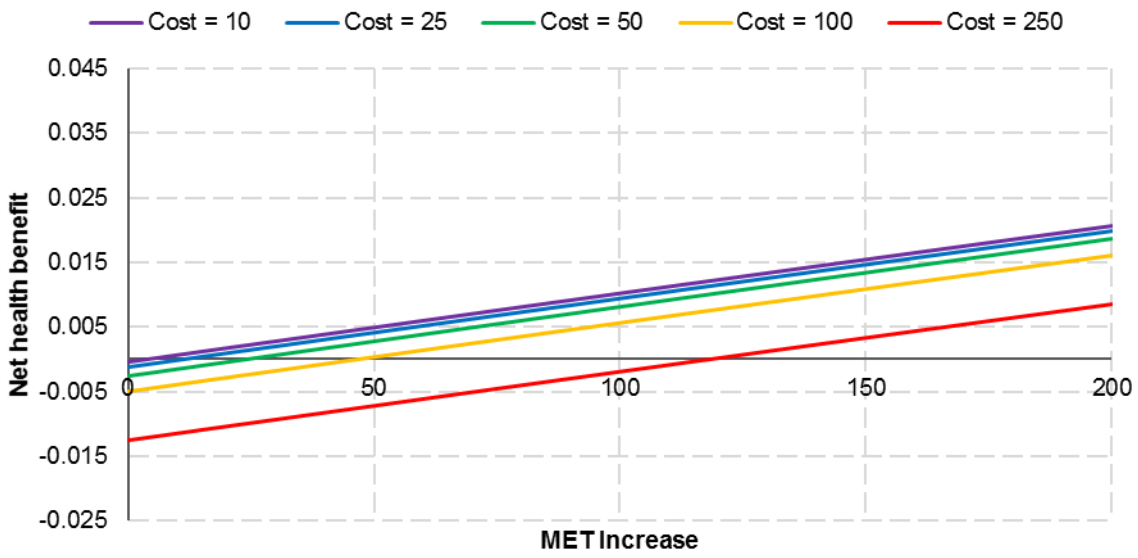
Figure 3.2: MET gain and cost scenario analysis (limited mobility population)



3.1.2 Activity gain decay, maintenance costs and the cost-effectiveness threshold

Figure 3.3 shows how the relationship between NHB, interventions costs and MET increases when the activity gains of 25% of the population immediately decay to half the initial increase. The minimum MET increase required for cost-effectiveness increases at each intervention cost: from 2 to 3 minutes for an intervention cost of £10 per person and from 59 to 67 for an intervention cost of £250 per person.

Figure 3.3: MET gain and cost scenario analysis (50% MET gain decay)



Two scenarios were run to consider the impact of maintenance costs on net health benefit. These are applied in each annual cycle and are calculated as proportion of the total intervention cost. This is informed by evidence from Sustrans [37] and the National Audit Office [38] that estimate annual maintenance costs somewhere between 1% and 5% of initial infrastructure costs; we therefore use these as our scenario values. The results, presented in

Figure **3.4** and Figure 3.5, show that the minimum MET increase required for cost-effectiveness increases marginally for small intervention costs and substantially for higher intervention costs. At intervention costs of £25 per person, the required increase rises from 6 in the base case to 7 and 11 for maintenance costs of 1% and 5% respectively. At intervention costs of £250 per person, the required increase rises from 59 in the base case to 69 and 112 for maintenance costs of 1% and 5% respectively.

Figure 3.4: MET gain and cost scenario analysis (1% maintenance costs)

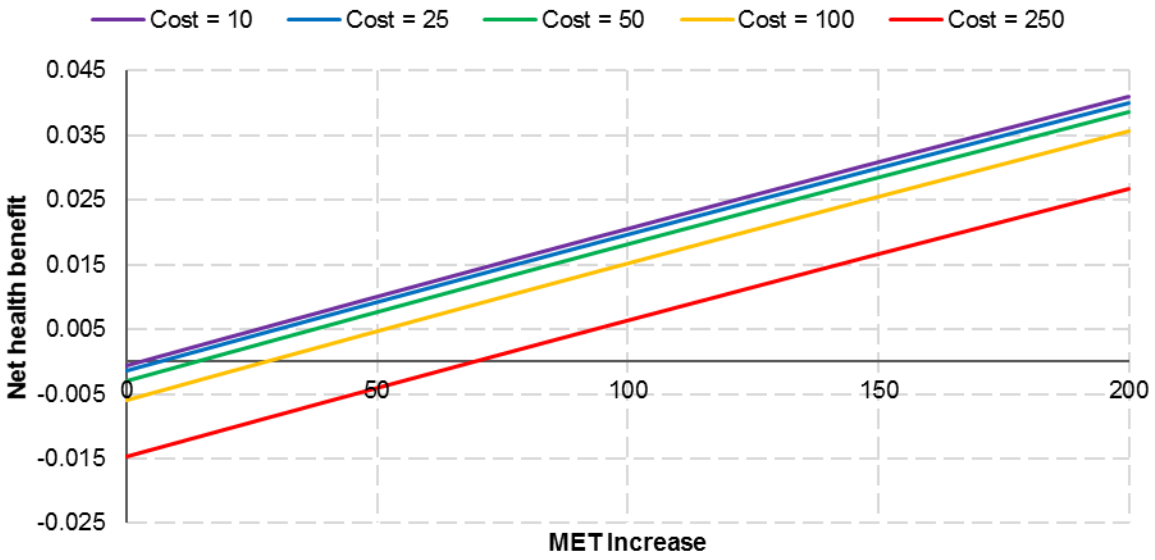
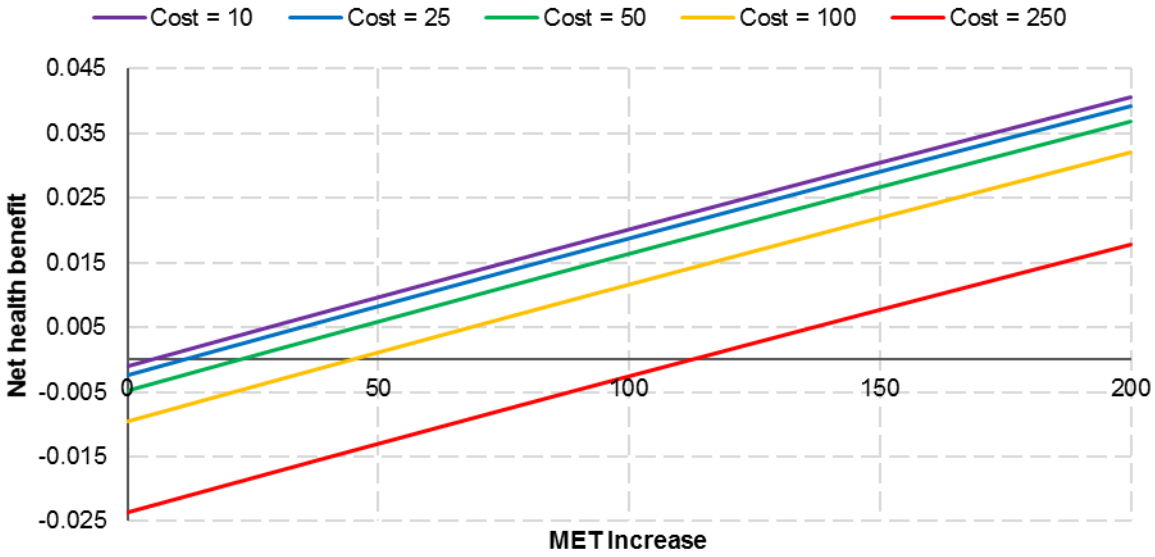


