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The economic benefits of a more physically active population

An international analysis

Marco Hafner, Erez Yerushalmi, William Phillips, Jack Pollard, Advait Deshpande, Michael Whitmore, Francois Millard, Shaun Subel, Christian van Stolk

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Published by the RAND Corporation, Santa Monica, Calif., and Cambridge, UK

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Preface

This report examines the potential economic benefits of physical activity. Specifically, it looks at the potential gains in economic output and healthcare expenditure savings under different physical activity improvement scenarios at the population level.

This study contributes to the existing literature in three ways. First, we synthesise and evaluate, in a systematic manner, the existing empirical evidence on the association between physical activity and mortality risk, using a meta-analytical approach to adjust for study heterogeneity and potential publication bias in the literature. Second, using large-scale, international workplace survey data, we quantify the associations between physical activity and workplace performance, with a specific focus on levels of sickness absence and levels of presenteeism. Finally, we examine the macroeconomic effects of reduced premature mortality and reductions in sickness absence and presenteeism associated with making the population of a country more physically active. The report will be of interest to policymakers in the fields of public health and at the same time to a much broader spectrum of readers, including private sector agents, in particular in the health and life insurance domains.

The Vitality Group, part of Discovery Ltd, commissioned RAND Europe to carry out this research project. RAND Europe had full editorial control and independence of the analyses performed and presented in this report. This work informs the public good and should not be taken as a commercial endorsement.

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RAND Europe
Westbrook Centre, Milton Road
Cambridge CB4 1YG
United Kingdom
Tel. +44 1223 353 329

Executive summary

According to the World Health Organization (WHO), insufficient physical activity is recognised as one of the leading risk factors for death, posing a global public health problem associated with up to 5 million premature deaths every year (Lee et al. 2012; WHO 2018). The health benefits of physical activity are relatively well established, with research showing that it is associated with lower risk of hypertension, cardiovascular disease, breast and colon cancer, as well as diabetes. Furthermore, physical activity has been associated with positive effects on mental health, possibly reducing the risk of the onset of dementia and having positive effects on anxiety and depression (PAGAC 2008, 2018). Despite the health benefits of physical activity, insufficient physical activity has become increasingly prevalent over the last decades. Globally, it is estimated that about 30 per cent of the population is physically inactive, but the prevalence rate varies across countries. For instance, the share of the population who are physically inactive is estimated to be more than twice as high in high-income countries than in low-income countries. Furthermore, in high-income countries, the prevalence of insufficient physical activity is growing over time (Guthold et al. 2018). The factors associated with increasing levels of physical inactivity have been identified as being partly due to insufficient participation in physical activity during leisure time and partly due to an increase in sedentary behaviour during domestic and occupational activities. In addition, an increase in passive modes of transport may be associated with lower physical activity at the population level (WHO 2018). With public health responses to address the problem often being inadequate and governments and public bodies having to address increasingly competing priorities with finite financial resources, economic analysis can help to quantify the scale of the issue and increase public and private engagement in the topic and motivate actions.

Most existing economic analyses on the economic burden of insufficient physical activity are based at the national level; only a few studies take a more global perspective (Ding et al. 2016, 2017). Existing studies use a range of methodologies, but most apply the cost-of-illness (COI) approach. However, these studies vary in terms of what costs are included (e.g. direct and indirect) and in terms of what health conditions associated with physical inactivity are considered, making a comparison of the burden across countries more challenging. For instance, some COI studies estimate the direct costs associated with physical inactivity in terms of national healthcare or medical expenditures for specific diseases, whereas other studies also try to take into account indirect costs associated with lost productivity, including, for instance, the loss in lifetime income for individuals dying prematurely because of a disease associated with physical inactivity (Ding et al. 2017).

Objectives and research approach of this study

The aim of this study is to examine the potential global macroeconomic implications of getting people to be more physically active across different countries by using a comprehensive modelling framework that overcomes some of the limitations of the traditionally applied methodologies in existing economic studies assessing the cost of physical inactivity. Our analytical approach represents a so-called lost-economic output approach because we apply a dynamic, multi-country, computable general equilibrium (CGE) macroeconomic model. Such a macroeconomic model simultaneously solves multiple equations that relate to production from firms' and households' demand, both within a country and between countries, through trade linkages. This type of modelling approach has gained ground in health economics in applications to HIV/AIDS, malaria, anti-microbial resistance, pandemic influenza and non-communicable diseases (see e.g. Rutten & Reed 2009; Smith et al. 2005; Taylor et al. 2014), among others. Our analysis examines how improvements in physical activity at the population level affect the effective labour supply in the economy through a reduction in premature mortality and improvements in productivity, which subsequently are reflected in and measured by changes in a country's or region's gross domestic product (GDP). We focus on GDP as the measure of total output of an economy because it represents a proxy for the health of an economy and because it is often the metric of interest for a variety of policy- and decision makers.

In essence, in order to achieve the study objectives, the study aims to answer the following research questions:

1. What are the potential global economic benefits associated with getting people to be more physically active and how do the economic effects vary by country?
    a) What is the contribution of premature mortality associated with insufficient physical activity?
    b) What is the contribution of insufficient physical activity associated with workplace productivity?
2. What level of healthcare expenditure could be saved?
3. What can public policy and private stakeholders do in order to improve physical activity levels at the population level?

This study contributes to the existing literature in three ways. First, we synthesise and evaluate, in a systematic manner, the existing empirical evidence on the association between physical activity and relative mortality risk, using a meta-analytical approach to adjust for study heterogeneity and potential publication bias in the literature. Second, using large-scale, international workplace survey data, we quantify the associations between physical activity and workplace performance, with a specific focus on levels of sickness absence and levels of presenteeism. Finally, putting some of these quantitative empirical estimates with regards to mortality and productivity together and applying them in the macroeconomic modelling framework, we assess how different physical activity improvement scenarios may affect the economy of different countries over a 30-year time horizon, up to the year 2050. Specifically, in our analytical approach, getting people to be more physically active affects the supply of effective labour through three mortality- and productivity-related mechanisms:

1. **Reduced mortality risk:** Insufficient physical activity is associated with a relative higher mortality risk and hence a reduction in the overall size of the labour force, or, in other words, the total number of individuals who provide their labour on the labour market. For instance, the meta-analysis conducted as part of this study suggests that the relative all-cause mortality risk is between 11 and 28 per cent lower for physically active individuals compared to inactive individuals.
2. **Reduced sickness absence (absenteeism):** Adequate levels of physical activity are associated with better physical and mental health. Prolonged periods of ill health and absence from work lead to reductions in the efficiency of labour. That is, the unit of labour (e.g. an individual in the labour force) is less efficient than it otherwise would have been. For instance, the empirical analysis presented in this report suggests that an individual who is not physically active reports, on average, a larger amount of working time lost due to absenteeism (between 0.44 and 0.86 days per year) compared to an individual who is physically active.
3. **Reduced presenteeism:** Similar to a reduction in sickness absence, a reduction in presenteeism makes each unit of labour more effective, by improving the performance at work. For instance, the empirical analysis presented in this report suggests that an individual who is not physically active reports, on average, a larger amount of working time lost due to presenteeism (between 2.6 and 3.71 days per year) compared to an individual who is physically active.

In line with existing literature, in this study we focus on absenteeism and presenteeism as measures of productivity. However, other studies have found a link between physical activity and productivity using other proxy variables for productivity. For instance, some empirical studies have found that participating regularly in sport and physical exercise might also be linked to higher earnings. Using longitudinal data from the Canadian National Population Health Survey, Lechner and Sari (2014) estimated the effects of participation in sports and exercise on individual labour market outcomes and found a 10 per cent increase in earnings for working-age adults, which is the equivalent earnings return of one to two years of schooling.

In the economic analysis, under three different physical activity scenarios, we consider the effects on a country's labour force by reducing levels of premature mortality as well as lowering levels of sickness absence and presenteeism and examine how the economy of a country would evolve over time compared to a baseline scenario with no physical activity improvements of the adult population. The scenarios applied in the analysis focus on the following three physical activity improvement situations:

1

Scenario 1: This improves the adult population physical activity level so that everyone reaches at least the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week (or the equivalent of about 600 MET-minutes per week). This scenario set only improves the activity levels of the inactive and the low active.

Scenario 2: This improves the adult population physical activity level of everyone by 20 percent, shifting everyone across the physical activity distribution to be more active. This scenario only improves the activity levels of those currently active and does not improve the activity levels of those performing no physical activity at all.

Scenario 3: This improves the adult population physical activity levels so that everyone below the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week (or the equivalent of about 600 MET-minutes per week) reaches this threshold and everyone above this threshold improves their physical activity level by 20 per cent. Scenario 3 is essentially a combination of scenarios 1 and 2. It represents a scenario whereby those individuals with a sedentary or low physically active lifestyle become active and those who are already active improve their activity levels as well.

For each scenario set, we assume that the improvements have been made at the outset, and we then follow the corresponding effects of these changes over time.

Key findings

Our analysis suggests that getting adults to be physically more active is associated with economic benefits.

The GDP effects of getting people to be more physically active

Table S.1 reports the estimated global GDP gains for the three scenarios relative to a baseline scenario with no improvement in physical activity levels by year. For each scenario we apply two sets of input parameters for the assumed lost days due to absenteeism or presenteeism associated with physical inactivity, a lower ('Low') estimate and a higher ('High') estimate, the latter possible taking into account also some indirect effects of physical inactivity on other health factors that are associated with sickness absence or presenteeism (e.g. chronic health conditions, obesity).

As reported in Table S.1, under scenario 1 – where it is assumed that all individuals currently not reaching the recommended levels of physical activity per week will reach them – by 2025, global GDP would be between 0.15 and 0.22 per cent higher compared to the baseline scenario with current physical activity levels. This corresponds to about US$138 billion to US$203 billion (Panel B of Table S.1) in 2025. To put these figures into perspective, we note that the annual GDP of New Zealand in 2018 was about US$205 billion. The gains in GDP under scenario 1 are estimated to increase over time and to reach between 0.17 and 0.24 per cent by 2050, or the equivalent of US$314 billion to US$446 billion.

It is important to stress that these figures represent annual gains, rather than one-off benefits. As the benefits of getting people to be more active – in terms of lower mortality, sickness absence and presenteeism rates – continue to accrue over time as the population changes, the annual GDP gains will not be the same year-on-year and will increase over time.

The estimated GDP gains for scenario 2, where it is assumed that all individuals improve their current physical activity levels by 20 per cent, are lower than for scenario 1. It is estimated that,

Table S.1: Estimated global GDP gain relative to baseline scenario with current physical activity levels, per year

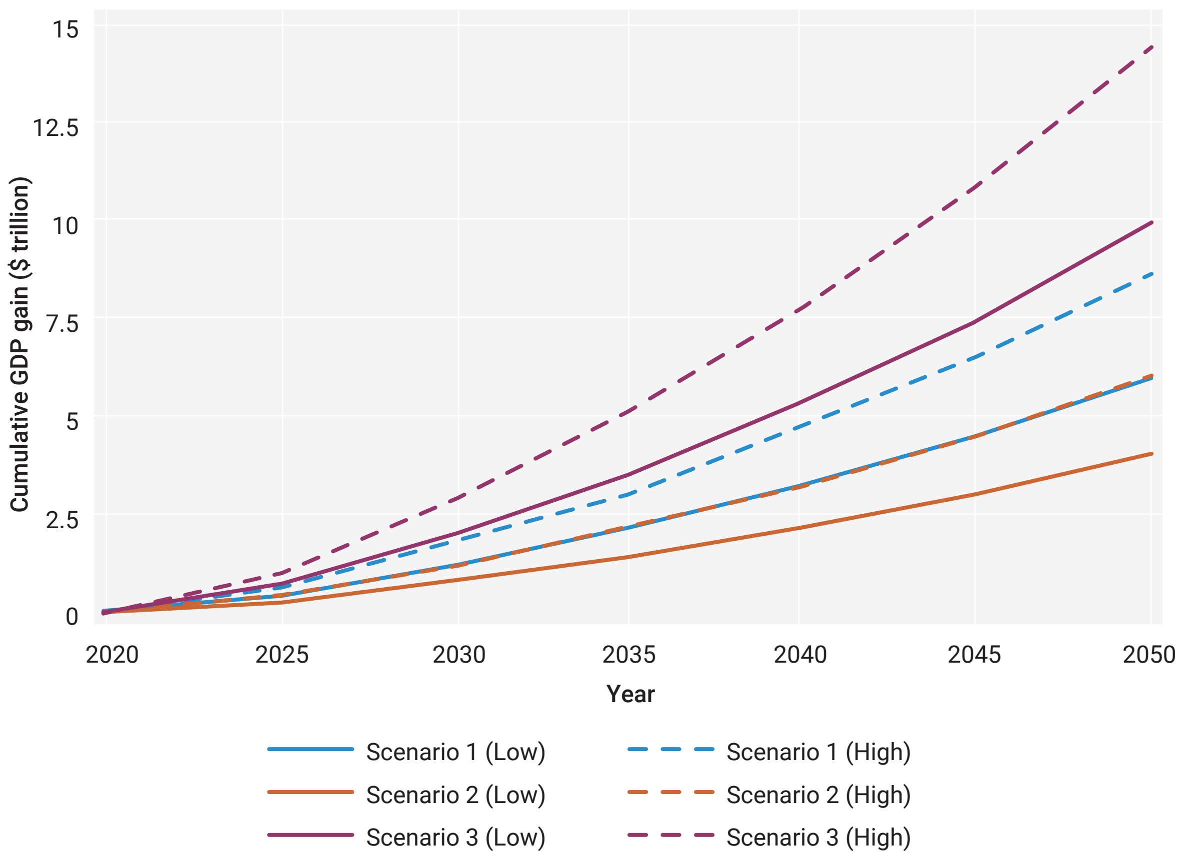
Panel A: Global GDP gain (per cent), per year						
	2025	2030	2035	2040	2045	2050
Scenario 1 (Low)	0.15%	0.15%	0.16%	0.16%	0.16%	0.17%
Scenario 1 (High)	0.22%	0.22%	0.23%	0.23%	0.23%	0.24%
Scenario 2 (Low)	0.10%	0.10%	0.11%	0.11%	0.11%	0.12%
Scenario 2 (High)	0.15%	0.15%	0.16%	0.16%	0.17%	0.17%
Scenario 3 (Low)	0.25%	0.25%	0.26%	0.27%	0.27%	0.28%
Scenario 3 (High)	0.36%	0.37%	0.38%	0.39%	0.40%	0.40%
Panel B: Global GDP gain (US$ billion present value 2019), per year						
	2025	2030	2035	2040	2045	2050
Scenario 1 (Low)	137.5	167.1	198.1	231.9	270.3	313.5
Scenario 1 (High)	203.3	243.1	285.6	332.4	385.7	446.3
Scenario 2 (Low)	93.4	111.5	132.5	156.7	185.0	218.3
Scenario 2 (High)	139.2	166.1	197.3	233.3	275.3	325.0
Scenario 3 (Low)	228.0	274.8	325.9	382.9	448.3	523.7
Scenario 3 (High)	338.3	404.1	476.6	558.1	652.1	760.8

Notes: Table entries represent per cent and absolute changes in global GDP for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for two variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

by 2025, under scenario 2, global GDP would be between 0.1 and 0.15 per cent higher compared to the baseline scenario with current physical activity levels, depending on whether we apply the sickness absence or presenteeism parameters that take into account only direct effects ('Low') or also potential indirect effects ('High') of physical activity. This corresponds to about US$93 billion to US$139 billion. This increases to between 0.12 and 0.17 per cent by 2050, or the equivalent of US$218 billion to US$325 billion.