Figure 3.5: MET gain and cost scenario analysis (5% maintenance costs)



The effect of changing the cost-effectiveness threshold from £20,000 to £30,000 and £10,000 per QALY are shown in Figure 3.6 and Figure 3.7, respectively. This change in threshold implies that the losses, in terms of health, of displacing other services to fund the new intervention are lower (£30,000) and higher (£10,000) than those of our base case. As expected, lower health opportunity costs mean that interventions with lower activity increases are also cost-effective; higher opportunity costs have the opposite effect. For example, as the threshold moves from £30,000 to £10,000, the minimum mean MET increase required for cost-effectiveness increases from 1.5 to 5 for interventions costing £10 per person, and from 15.5

to 48 for interventions costing £100 per person. The effects of changing opportunity costs are much greater at higher intervention costs are higher and is shown by the greater spread of the lines.

Figure 3.6: MET gain and cost scenario analysis (cost-effectiveness threshold at £30,000)

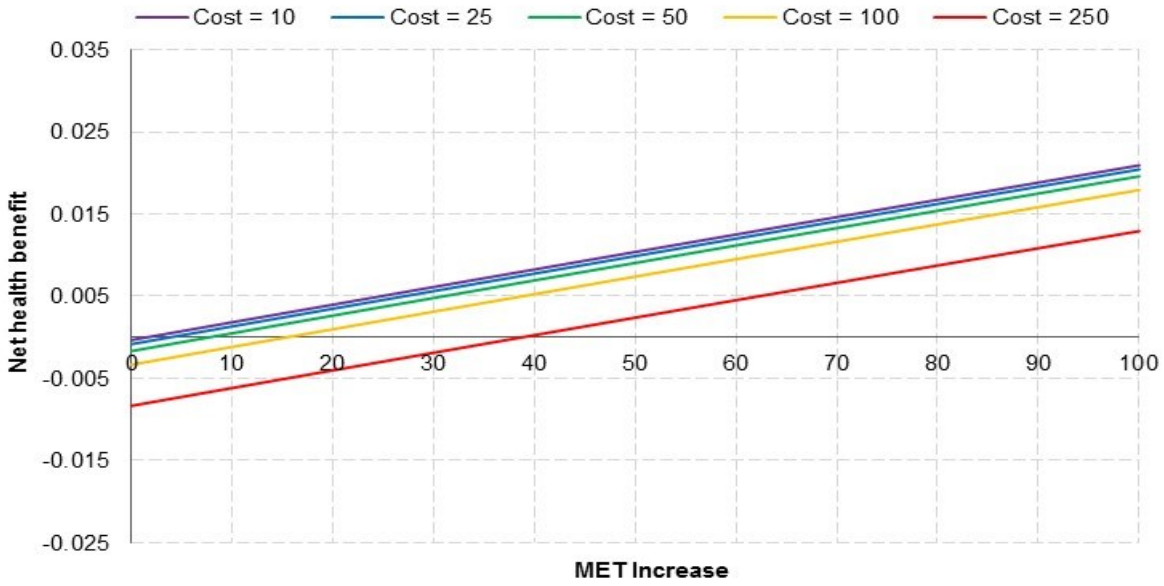


Figure 3.7: MET gain and cost scenario analysis (cost-effectiveness threshold at £10,000)

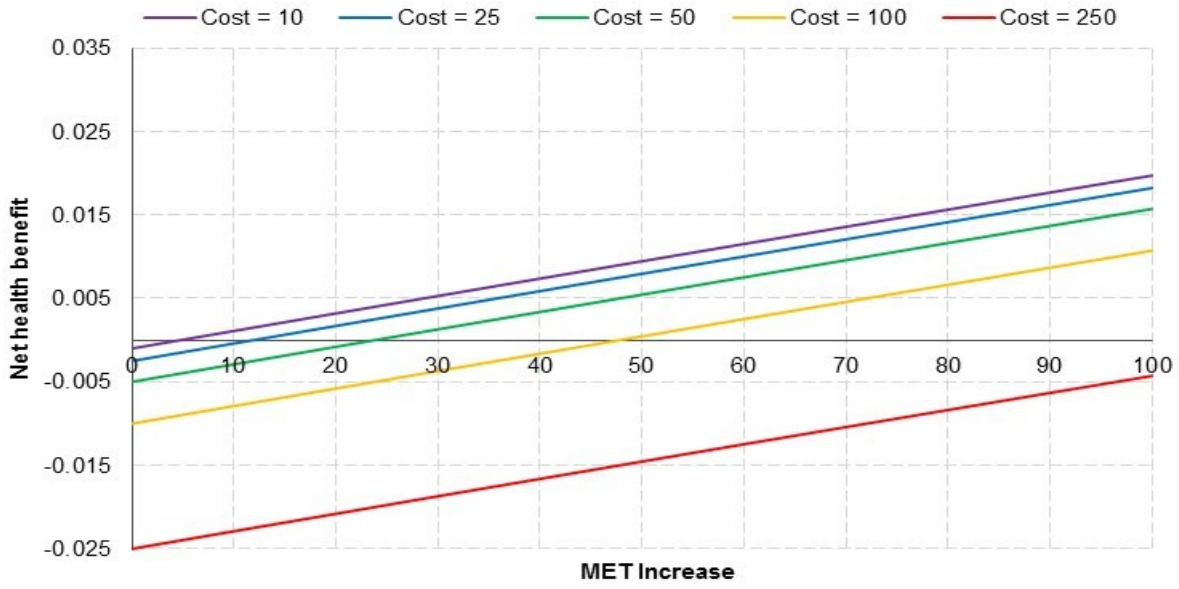


Table 3.1: Summary of MET minutes per week required for an intervention to be cost-effective by scenario and intervention cost

	Intervention cost				
Scenario	**£10**	**£25**	**£50**	**£100**	**£250**
Base case	2.5	6	11.5	23	59
Limited mobility population	1.5	4	8	16	41
50% decay of activity gain	5	11	23	47	119
1% maintenance costs	3	7	13	27	69
5% maintenance costs	4	11	22	45	112
CET = £30,000	1.5	4	8	15.5	38.5
CET = £10,000	5	12	24	48	>100

Notes:

1. CET = cost-effectiveness threshold; MET = metabolic equivalent time
2. The base case refers to a scenario for the general population in which CET=£20,000, no treatment effect decay is implemented and there activity gains are uniform across the population (τ=0)

3.2 CASE STUDY RESULTS

The cost-effectiveness summaries and cost threshold analyses are provided in Tables 3.2 to 3.6 and Figures 3.8 to 3.14, respectively. The multicomponent interventions are the most cost-effective: Cycling Demonstration Towns, Smarter Choices, Smarter Places and Active Living by Design yield ICERs of £2,496, £4,423 and £1,397, respectively. The Connswater Community Greenway is also cost-effective at an ICER of £7,652. With a US-based intervention cost estimate of over £200 per person, park renovations are not cost-effective, with an ICER of £215,989.

The cost thresholds, meanwhile, indicate the maximum intervention cost that an intervention can be for it to be cost-effective. Cycling demonstration towns and the Fitter for Walking scheme are nearly identical in this respect, with cost thresholds of approximately £100. Owing to much greater health benefits (0.025 QALYs versus 0.003 and 0.004 QALYs), the Smarter Choices, Smarter Places scheme remains cost-effective at intervention costs of up to around £440 per person. The Connswater Community Greenway, meanwhile, is cost-effective up to a price of £200 per person. The Active Living by Design programme had higher cost thresholds £830 per person. The highest threshold observed is for the new greenway, which was cost-effective up to a cost of £950 per person. At the other end of the scale are park renovations, which are cost-effective only up to an intervention cost of £20 per person.

Table 3.2: Cost-effectiveness results for Cycling Demonstration Towns

	Intervention	Comparator	Incremental
Intervention costs	£11	£0	£10.96
Breast cancer	£731	£730	£0.30
Colon cancer	£175	£175	£0.05
Diabetes	£4,258	£4,259	-£0.24
Stroke	£4,303	£4,301	£1.29
CHD	£2,415	£2,414	£0.50
Total costs	£11,892	£11,879	£12.85

Healthy QALY	16.17	16.17	0.0053
Comorbidity QALY loss	0.87	0.87	0.0001
Net QALYs	15.30	15.29	0.0051

ICER	**£2,496**

Net health benefit	**0.005**

Figure 3.8: Cost-effectiveness of Cycling Demonstration Towns by intervention cost

Table 3.3: Cost-effectiveness results for Smarter Choices, Smarter Places

	Intervention	Comparator	Incremental
Intervention costs	£91	£0	£90.95
Breast cancer	£732	£730	£1.33
Colon cancer	£175	£175	£0.20
Diabetes	£4,258	£4,259	-£1.02
Stroke	£4,307	£4,301	£5.70
CHD	£2,417	£2,414	£2.20
Total costs	£11,979	£11,879	£99.37
Healthy QALY	16.19	16.17	0.0230
Comorbidity QALY loss	0.88	0.87	0.0006
Net QALYs	15.32	15.29	0.0225
ICER			**£4,423**
Net health benefit		**0.017**	

Figure 3.9: Cost-effectiveness of Smarter Choices, Smarter Places by intervention cost

Figure 3.10: Cost-effectiveness of Fitter for Walking by intervention cost

Table 3.4: Cost-effectiveness results for park renovations

	Intervention	Comparator	Incremental
Intervention costs	£212	£0	£211.98
Breast cancer	£731	£730	£0.06
Colon cancer	£175	£175	£0.01
Diabetes	£4,259	£4,259	-£0.05
Stroke	£4,302	£4,301	£0.24
CHD	£2,415	£2,414	£0.10
Total costs	£12,092	£11,879	£212.34

Healthy QALY	16.17	16.17	0.0010
Comorbidity QALY loss	0.87	0.87	0.0000
Net QALYs	15.29	15.29	0.0010

ICER	**£215,989**

Net health benefit	**-0.010**

Figure 3.11: Cost-effectiveness of park renovations by intervention cost

Table 3.5: Cost-effectiveness results for Connswater Community Greenway

	Intervention	Comparator	Incremental
Intervention costs	£72	£0	£71.87
Breast cancer	£731	£730	£0.58
Colon cancer	£175	£175	£0.09
Diabetes	£4,258	£4,259	-£0.46
Stroke	£4,304	£4,301	£2.48
CHD	£2,415	£2,414	£0.96
Total costs	£11,955	£11,879	£75.52

Healthy QALY	16.18	16.17	0.0101
Comorbidity QALY loss	0.87	0.87	0.0002
Net QALYs	15.30	15.29	0.0099

ICER	**£7,652**

Net health benefit	**0.006**

Figure 3.12: Cost-effectiveness of Connswater Community Greenway by intervention cost