Across the three scenarios, the GDP gains of making people more physically active are largest for scenario 3, where it is assumed that physically inactive individuals reach at least the recommended threshold of about 600 MET-minutes of activity per week and everyone above this threshold improves their current level of activity by 20 per cent. We estimate that, by 2025, global GDP could be between 0.25 per cent and 0.36 per cent higher compared to the baseline scenario with current physical activity levels. This corresponds to between US$228 billion and US$338 billion by 2025. This is about the same as Denmark's GDP in 2018 (US$325 billion). Similarly to the other two scenarios, the estimated relative GDP gain increases over time. By 2050, global

Figure S.1: Estimated cumulative global GDP gain over 30 years relative to baseline scenario with current physical activity levels (US$ trillion present value 2019)



Notes: Figure entries represent cumulative changes in global GDP over 30 years for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

GDP would be between 0.27 and 0.4 per cent higher compared to the baseline scenario with no physical activity improvement, corresponding to between US$523 billion and US$760 billion. Breaking down the estimated GDP gains by mechanism – (a) reduced mortality; (b) reduced sickness absence; (c) reduced presenteeism – we find that reduced mortality and reduced sickness absence are responsible for about 30 percent of the overall gains, whereas reduced presenteeism is responsible for about 70 percent.

Furthermore, given that the benefits of making people more active increase over time in relative terms, it is possible to calculate the cumulative GDP gain (see Figure S.1). Unlike the annual GDP gains presented above, these represent the total economic benefits over the duration of a given scenario.

Table S.2: Estimated global cumulative GDP gain over 30 years relative to baseline scenario with current physical activity levels

Panel A: Cumulative global GDP gain (US$ trillion present value 2019), by year						
	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Scenario 1 (Low)	0.4	1.2	2.1	3.2	4.5	6.0
Scenario 1 (High)	0.6	1.7	3.1	4.7	6.5	8.6
Scenario 2 (Low)	0.3	0.8	1.4	2.2	3.0	4.0
Scenario 2 (High)	0.4	1.2	2.1	3.2	4.5	6.0
Scenario 3 (Low)	0.7	2.0	3.5	5.3	7.4	9.9
Scenario 3 (High)	1.0	2.9	5.1	7.8	10.8	14.4
Panel B: Cumulative global GDP gain (US$ present value 2019) per adult person, by year						
	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Scenario 1 (Low)	70.4	185.6	305.1	430.1	561.8	704.9
Scenario 1 (High)	104.2	272.7	445.3	624.8	812.4	1,015.7
Scenario 2 (Low)	47.9	125.2	205.0	289.2	379.1	478.7
Scenario 2 (High)	71.3	186.5	305.3	430.6	564.4	712.6
Scenario 3 (Low)	116.8	306.8	503.2	709.3	927.5	1,166.5
Scenario 3 (High)	173.3	453.6	741.2	1,041.5	1,358.5	1,705.2

Notes: Table entries in Panel A represent cumulative changes in global GDP over 30 years for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High'). Entries in Panel B represent the cumulative GDP gain per adult person by year, where the cumulative GDP gain is divided by the adult population in a given year.

As reported in Table S.2, The cumulative global GDP gain for scenario 1 by 2025 is estimated to be between US$0.4 trillion and US$0.6 trillion, which corresponds to between US$70 and US$104 per person. The cumulative global GDP gain rises to between US$6 trillion and US$8 trillion by 2050, corresponding to between US$704 and US$1016 per person.

The cumulative global GDP gain by 2025 for scenario 2 is estimated to be between US$0.3 trillion and US$0.4 trillion, or between about US$48 and US$71 per person. The cumulative global GDP gain increases to between US$4 trillion and US$6 trillion by 2050. For scenario 3, the cumulative global GDP gain compared to the baseline scenario is estimated to be between US$0.7 trillion and US$1 trillion, corresponding to between US$117 and US$173 per person. For scenario 3, the cumulative GDP gain increases to between US$9.9 trillion and US$14.4 trillion by 2050. That is almost the equivalent of China's current GDP.

Beyond the estimated global economic gains of getting people to be more physically active under three different scenarios, we also break down the estimated GDP gains by country or region.[1] Overall, across the three scenarios, the United States and the United Kingdom are among the countries with some of the largest absolute and relative gains in GDP terms of getting people to be physically more active.

The potential direct healthcare expenditure savings associated with getting people to be more physically active

The second analysis presented in the report represents an estimation of the potential direct healthcare expenditure savings associated with the three different scenarios of physical activity improvements outlined above. Following a similar methodology as applied by Ding et al. (2016), we focus on the healthcare cost associated with physical inactivity for five disease areas, namely, coronary heart disease, stroke, type 2 diabetes, breast cancer and colon cancer. We present the healthcare expenditure benefits associated with a more physically active population separately from the effects on overall economic output because changes in healthcare expenditure could have very country-specific macroeconomic effects, depending on the prevalent health system in each country (e.g. public or private). As the macroeconomic model used for the analysis does not include a specific health system for each of the countries included, the changes in healthcare expenditure are reported separately. Following Ding et al. (2016), we estimate the healthcare costs attributable to physical inactivity using a population-attributable fraction approach (PAF) in relation to the five disease areas. The PAFs for each disease can be interpreted as the proportion of disease (or mortality) that would not exist in the absence of physical inactivity. The five disease areas have been selected due to the relatively well-established and strong evidence on the relative risk associated with these areas from physical inactivity based on the scientific literature.

Overall, we estimate that under scenario 1 about US$8.7 billion in global healthcare expenditure could be saved by getting people to be more physically active. Due to global population changes, these potential savings increase to US$16 billion by 2050, compared to the baseline scenario of no physical activity improvements. Under scenario 2, we estimate the potential healthcare expenditure savings to be about US$5.2 billion and US$8.3 billion by 2050. Under scenario 3, we estimate the potential healthcare expenditure savings to be US$11.2 billion, which increase to US$20.6 billion by 2050.

With regards to the estimates presented on the potential savings in direct healthcare cost expenditures, it has to be highlighted that the estimates are based on improving the adult population only. However, there may also be direct expenditures associated with physical inactivity for children or adolescents. Furthermore, in line with limitations set out by Ding et al. (2016), it has to be highlighted that the estimates reported are based on only five diseases for which the existing literature suggests moderate to strong evidence for the association with physical activity, but that there are possibly more relevant diseases. Hence, these estimates likely represent an underestimation of the potential direct healthcare cost savings associated with different physical activity improvement scenarios.

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1 See section 4.2.3 of the report for the country-specific findings.

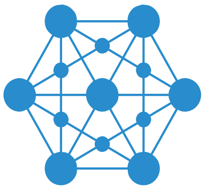
What works in getting people to be more physically active?

There are significant barriers to an individual changing their physical activity. These barriers include a set of personal behaviours and attitudes, the predisposition of the individual to be physically active and the environment in which the individual lives and works. Some researchers point to specific personal barriers, such as limited time, lack of resources, not being predisposed to exercise and the absence of companionship in undertaking exercise (Reichert et al. 2007). Creating enduring change in physical activity is hard. Nonetheless, decision makers at different levels (e.g. individual, workplace, government) have a wide array of evidence-based interventions and programmes to consider. We see these, broadly, as sitting in four (not mutually exclusive) areas:

Change behaviour and attitudes. Decision makers could consider approaches that may encourage individuals to shift their behaviour or that may change the attitudes of individuals. Interventions could consist of individual or community messaging, incentives (either gain-framed or loss-framed) to change behaviour, and encouraging a psychological state whereby individuals build efficacy and take more responsibility for their health behaviour. Humans are social animals, and therefore approaches that have a community, social or family dimension tend to be more effective. These approaches make individuals feel part of a group or community that reinforces positive behaviours. A range of goal-oriented approaches and approaches that include some feedback or monitoring have some effect on physical activity as well. Technology can be an enabler in the way that these approaches are delivered in different settings.

Provide an environment that encourages physical activity. We see from the studies included here that context matters a great deal. There are a number of examples where individuals have poor access to facilities. Studies focus on community and workplace design and whether local areas and workplaces are set up to encourage physical activity and indeed have the infrastructure required. Certain communities may promote the use of cars over walking and cycling, for instance. Infrastructure may also be intimidating to individuals, and studies speak about 'safe' access to infrastructure. Finally, certain environments, such as schools and community centres, are obvious places to provide facilities or physical activity interventions. We find that a range of community-based and school-based strategies can be effective.