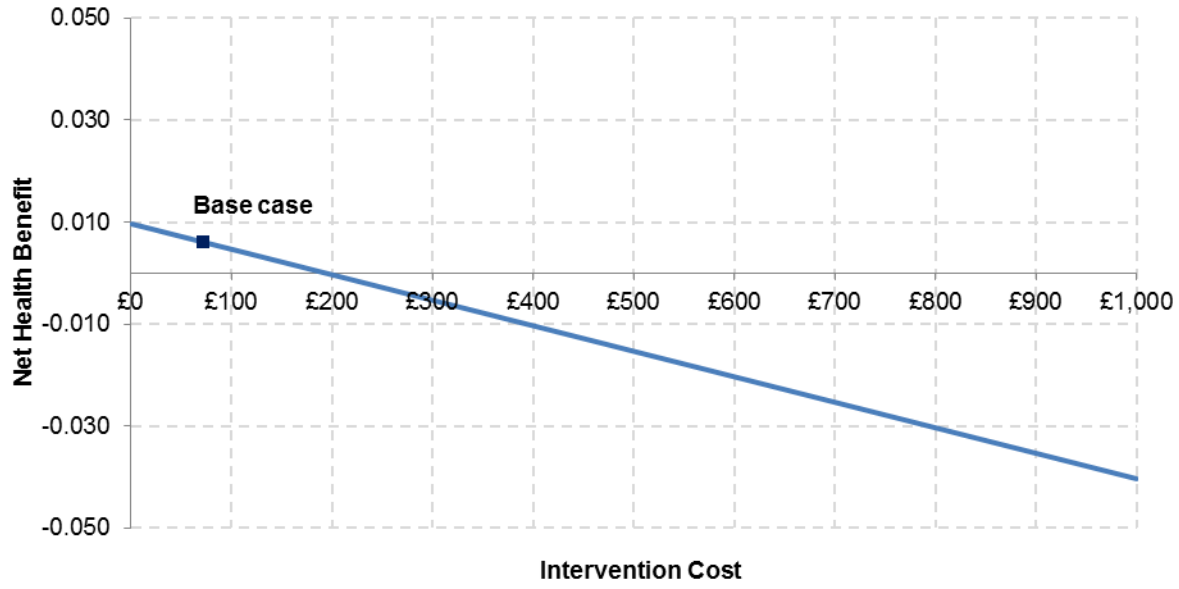


Figure 3.13: Cost-effectiveness of unspecified new greenway by intervention cost

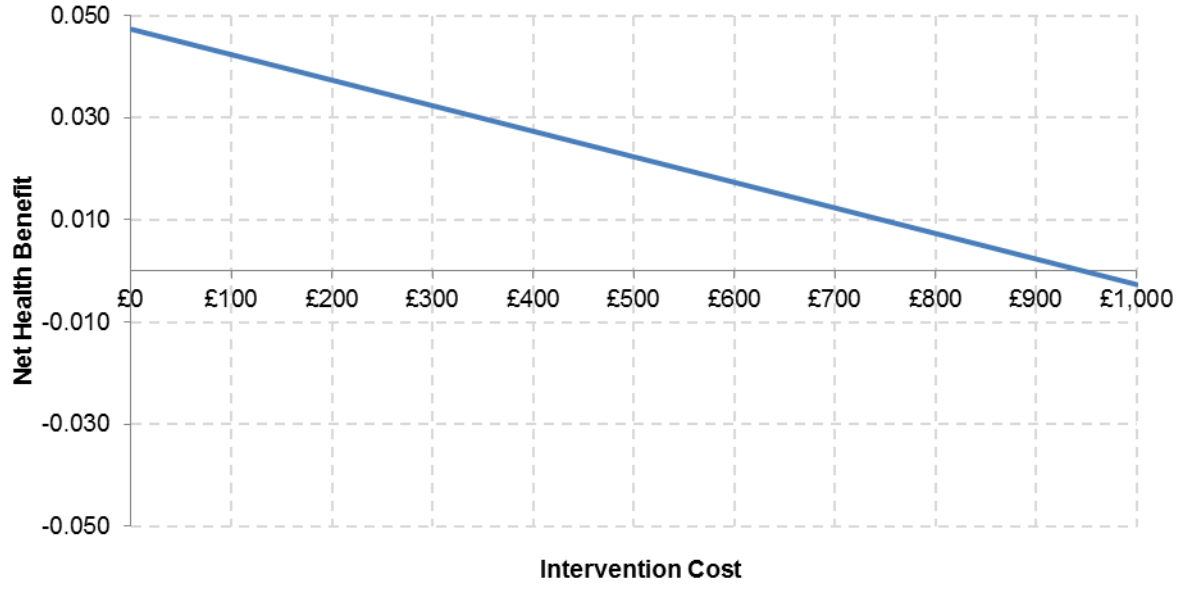


Table 3.6: Cost-effectiveness results for Active Living by Design

	Intervention	Comparator	Incremental
Intervention costs	£43	£0	£42.99
Breast cancer	£733	£730	£2.52
Colon cancer	£175	£175	£0.38
Diabetes	£4,257	£4,259	-£1.85
Stroke	£4,312	£4,301	£10.91
CHD	£2,419	£2,414	£4.20
Total costs	£11,939	£11,879	£59.16
Healthy QALY	16.21	16.17	0.0434
Comorbidity QALY loss	0.88	0.87	0.0011
Net QALYs	15.34	15.29	0.0424
ICER			**£1,397**
Net health benefit		**0.039**	

Figure 3.14: Cost-effectiveness of Active Living by Design by intervention cost

3.3 SENSITIVITY ANALYSIS

To ascertain the robustness of the results, we performed univariate sensitivity analysis of 32 separate parameters contained in the model. The base case assumed a τ value of 0 and that there was no decay of effect. This involves each selected parameter being varied in isolation to assess its impact on the model's results. We summarise these results in a series of tornado diagrams that plot many univariate sensitivity analyses simultaneously, and allows the key drivers of the model to be identified as the impact of each parameter can be directly compared with all the others. For each parameter, a high and low value replace the base case value and the difference in NHB is shown.

The amount by which the parameter was varied for the high and low values depended upon the data we had. For parameters where uncertainty was quantified by a standard error or confidence interval (effect of MET on risk and HRQOL), we used the upper and low 95% confidence band values. Thus, parameters which we are more certain of are varied to a lesser degree, reducing its relative impact on NHB. For parameters where this information was not available, the base case values were adjusted by a factor of 20%.