Promote participation in physical activity programmes and interventions. Decision makers also need to encourage participation in programmes and interventions. Access to programmes and interventions is one part of the equation. This may affect certain groups more, such as the poor, ethnic minorities and those on low incomes. Certain workplaces may offer certain benefits that encourage physical activity (e.g. gym membership) only to more senior employees or those on higher incomes. Next to access, awareness can be a significant barrier. Awareness of interventions and programmes in different contexts can be low, and, as a result, the participation in such programmes could be limited. One problem is that interventions can be seen as a tick-box exercise by decision makers and that little thought is given to how to create awareness of and drive participation in interventions. In some cases, only the most motivated will participate, typically those who do more in terms of physical activity already. In terms of promoting participation, some of the approaches aimed at behaviour and attitude change could be helpful and effective as well.



Build mutually reinforcing approaches to encourage more physical activity across society. Interventions and programmes can often be quite fragmented and even isolated. Therefore, different interventions may need to sit alongside each other to produce a greater effect. This can be true of a health and well-being programme in the workplace that uses multiple interventions or that leverages a sectoral or national campaign on physical activity to make changes in its offer. Similarly, a community-based approach may require a set of mutually reinforcing interventions that target different barriers to individuals – and perhaps population groups – taking up physical activity. Clusters of interventions may be used to try to change an environment or prevailing culture. Systems may need to be built at different levels, including regulatory approaches, information campaigns, community-based approaches, sectoral approaches, workplace interventions and individually targeted interventions.

There are also some general and perhaps obvious lessons for decision makers. There can be misalignment between the intervention design and the needs of the group that the intervention is targeting. Specific groups or populations may have specific barriers to taking up physical activity. Programme or intervention design may have to be adjusted for specific groups. Specific populations may have preferences around how the intervention or programme is delivered, for instance, face to face or technology based. The substance of the intervention may also matter. For instance, walking-based interventions seem more effective in some settings than running-based interventions. Adherence is also an issue. Compliance with physical activity programmes and interventions even when individuals decide to participate in the first place can be problematic in certain populations. This finding speaks to carefully considering the needs and preferences of a specific population in programme design and thinking through how involvement can be sustained over time. The risk is always that decision makers will focus on low-hanging fruit. Clearly, expense is involved in putting interventions and programmes together.

Our report shows the economic benefits associated with individuals becoming more physically active across a range of countries. It also highlights that there is a growing evidence base on what interventions decision makers can consider in different settings. The challenge remains to create a culture of health that promotes healthy lifestyles across communities, sectors and populations in societies. Our evidence shows that if creating such a culture can be achieved, we can create healthier and more prosperous societies.

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Abbreviations and acronyms

BMI	body mass index
BHW	Britain's Healthiest Workplace
CGE	computational general equilibrium
COI	cost of illness
FAT	Funnel Asymmetry Test
FUSP	first uninterrupted sleep period
GPAQ	Global Physical Activity Questionnaire
GTAP	Global Trade Analysis Project
ILO	International Labour Organisation
IPAQ	International Physical Activity Questionnaire
MRA	meta-regression-analysis
OECD	Organisation for Economic Co-operation and Development
OLS	ordinary least squares
PAF	population-attributable fraction
PAGAC	Physical Activity Guidelines Advisory Committee
PEESE	precision-effect estimate with standard error
PET	Precision Effect Test
RR	relative risk
SAM	social accounting matrix
SWB	subjective well-being

UWES	Utrecht Work Engagement Scale
WHO	World Health Organization
WLS	weighted least-squares
WPAI	work productivity and activity impairment

Acknowledgements

The authors would like to thank the quality-assurance reviewers, Charlene Rohr (RAND Europe) and Professor Alex Armand (NOVA University Lisbon). We would also like to thank Professor Nicholas Peters (Imperial College London) for comments on previous drafts of this report.

Furthermore we would like to thank Martin Stepanek and Tom Davis from Vitality UK for discussions on data inputs relevant to the study.

We would also like to thank Akis Gkoukis, Cloé Gendronneau, and Clement Fays (all RAND Europe) for invaluable help and assistance during the research process.

All views expressed in this report are the authors', and remaining errors are also our own.

1 Introduction

According to the World Health Organization (WHO), insufficient physical activity is recognised as one of the leading risk factors for death, posing a global public health problem (WHO 2018). The health benefits of physical activity are relatively well established, with research showing that it is associated with lower risk of hypertension, cardiovascular disease, breast and colon cancer, as well as diabetes. Furthermore, physical activity has been associated with positive effects on mental health, possibly reducing the risk of the onset of dementia and having positive effects on anxiety and depression (PAGAC 2008). Despite the health benefits, insufficient physical activity has become increasingly prevalent over the last decades. Globally, it is estimated that about 30 per cent of the population is physically inactive, but the prevalence rate varies across countries. For instance, the share of the population who are physically inactive is estimated to be more than twice as high in high-income countries than in low-income countries. Furthermore, in high-income countries the prevalence of insufficient physical activity is growing over time (Guthold et al. 2018). Factors associated with increasing levels of physical inactivity have been identified as being partly due to insufficient participation in physical activity during leisure time and partly due to an increase in sedentary behaviour during domestic and occupational activities. In addition, an increase in passive modes of transport may be associated with lower physical activity at population level (WHO 2018).

Globally, it is estimated that every year physical inactivity is associated with more than 5 million premature deaths (Lee et al. 2012) and contributes to global healthcare expenditures as well as lost productivity (Ding et al. 2017). While many countries have developed national action plans to tackle the growing prevalence of physical inactivity, gaps and challenges persist with their implementation, often associated with an uncoordinated or underfunded approach (Sallis et al. 2016). With public health responses to address the problem often being inadequate and governments and public bodies having to address increasingly competing priorities with finite financial resources, economic analysis can help to quantify the scale of the issue and increase public and private engagement in the topic and motivate actions. Put another way, estimating the potential cost of insufficient physical activity could provide information with regard to the burden and the potential current and future costs to societies of not taking action now.

Most existing economic analyses on the economic burden of insufficient physical activity are based at the national level; only a few studies take a more global perspective (Ding et al. 2016, 2017). Existing studies use a range of methodologies, but most apply the cost-of-illness (COI) approach. However, these studies vary in terms of what costs are included (e.g. direct and indirect) and in terms of what health conditions associated with physical inactivity are considered, making a comparison of the burden across countries more challenging. For instance, some COI studies estimate the direct costs associated with physical inactivity in terms of national healthcare or medical expenditures for specific diseases, whereas other studies also try to take into account indirect costs associated with lost productivity, including, for instance, the loss in life-time income for individuals dying prematurely because of a disease associated with physical inactivity (Ding et al. 2017). COI is a relatively straightforward, easy-to-understand methodological approach that summarises the direct and indirect cost associated with a specific disease or negative lifestyle behaviour (e.g. smoking). However, it has limitations. For instance, it often displays only the costs that occur within a given year, even though in reality, the effects of getting people to be more healthy (e.g. by reducing the prevalence of physical inactivity) can vary if we observe them over a longer time period. Furthermore, COI studies do not take into account second-order, or spill-over, effects of a healthier population that likely would play out in reality. For instance, healthier individuals may live longer, and they may be more productive than non-healthy individuals, earn more income and consume more. That is, the benefits of being healthier would apply to the individual themselves, but because they may consume more, save more and pay more taxes, they would subsequently create further external positive effects on other agents in the economy (e.g. firms, the government).

1.1. Objectives of this study

Against this background, the aim of this study is to examine the potential global macroeconomic implications of getting people to be more physically active across different countries by using a comprehensive modelling framework that overcomes some of the limitations of the traditionally applied methodologies in existing economic studies assessing the cost of physical inactivity. Our analytical approach represents a so-called lost-economic output approach because we apply a dynamic, multi-country, computable general equilibrium (CGE) macroeconomic model. Such a macroeconomic model simultaneously solves multiple equations that relate to production from firms' and households' demand, both within a country and between countries, through trade linkages. This type of modelling approach has gained ground in health economics in applications to HIV/AIDS, malaria, anti-microbial resistance, pandemic influenza and non-communicable diseases (see e.g. Rutten & Reed 2009; Smith et al. 2005; Taylor et al. 2014), among others. The analysis is focused on how improvements in physical activity at the population level affect the effective labour supply in the economy through a reduction in premature mortality and improvements in productivity, which subsequently are reflected in and measured by changes in a country's or region's gross domestic product (GDP). We focus on GDP as the measure of total output of an economy because it represents a proxy for the health of an economy and because it is often the metric of interest for a variety of policy- and decision makers. In essence, the specific contribution of this study towards the current debate can be summarised as follows:

First, insufficient physical activity has been associated with numerous negative health outcomes and hence an elevated mortality risk. In this study, we review the existing literature on the associations between insufficient physical activity and (all-cause) mortality risk and aim to synthesise and evaluate existing empirical evidence using a meta-analytical approach. The contribution of the meta-analysis is to derive relative mortality risk estimates related to insufficient physical activity, adjusted for different study characteristics. While meta-analyses on the topic already exist, our analysis pays particular attention to potential publication bias in the literature and aims to identify specific study variables that may explain the observed research outcomes, including, for instance, whether the geography of the study sample matters or whether the inclusion of certain lifestyle factors may affect the predicted mortality risk. In addition, we extend the scope of previous reviews by including the most recent publications in our analysis.

Second, in order to assess the economic effects of insufficient physical activity, it is important to quantify the potential productivity effects associated with physical activity improvements at the population level, specifically of the active labour force within a country. Some previous studies have empirically assessed the association between physical activity and workplace performance or productivity, focussing on such measures as sickness absence rates associated with physical inactivity. But due to lack of data or insufficient sample size, these studies were restricted to focusing on specific outcome variables only or were not in a position to sufficiently adjust for confounding factors that may simultaneously affect physical activity and productivity outcomes (e.g. being a parent of a young child or having a long commuting time to work). In order to assess the association between physical activity and different metrics of work performance, we use a large, international employer-employee dataset that includes a huge variety of relevant variables that may jointly determine physical activity and work performance. These variables also allow us to examine the association not only between physical activity and sickness absence, but also between physical activity and presenteeism. Presenteeism is when individuals are at work when they are in sub-optimal health and hence are less productive than they would otherwise be. Empirical evidence suggests that presenteeism is a much larger contributor to productive time lost at work than absenteeism (e.g. Burton et al. 2007).

Finally, putting some of these quantitative empirical estimates with regards to mortality and productivity together and applying them in the macroeconomic modelling framework, we assess how different physical activity improvement scenarios may affect the economy of different countries over a 30-year time horizon, up to the year 2050. Specifically, in our analytical approach, getting people to be more physically active affects the supply of effective labour through three mortality- and productivity-related mechanisms:

- **Reduced mortality risk:** Premature deaths due to insufficient physical activity permanently reduce not only the size of the labour force, but also the size of the wider population, which directly influences not only the current, but also the future population. In other words, the effects of insufficient physical activity accumulate over time. For instance, the death of a worker affects the year in which the death occurs, but also continues to be a part of the burden in subsequent years because it also includes the potential 'death' of all of the deceased's future offspring.
- **Reduced sickness absence:** Prolonged periods of ill health and absence of work lead to reductions in the efficiency of labour. That is, each unit of labour (e.g. an individual in the labour force) is less efficient, representing a direct effect on the effectiveness of the working-age population.
- **Reduced presenteeism:** Similar to a reduction in sickness absence, a reduction in presenteeism is making each unit of labour more effective, by improving the performance at work.

To the best of our knowledge, no other study so far has applied a similar dynamic multi-country macroeconomic model to assess the economic implications of improvements in physical activity at the population level.

1.2. Research approach of this study

In order to achieve the study objectives, the study aims to answer the following research questions:

1. What are the potential global economic benefits associated with getting people to be more physically active and how do the economic effects vary by country?
    a) What is the contribution of premature mortality associated with insufficient physical activity?
    b) What is the contribution of insufficient physical activity associated with workplace productivity?
2. What level of healthcare expenditure could be saved?
3. What can public policy and private stakeholders do in order to improve physical activity levels at the population level?

In order to address the research objectives and questions formulated above, our research incorporates three methodological strands:

1. **Literature review**: We review the available literature in order to collect available evidence about the associations between physical activity and health outcomes, work performance and productivity. It is important to highlight that the Physical Activity Guidelines Advisory Committee (PAGAC) published two comprehensive reports, in 2008 and 2018, for the US Department of Health and Human Services, summarising and assessing in much detail the existing evidence in the area of physical activity. Both reports cover a wide range of relevant topics in physical activity and hence form another important source of evidence for this report as well. For the meta-analysis on the association between physical activity and all-cause mortality, we also systematically review the existing literature. Appendix B provides more detail on the approach taken with regards to the meta-analysis.
2. **Statistical modelling**: We use multivariate regression techniques to examine the associations between physical activity and a range of outcomes, including mortality, workplace productivity in terms of absenteeism and presenteeism, as well as other outcomes of interest (e.g. mental health, sleep). The statistical analysis conducted in this study serves two purposes. First, it contributes to the existing academic literature by using a large-scale, international dataset to test existing research hypotheses. Second, it provides important parameter estimates that feed into the macroeconomic model to assess the economic benefits of a more physically active population. Appendix A provides more detail about the statistical analysis.
3. **Economic modelling:** We apply a comprehensive macroeconomic model that enables us to assess the potential economic benefits of improving physical activity levels across different countries, drawing on parameter estimates generated in the statistical analysis of this study, as well as data for model calibration purposes from other relevant databases. We outline the model in more detail in Appendix E.

1.3. Structure of this report

Chapter 2 provides background on physical activity and how it is measured, and on the current physical activity guidelines. Chapter 3 reviews the evidence on the benefits of physical activity in relation to health, well-being and workplace performance and productivity. Chapter 4 then estimates the potential economic benefits of getting people to be more physically active, specifically focusing on the effects on GDP and healthcare expenditure savings. Chapter 5 concludes by discussing the evidence on what works at the individual, company and government or public health level in improving physical activity levels.

2 Background on physical activity: Definitions, measurement, guidelines and the prevalence of physical inactivity

This background chapter provides context on the growing relevance of physical activity in public health strategies and guidelines in disease prevention over time. It further provides an overview on what domains of physical activity exist and how physical activity can be measured. Finally, this chapter discusses the current guidelines regarding recommended levels of physical activity for different age groups.

2.1. The growing relevance of physical activity in public health policy strategies and guidelines

The origins of the present-day research on physical activity and exercise can be traced back to the 1950s and 1960s, when the United States and Canada were considered to be facing a heart disease epidemic (see Dalen et al. 2014; Jones & Greene 2013 for a discussion on the coronary heart disease epidemic in the 1950s and 1960s in North America). Recognising the limitations of prevailing post-hoc cure/treatment strategies, policymakers and healthcare practitioners set out to examine the root causes and identify possible prevention strategies (Melhado 2006; Pearson 2011). This resulted in researchers from two distinct scientific areas – exercise science and epidemiologic science – collaborating to identify possible strategies to address the heart disease epidemic.[2]

These efforts to understand and contain the heart disease epidemic of 1950s and 1960s were first articulated in a 1974 report published by the Canadian Ministry of National Health and Welfare. Titled *A New Perspective on the Health of Canadians*, this report sought to demarcate clinical healthcare as distinct from disease prevention and, in particular, to demarcate promotion of a healthy 'lifestyle' as a specific policy outcome targeting public welfare (Lalonde 1974).[3] The report emphasised the importance of 'lifestyle' as the implicit and explicit choices made by individuals regarding a range of habits, from eating, sleeping, and working hours, to the extent of

2 Notable recent examples of research where these fields of studies collaborate include the 2008 study by the American College of Sports Medicine and the American Heart Association (Haskell et al. 2007) and the 2010 study by the British Association of Sport and Exercise Sciences (O'Donovan et al. 2010), both of which combine exercise science and epidemiological science.

3 Headed by the Honourable Marc Lalonde, who was then in charge of the ministry, this report is popularly referred to as the Lalonde report. At that time, it was a benchmark study in attempting to redefine the scope of what a health ministry would cover and how to broaden its focus from clinical health.

physical activity. The report was the first of its kind and has arguably continued to play a role in the debate on health and healthcare policy in Canada and a number of other developed nations (see Glouberman 2001; Health Canada/Santé Canada 1998; Low & Thériault 2008).