Two tornado diagrams for the general population are shown in Figure 3.15 and Figure 3.16. These represent pessimistic and optimistic scenarios, respectively. The pessimistic scenario uses an intervention costing £100 per person and generating a mean increase of 10 MET minutes per week. The optimistic scenario intervention costs £25 per person and increases MET minutes per week by 50. The analyses are run over a lifetime time with zero decay and cost-effectiveness threshold of £20,000 per QALY.

The tornado diagrams show that a highly influential parameter is the effect of MET minutes per week on mortality risk for females over 65. The same parameter for males and the mean increase in MET minutes per week are also key drivers of NHB. Intervention cost, meanwhile, was influential in the pessimistic scenario only. In these comparisons, none of the parameters have enough of an impact to change the direction of results within the range varied. Co-morbidity costs and disutilities had virtually no impact on the result. However, the relationship between comorbidity risk and physical activity did have a small influence on NHB. Of the comorbidities, stroke was the most important.

Figure 3.17 and Figure 3.18 show the tornado diagrams when the pessimistic and optimistic scenarios, respectively, are run for the limited mobility population. In both cases, the comorbidity costs and disutilities are again largely inconsequential. When MET gain is low and intervention cost is high (Figure 3.17), the effect of MET on mortality for females over 65 is still the most influential parameter. However, intervention cost and the effect of MET on utility score take on a greater role in determining the net health benefit compared to when analyzing the general population. In the optimistic scenario (Figure 3.18), the influence of intervention cost is again far less. A direct comparison with the general population in Figure 3.16 again demonstrates how for the limited mobility population, the impact of MET minutes per week on utility score is a greater driver of the results.

Figure 3.15: Tornado diagram (10 MET minutes per week increase, £100 per person intervention cost, general population) – pessimistic scenario

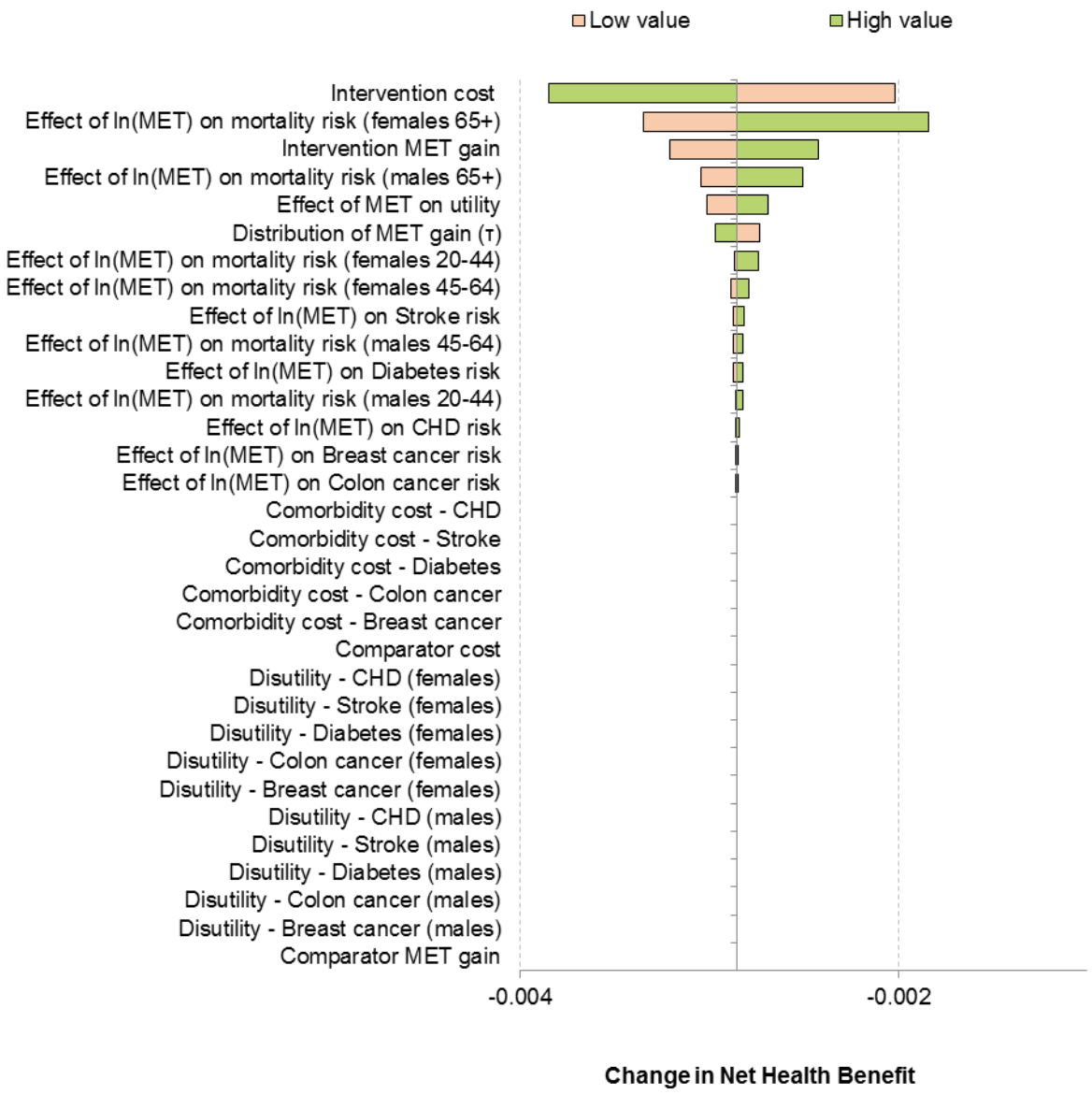


Figure 3.16: Tornado diagram (50 MET minutes per week increase, £25 per person intervention cost, general population) – optimistic scenario