This emphasis on lifestyle as a key ingredient of health outcomes and thus as a critical factor in controlling the risk of disease was further strengthened by a US government report published in 1975, titled *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*. That report endorsed the key messages from the Lalonde report and called for further examination of 'lifestyle behaviours' in order to promote individual health and prevent diseases from taking hold (see U.S. Department of Health, Education, and Welfare 1979).[4]

In both of these reports, exercise science and epidemiology remained at the core of the healthcare strategy and policy solutions being suggested to improve public health and welfare. The role and importance of physical activity as part of improving public healthcare, pro-actively preventing disease and targeting a specific kind of mortality (health disease) has since then become a norm of healthcare policy in most economically developed nations (e.g. see Institute of Medicine Committee for the Study of the Future of Public Health 1988; Tulchinsky & Varavikova 2014).[5] Several developed nations, such as the United Kingdom (Department of Health and Social Care 2011), Germany (Rütten & Pfeifer 2016) and Australia (Australian Government Department of Health 2014), and several agencies, such as the World Health Organization (2010) and the Organisation for Economic Co-operation and Development (OECD) (Graf & Cecchini 2017), have reported similar findings on the influence of lifestyle behaviours in relation to disease prevention and mortality reduction strategies.

The research on physical activity and on understanding its role in disease prevention has also expanded from its origins in exercise science and epidemiology to include other fields of study, such as behavioural science (e.g. Lim & Wang 2009; Michie et al. 2011), clinical science (e.g. Clarkson & Thompson 2000; Fletcher et al. 2005), recreation science (e.g. Giles-Corti & Donovan 2002; Kaczynski & Henderson 2007; Sallis 2009), transportation science (e.g. Brownson et al. 2009; Sallis et al. 2004), urban planning and built environment (e.g. Durand et al. 2011; Giles-Corti et al. 2016; Sallis 2009; Sallis et al. 2016), political science (e.g. Atwood et al. 1997; Brownson et al. 2005; Fafard 2008), and other disciplines, such as systems thinking (see Kohl et al. 2012) and innovation economics (see Kickbusch 2009; Pate et al. 1995; Williams 1985).[6]

4 The US government continued to expand its research into and advocacy of physical activity as a means of improving health. More recently, the US government has released physical activity guidelines (in 2008 and 2018) advocating a strong emphasis on physical activity and exercise as a means of improving physical and mental health in conjunction with prevention of various cardiovascular and musculoskeletal diseases (US Department of Health and Human Services 2018).

5 See Powles (2015) for a more in-depth discussion on public health policy in developed countries, including the role of policy in relation to average levels of population health and economic and environmental factors contributing to the public health outcomes in relation to various diseases.

6 See also Haskell (2012) and Kohl 3rd et al. (2012) for further discussion on multidisciplinary research on physical activity.

2.2. How has physical activity been defined and measured in existing literature?

Physical activity is generally referred to as bodily movement produced by skeletal muscles that results in the individual expending energy (Caspersen et al. 1985).[7] Physical activity is thus a spectrum of activity that involves accumulation of movement throughout the day, not specifically associated with a location (e.g. a running site, a gymnasium), type (e.g. running, weight lifting, or swimming), or purpose (i.e. losing weight, gaining muscle, or running a 5K event) (Ainsworth et al. 1993; Centers for Disease Control, 1980).[8] Physical activity can be characterised in terms of the time or location of the activity in conjunction with the relative intensity of the activity, depending on the individual's physical fitness level. When considering the intensity of the activity, different terms have been applied, such as sedentary behaviours and light-, moderate- and vigorous-intensity activities.

The literature makes a distinction between exercise and other physical activities in terms of the planning, frequency, and outcome orientation of exercise. Drawing on Caspersen et al. (1985), exercise is treated as a planned, structured, repetitive physical activity which is intended to improve or maintain physical fitness, performance and health (see also Paffenbarger Jr et al. 1986; Wilmore et al. 1994). Exercise is thus a subset of the spectrum of activities covered by physical activity, and although it often covers moderate to vigorous intensities, it is distinguished by the 'intentionality' of the activity.[9] Since a number of activities (e.g. walking, cycling) can be done at different intensities, the distinction between physical activity and exercise is often likely to be subjective and there is likely to be significant overlap when specific physical activities are considered.[10] Throughout the rest of this section, where relevant, we refer to the intensity of the physical activity and the exercise to provide more context to the type of activity being discussed.

Light- and moderate-intensity physical activities can occur throughout the day, for a range of purposes (not specifically for physical fitness or performance) and in a variety of settings (Westerterp 2001). Physical activities in this range can result in physiological outcomes related to aerobic capacity, muscle and bone strengthening, and balance and flexibility training (Troiano et al. 2008; Westerterp 2001). Since this subset of physical activity can occur throughout the day, its health-enhancing value is incidental and not dependent on the purpose of the activity (e.g. walking to the nearest bus station to catch a bus, although not specifically aimed at exercise, provides health benefits). The 2018 PAGAC scientific report has argued that non-leisure forms of physical

7 Although Caspersen et al.'s (1985) definition is more than 30 years old, it is one of the most widely cited definitions and thus can be considered the definitive description of physical activity. Their description has also been adopted by the WHO. See https://www.who.int/dietphysicalactivity/pa/en/ (accessed 17 July 2019); Blair et al. (2001).

8 The emphasis (or rather lack of it) on purpose and on physical activity providing health benefits (even if incidental and not specifically targeted as an outcome) was notably outlined in a report by the (then-) US Department of Health and Human Services in 1980 titled *Promoting Health, Preventing Disease: Objectives for the Nation*. At the time of its initial release in 1980 and its iterations in 1990 and 2000, part of the critique of the report identified lack of data to measure the outcomes as a key challenge (Andersen & Mullner 1990). Even with the emergence of wearable devices which enable such measurement, some of these challenges arguably remain (see Hänsel et al. 2015; Tana et al. 2017).

9 Thus, all exercise can be considered a type of physical activity, but not all physical activity can be deemed exercise.

10 See Norton et al. (2010) for a discussion on the terminology surrounding physical activity and exercise.

activity, such as cycling to work, can be recognised as promoting physical activity and accruing resultant health benefits thereof.

The intensity of the physical activity is only one of the approaches to measuring physical activity, however. The time and location of the activity and the intensity of the physical activity defined in conjunction with the physical condition of the individuals involved represents another possible way to measure physical activity. When the time and location factors of the physical activity are considered, physical activity can be categorised into whether it takes place in relation to work (occupational), at home (household), as part of activities that are aimed at leisure (rather than pursuit of exercise or physical activity), or while attempting to move from one place to another (transportation) (Caspersen et al. 1985; see also Löllgen et al. 2009 for a more recent discussion).

Another relevant dimension is excessive sedentary behaviour, which is characterised as any behaviour while being awake with very low energy expenditure, such as sitting, lying or reclining (van der Ploeg & Hillsdon 2017). Individuals can be physically active (e.g. reaching recommended physical activity levels overall) but sedentary (e.g. sitting for the majority of their working time).

The intensity of the activity as aligned with the physical fitness of the individual involved also offers a broader approach to measuring physical activity.[11] Such an approach recognises different body types and physical fitness levels to understand the energy expended as part of the physical activity. Measured as either absolute or relative intensity of the activity, possible measures for the physical activity thus include metabolic equivalents (METs), levels of oxygen consumed, kilocalories used (burned), or energy expended in joules. Of these, MET appears to be one of the most used units in the literature on physical activity.

One metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml oxygen per kg body weight per minute (Jette et al. 1990).[12] METs can then be used to describe the energy spent by an individual through most physical activities relative to the amount of oxygen consumed will sitting at rest. For example, the METs taken up by different physical activities for an average adult are shown in Table 2.1. With MET as the unit of measurement, Ainsworth et al. (2011) and Butte et al. (2018) provide the average rates of energy expenditure for a number of day-to-day physical activities for the general adult population. These rates are useful to reference to understand the intensities of various types of physical activity and how these could contribute to physical well-being. However, METs typically represent measures of absolute intensity, since they provide statistical averages rather than individual indicators of actual energy expenditure, which will vary depending on individual circumstances. In contrast to the measures of absolute intensity, measures of relative intensity of physical activity offer a variable scale to understand the physical activities as aligned with the physical capability of the individual. The emphasis of the relative intensity measure is thus on the ‘relative’ ease or difficulty with which the individual can perform the physical activity. Such a measure is physiological and

11 See section 2.2 for a more detailed discussion on the link between physical activity and physical fitness.

12 The initial values of MET were based on experiments to measure resting metabolic rate (RMR) for a 40-year-old male participant weighing 70 kg. The accuracy of the MET value will vary for specific persons because it is dependent on such factors as the lean body mass, health, age, and physical fitness level of the individual. Available evidence suggests that, on average, 1 MET typically overestimates the energy expenditure and oxygen consumption by 20%–30%. See Byrne et al. (2005) and Savage et al. (2007).

can be described using aerobic capacity (VO_2max),[13] percent of maximal heartrate (Brage et al. 2007; Keytel et al. 2005), or the individual's assessment of how easy or difficult they found the task to perform (i.e. self-reported health data) (Ainsworth et al. 1993; Sallis and Saelens 2000; Siconolfi et al. 1985; Prince et al. 2008).

Table 2.1: METs associated with different physical activities

Intensity of physical activity	Physical activity	MET
Light intensity (MET < 3)	Sleeping	0.9
	Watching television	1.0
	Writing, desk work, typing	1.5
	Slow walking (< 1.7 miles per hour, or < 2.7 km per hour)	2.3
	Walking (~ 2.5 miles per hour, or ~ 4 km per hour)	2.9
Moderate intensity (3 to 6 MET)	Walking (~ 3 miles per hour, or ~ 4.8 km per hour)	3.3
	Home exercise/light calisthenics	3.5
	Walking (~ 3.4 miles per hour, or ~ 5.5 km per hour)	3.6
	Bicycling to work (<10 miles per hour, or <16 km per hour)	4.0
	Bicycling	5.5
	Sexual activity	5.8
Vigorous intensity (> 6 MET)14	Jogging (< 5 miles per hour, or < 8 km per hour)	7.0
	Heavy calisthenics (e.g. pushups, pull-ups, sit-ups) or running	8.0
	Jogging (~ 5.6 miles per hour)	8.8
	Rope jumping (66 jumps per minute)	9.8
	Rope jumping (70 jumps per minute)	10.0
	Rope jumping (84 jumps per minute)	11.0
	Jogging (~ 6.8 miles per hour)	11.2

Sources: Ainsworth et al. (1993, 2011); Frappier et al. 2013; Jette et al. (1990).

Since physical activity covers a wide spectrum of intensities and time and location factors, aligning health outcomes with a sufficient degree of precision is a challenge. Adding to this challenge is the fact that physical activity measures in population surveys are often based on an individual's self-reported perception of activities and their corresponding intensity levels. In order

13 VO_2max (V for volume, O_2 for Oxygen, and max for maximum) is the maximum rate of oxygen consumption measured during exercise of increasing intensity. It is measured either as an absolute rate, for example in litres of oxygen per minute (L/min) or as a relative rate, for example, in millilitres of oxygen per kilogram of body mass per minute (mL/(kg·min). See Dlugosz et al. (2013) and Hawkins et al. (2007).

14 We recognise that some of these activities may also qualify as physical exercise and need to be considered in conjunction with the physical fitness of the individual involved.

for individuals and health practitioners to more accurately make relevant decisions, the incidence and patterns of health-specific behaviour (including physical activity and exercise) need to be monitored with suitable methods and frequencies. The emergence of wearable devices provides a better way of measuring activity levels and associated potential health outcomes continuously compared to previous methods, which relied heavily on self-reporting (see Beard & Bloom 2015; Montgomery et al. 2018; Patel et al. 2015). The monitoring data that are collected may enable the extent of physical activity undertaken by individuals and specific demographics to be understood at a more granular level. Despite the increased acceptance of the role of device-measured data on physical activity, however, the reliability of such data remains open to question, and although such data play a useful role, measuring physical activity with sufficient accuracy remains an ongoing challenge (Hänsel et al. 2015; Tana et al. 2017).

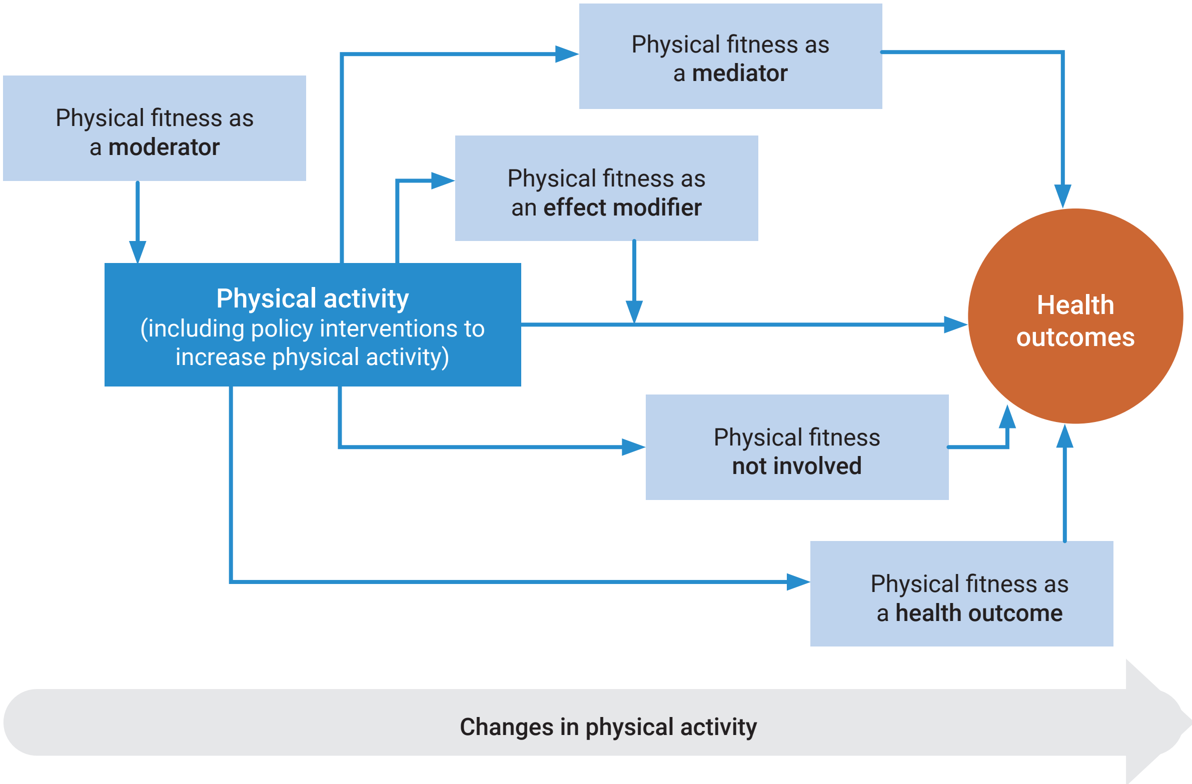
2.3. What are the associations among physical activity, exercise and physical fitness?

Having identified the possible role and importance of physical activity, we need to discuss its association with physical fitness. Physical fitness is defined as an individual's ability to perform muscle-powered work. Its manifestation in the individual being able to walk, run, climb stairs, or deal with heavy objects is crucial to determining the different health outcomes that are the result of exercise and physical activity (Caspersen et al. 1985; see also Blair et al. 2001). Physical fitness, in the form of cardiorespiratory fitness and musculoskeletal fitness, has been known to greatly contribute to lower rates of all-cause and cardiovascular mortality, in addition to reducing the likelihood of non-communicable diseases (Ross et al. 2016).[15] Differentiated at varying levels of energy and vigour, physical activity and exercise are arguably correlated and contribute to physical fitness and thus to health and well-being in a positive way (Jackson et al. 2009). Across the spectrum of different physical activities of varying intensity, increased physical activity is generally seen to result in increased physical fitness and better health outcomes (Garber et al. 2011; Warburton et al. 2006). In particular, Garber et al. (2011) argue that the results (i.e. increased physical activity leading to increased physical fitness) are more pronounced among those whose physical fitness is at the low end of the spectrum.