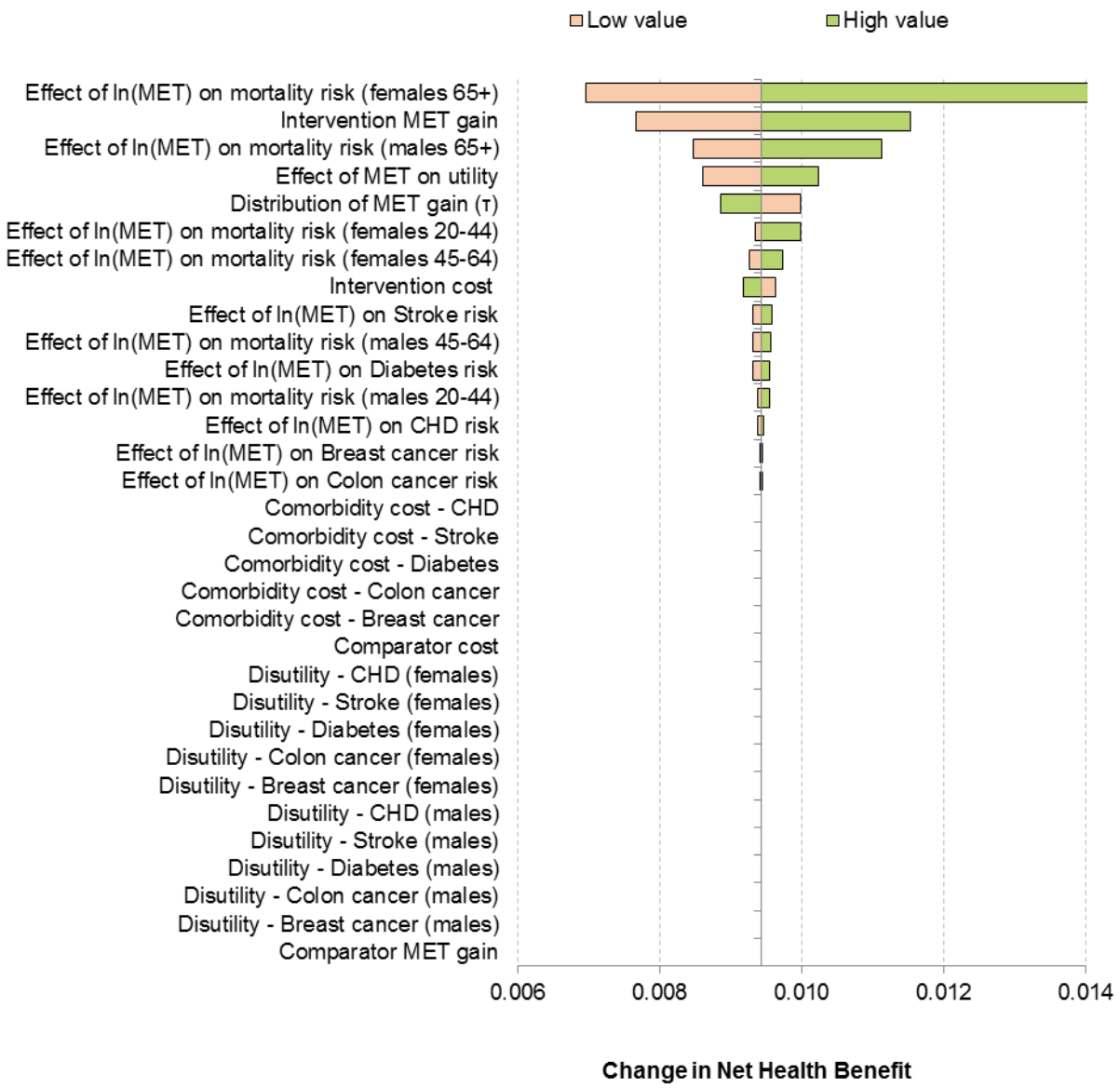


Figure 3.17: Tornado diagram (10 MET minutes per week increase, £100 per person intervention cost, limited mobility population) – pessimistic scenario

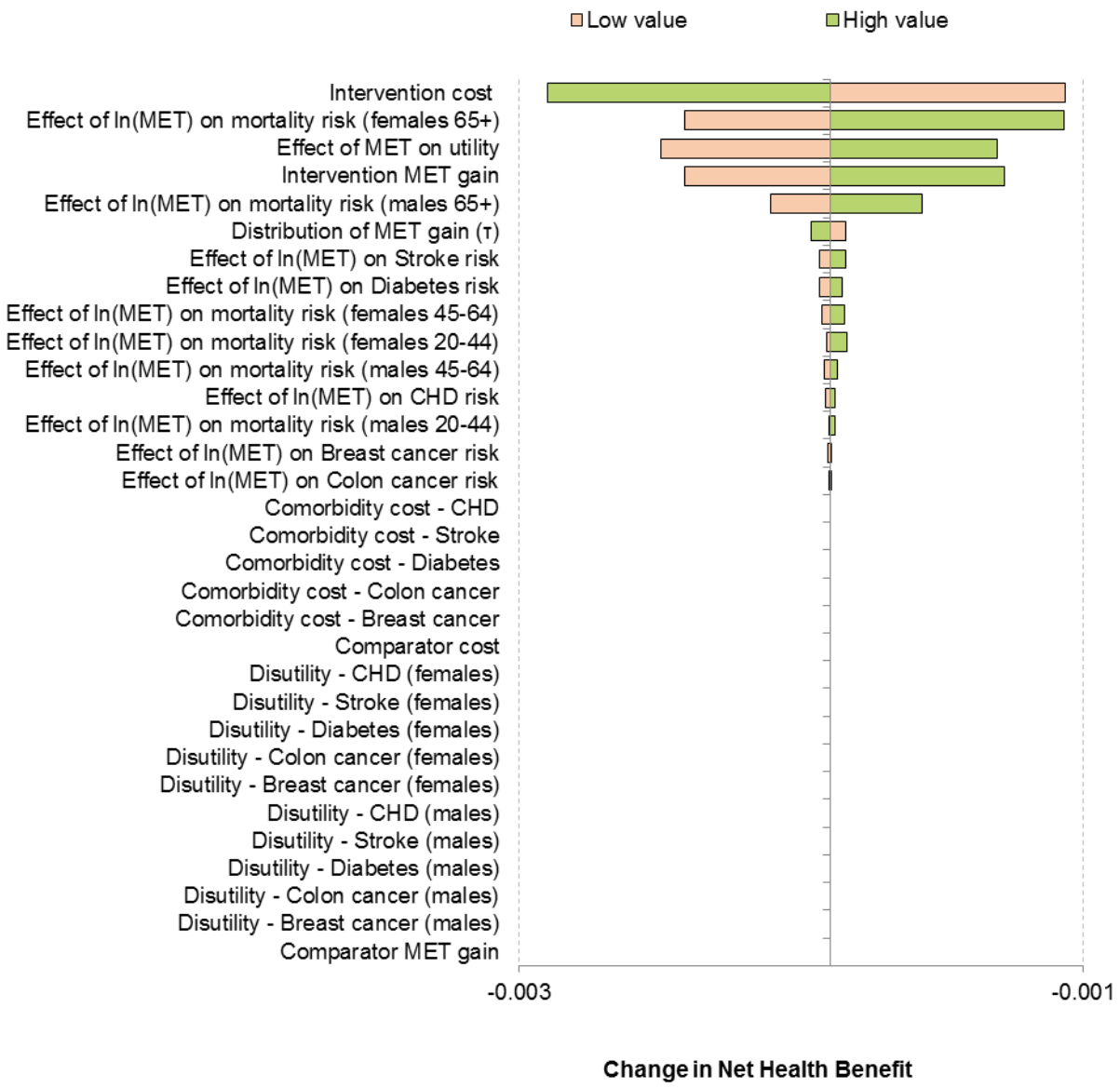
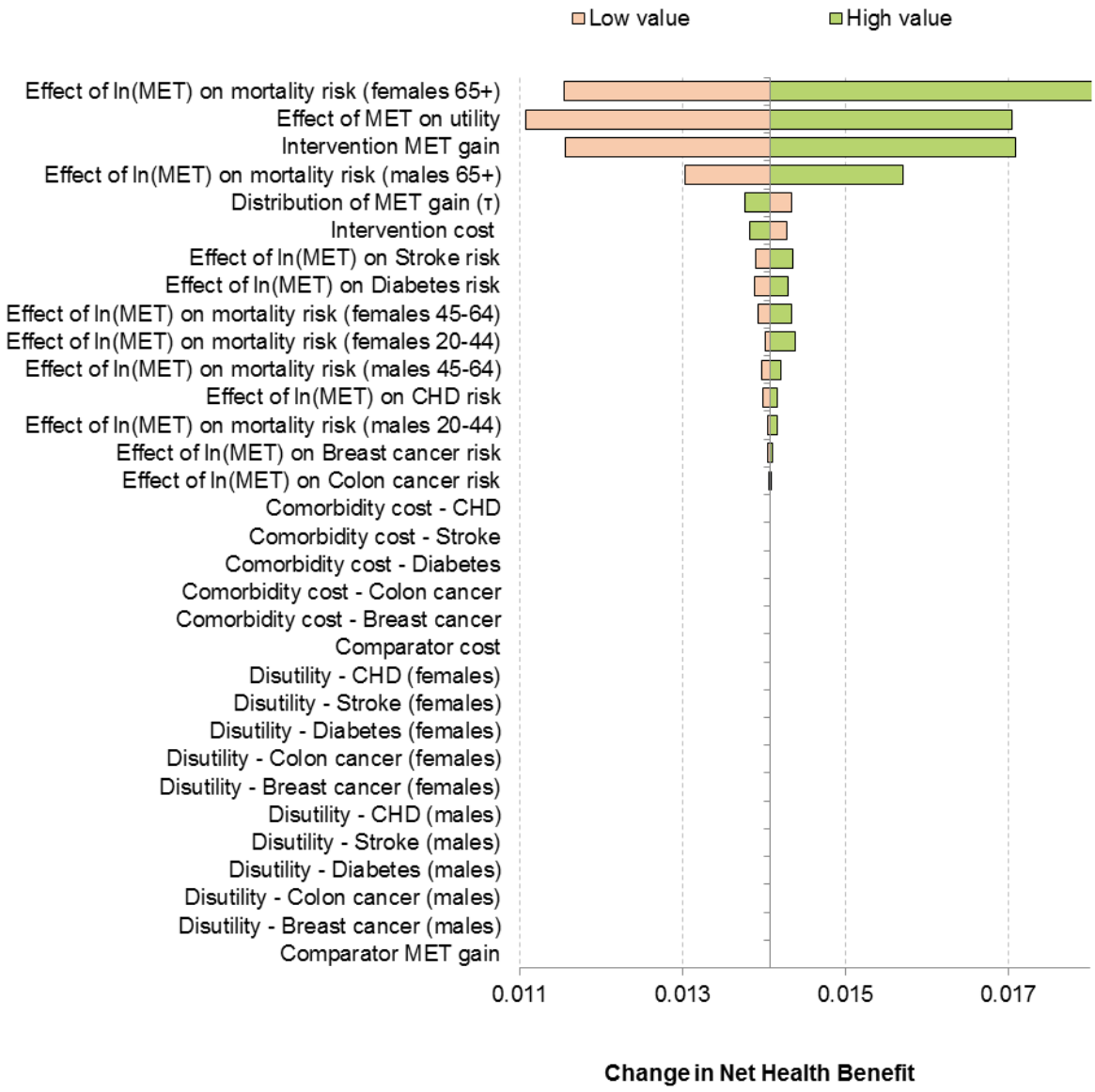


Figure 3.18: Tornado diagram (50 MET minutes per week increase, £25 per person intervention cost, limited mobility population) – optimistic scenario



Section 4: Discussion

This economic evaluation can be used to demonstrate the likely cost-effectiveness of an environmental intervention designed to improve physical activity, given its effectiveness at improving physical activity and the per person cost. Scenario analyses show, for a given range of intervention costs, what improvements in physical activity are required for an intervention to be cost-effective. For interventions costing £25 per person, the increase in MET minutes per week required for cost-effectiveness is 5.5, i.e. the equivalent of 2.5% of the population cycling an additional 30 minutes per week. On the other hand, an intervention costing £250 per person would require mean MET minutes per week to increase by 39 in order to be cost-effective. This is equivalent to 26% of the population cycling an extra 30 minutes per week. However, these are dependent upon two central assumptions underpinning the base case analysis: (i) activity gains are maintained through the life course and (ii) interventions do not impose any annual maintenance costs. Assuming an instantaneous 50% decay on activity gains was associated with 98% increase in the minimum MET minutes per week required for cost-effectiveness. The increase was 84% when we assumed that annual maintenance costs were 5% of the initial intervention cost.

The scope of environmental interventions that are covered by the guidance is broad, and the cost-effectiveness of any intervention may depend on how and to whom they are delivered. For example, cycling lanes may generate long-term increases in physical activity if it is placed in an area with little existing infrastructure, but only short-term increases if it is a novel addition to multiple existing routes. Similarly, constructing a park may affect the less or more active individuals depending on how active the neighbouring populace is. Our results indicate that the distribution of physical activity gains is not a strong determinant of cost-effectiveness. However, the ability of the intervention to sustain activity in the long-term is much more so, particularly when the intervention cost is higher. Another factor not considered in this analysis is the cost of maintaining improvements to the built and natural environment, such as resurfacing paths or pruning trees and bushes. Whilst these are likely to have small per person costs when spread over a population, their inclusion will reduce the cost-effectiveness of an intervention.

Our analysis also showed how smaller MET gains are required for interventions to be cost-effective for limited mobility populations. Driving these results are the lower baseline physical activity levels of this population, which mean that any increases in physical activity create greater relative comorbidity and mortality risk reductions and larger health gains. However, caution should be taken when interpreting the cost-effectiveness results for this subpopulation, since the benefits of the environmental interventions that this guidance concerns will not tend to be solely concentrated amongst those with limited mobility. The costs and benefits will, in reality, be shared with general population; their inclusion will change the cost-effectiveness.

The case study results show that three of the main intervention themes (changes to transport infrastructure, public transport frequency and access and open space access and street

design) can be highly cost-effective ways of increasing physical activity and improving health. The scheme for increasing public transport frequency and access, Smarter Choices, Smarter Places, performed particularly well and would be cost-effective up to an intervention cost of around £440 per person (£22,000,000 for a population of 50,000 people). The least cost-effective intervention was found for park renovation, which was cost-effective up to an intervention cost of £25 per person. Such an estimate however, depends largely upon the facilities available in the park.

It is important to note that, in our case studies, the per person net health benefits that we report relate strictly to the populations defined in the intervention. For the three larger, multicomponent interventions (Cycling Demonstration Towns, Smarter Choices, Smarter Places and Active Living By Design), our results are representative of larger populations more akin to those considered by decision-makers. However, much more caution should be taken when interpreting the results of park renovation, new greenway and the Connswater Community Greenway project. This is because the study populations are limited to within a short distance of where the intervention takes place. Although expanding the population size (to reflect the whole local authority, for instance) will also reduce the average cost of these interventions, we would also expect average activity gain to fall, as those further away from the intervention are less likely to benefit. Therefore, the impact of this limitation will depend on how much of the population relevant to the decision-maker is included in the study population.

Sensitivity analyses investigated the robustness of the results to changes in specific parameter values. Of the 32 we analysed, the effect of physical activity on the mortality risk of women over 65 was a consistently influential parameter on NHB, regardless of the intervention characteristics or the target population. This is likely a combination of two factors: first, the absolute effect of activity for this subgroup on relative risk was much larger than for any other, and covered the age group in which risk was at its highest. The second factor is the uncertainty around this and the other parameters extracted from the Anderson *et al.* study. The 95% confidence interval for the parameter of interest had a range of 0.064, compared to a range of 0.01 for the effect of activity on stroke risk, which was extracted, conversely, from a large meta-analysis. Also noteworthy was the greater influence of the effect of activity on HRQOL for limited mobility populations. This is likely explained by the lower baseline physical activity levels of this group, which mean that increases in activity generate relatively more health benefits.

A number of simplifying assumptions were required to undertake the analysis; the following section will explore their potential impacts on our results.

A critical assumption that underpins all of our results is the reliability of the physical activity distributions observed in the 2014 Health Survey for England as being representative of the general and limited mobility populations. Given that survey weights could not be used to adjust the observations in this stage of the analysis, selection bias could be factor if, for example, the less active are less likely to participate in the survey. This could have the potential impact of the average activity levels being overestimated and NHB underestimated.

The temporal effects of physical activity are also simplified in the model. Risk reductions occur instantaneously for both mortality and comorbidities, whereas in reality these benefits will likely be transferred incrementally. This would cause NHB to be overestimated since the health benefits of extra activity are overestimated. Similarly, when activity improvements are expected to decay, affected individuals will do so immediately and entirely. This would have the opposite effect of underestimating NHB since the small risk reductions in the decaying period are removed. However, we would expect that both of these effects to be small given the small absolute changes to the relative risks that even large improvements in MET minutes per week endows.

The use of a continuous treatment effect (increase in MET minutes per week) placed greater restrictions on evidence that could be integrated into the model, since multiple data points (i.e. activity level thresholds) were required in order to fit continuous relative risk functions. This meant that, of the large number of comorbidities that are associated with physical activity, only five were explicitly modelled in the analysis. This was potentially offset by estimating HRQOL as a function of physical activity level, since some of the impact of activity on comorbidities (and thereby HRQOL) was incorporated into the utility scores without being explicitly modelled. Any impact not captured, however, would mean that the net health benefits presented in this analysis are underestimated.

The estimation of the physical activity gains and costs associated with the case study interventions also presents a further limitation. Two of the studies examined calculated activity gains by the observation or surveying of service users. This would invariably lead to higher estimates of activity as it precludes people not regularly using the service, who it may be assumed are less active.

Lastly, there are a number of intervention effects that are not captured in the model. An example of health benefits not incorporated in the model is the reduction in comorbidities associated with the reduction in vehicle use, which in turn will reduce air pollution. Similarly, physical activity gains may involve switching from driving to cycling, which will have a net effect on an individual's mortality risk: these effects are not accounted by the model either. We also do not include the potential benefits of preventing disease in individuals who are productive members of society. Whilst this may be of interest to decision-makers, a consistent analysis would have to take into account how removing funding from other health-improving programmes to finance a new intervention will reduce productivity. Currently, no such analyses have been conducted.

Given the importance of physical activity in improving health and the importance of the natural and built environment in influencing activity levels, the analysis presented here provides valuable information on the relationship between the cost-effectiveness of potential interventions and their characteristics, namely their cost and the physical activity improvements they generate.

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