Figure 2.1 provides a framework to explain the correlation between physical fitness and physical activity. As illustrated in Figure 2.1, owing to the spectral nature of physical activity, the suggested pathways into specific health outcomes vary. However, the positive effect of physical activity and fitness on health outcomes appears to be consistently highlighted in the evidence since the 1980s (Blair et al. 1989; Malina 1996; Warburton et al. 2006).

15 Although most of the studies on physical activity and associated health outcomes have predominantly used male participants, there is growing evidence on the effects of higher physical activity and fitness on women, too. See, for example, Belza and Warms (2004); King et al. (1995); Segar et al. (2002); Speck and Looney (2001); Stadler et al. (2009).

Figure 2.1: The role of physical fitness and the pathways between physical activity and health outcomes



Source: Based on Physical Activity Guidelines Advisory Committee (2018).

2.4. Injuries and other risks associated with physical activity

Most of the available evidence suggests that although regular physical activity is highly beneficial, it is necessary to be physically active for the requisite duration, intensity and frequency depending on the individual's physical fitness (Blair et al. 1989; Malina 1996; Warburton et al. 2006). Incorrectly done, physical activity may prove harmful and result in such outcomes as muscular injuries and cardiac events (Hootman et al. 2001; Thacker et al. 2004). The risk of injury also depends on whether the physical activity is part of group sports-related activities, such as football, basketball or baseball, which involve various degrees of contact, in contrast to solo physical activities, such as running or swimming (Bahr & Holme 2003; Knowles et al. 2006). The risk of injury further depends on how the individual is able to cope with increases or changes in physical activity across the spectrum of various activities and whether their current physical condition can adapt to the changes or increases in activity (Knapik 2015; Pons-Villanueva et al. 2009). Available evidence suggests that with increased physical activity and increased physical fitness, the individual's ability to cope with increased intensity, duration and frequency of physical activity also increases (Knapik et al. 2003; Warburton et al. 2006). That ability depends, however, on the specific nature of the activity being done (PACAG 2018). For example, a habitual runner, who will have increased cardiovascular capacity and stronger legs, may not be well equipped for weightlifting, since the muscles required for these activities are entirely different.

2.5. Physical activity guidelines and the prevalence of physical inactivity

The physical activity guidelines from different public policy stakeholders vary. For instance, the PAGAC (2008) scientific report suggests that public physical activity guidelines expressed using MET-minutes may not be useful for the general public as the concept of METs may be difficult to understand and become familiar with. The report concludes that as long as people roughly follow the guidelines of achieving at least 500 to 1,000 MET-minutes per week, it might be simpler to express guidelines in terms of minutes of moderate-intensity and vigorous-intensity activity. The information laid out in the PAGAC (2008) report aims to express the physical activity guidelines in terms of minutes of activity, suggesting at least 150 minutes of moderate-intensity activity as meeting the recommended minimum level of activity, which is the equivalent of 75 minutes per week of vigorous-intensity activity.[16]

The WHO has similar recommendations with regards to physical activity. Its global recommendations were developed in order to promote physical activity as a way of preventing non-communicable diseases at the population level (WHO 2010, 2019).[17] Generally, the WHO considers a variety of different physical activity domains as relevant, namely:

- **Leisure-time**: This refers to different types of recreational activities, including sports, exercise and hobby, for example, swimming, walking, dancing, hiking or gardening;
- **Occupational**: This refers to work-related physical activity, for example, manual labour, lifting or carrying objects, or walking;
- **Transport**: This includes walking or cycling for transport, for example, walking or climbing stairs to access public transport or using a bicycle for one's commute; and
- **Household**: This refers to household activities, for example, household chores, such as cleaning, or shopping or childcare.

The WHO has developed tailored recommendations for different age groups in terms of the minimum thresholds of physical activity recommended to promote health, as outlined in Table 2.2. Depending on the assumptions on the average MET assigned to a moderate-intensity or vigorous-intensity activity, the WHO recommendations with regards to the minimum threshold of activity for adults 18 and older roughly correspond to between 500 and 600 MET-minutes per week.[18]

16 The guidelines set out as part of the PAGAC (2008) report also addressed that some people do both, engaging in a mix of moderate-intensity and vigorous-intensity activity in a given week. Hence the rule of thumb that 1 minute of vigorous-intensity activity is equivalent to 2 minutes of moderate-intensity activity.

17 Non-communicable diseases include, among others, cardiovascular disease, cancer, and diabetes.

18 For example, 150 minutes of activity at an average of 6 MET is equal to 600 MET-minutes, and 75 minutes of activity at 8 MET is also equal to 600 MET-minutes.

Table 2.2: WHO recommendations for weekly level and duration of physical activity by age group

Age group	Recommendation per week
Infants (less than 1 year of age)	At least 30 minutes of physical activity
Children (aged 1 to 4)	At least 180 minutes of physical activity of any intensity spread throughout the day
Children and adolescents (aged 5 to 17)	At least 60 minutes of moderate-to-vigorous-intensity activity[19]
Adults (aged 18 to 64)	At least 150 minutes of moderate-to-vigorous-intensity physical activity or at least 75 minutes of vigorous-intensity activity[20]
Adults (aged 65 and older)	At least 150 minutes of moderate-intensity aerobic exercise or at least 75 minutes of vigorous-intensity aerobic exercise[21]

Sources: WHO (2010, 2019).

Combining the information provided in Table 2.1 and Table 2.2, above, the following combinations of activities and corresponding intensity would be equivalent to reaching 600 MET-minutes:

- 207 minutes of slow walking (2.9 MET);
- 150 minutes of cycling to work at <10 miles (<16 km) per hour (4 MET);
- 171 minutes of home exercise/light calisthenics (3.5 MET);
- 86 minutes of jogging at <5 miles (< 8km) per hour (7 MET); and
- 55 minutes of rope jumping at a rate of 84 jumps per minute (11 MET).

Based on the definitions in Table 2.2, the prevalence of insufficient physical activity among adults globally in 2016 was about 27.5 per cent (Guthold et al. 2018). There is substantial difference across gender groups, with about 23.4 per cent of men and 31.7 per cent of women not reaching the recommended minimum levels of physical activity. Furthermore, there is substantial variation in insufficient physical activity across regions. The highest levels of insufficient physical activity were found in Latin America and the Caribbean (about 43.7 per cent), South Asia (43 per cent) and high-income Western countries (42.3 per cent). The lowest levels of insufficient physical activity are generally observed in Oceania (12.3 per cent), East and Southeast Asia (17.6 per cent) and sub-Saharan Africa (17.9 per cent). According to the study by Guthold et al. (2018), the prevalence of insufficient physical activity in high-income Western countries is on the rise.

19 More than 60 minutes is preferable, as this leads to even better health outcomes according to the guidelines.

20 Additional health benefits are expected from 300 minutes of moderate-intensity or 150 minutes of vigorous-intensity exercise according to the guidelines. Further, if possible, aerobic activity should be performed in bouts of at least 10 minutes.

21 Additional health benefits are expected from 300 minutes of moderate-intensity aerobic physical activity or 150 minutes of moderate-to-vigorous- or vigorous-intensity activity.

3 The benefits of physical activity: Associations with health, well-being and workplace performance

Existing scientific evidence suggests that regular physical activity is associated with a variety of different health benefits, including the prevention of cardiovascular disease, diabetes, cancer, hypertension, obesity and premature mortality (e.g. Reiner et al. 2013; Warburton & Bredin 2017). Furthermore, there is evidence that regular physical activity protects against the onset of depression and anxiety disorders (PAGAC 2008) and that physical activity represents an effective treatment option for reducing anxiety and depressive symptoms (PAGAC 2018). There is further evidence that physical activity is associated with better sleep outcomes and may also be associated with better work performance.[22]

In this chapter, we non-systematically review some of the existing evidence on the associations between physical activity and outcomes such as physical health, mental health, sleep, mortality risk, as well as work performance and productivity. Where applicable, we also discuss findings from our own statistical analysis in relation to the associations between insufficient physical activity and all-cause mortality, and the associations between physical activity and mental health, sleep, and work impairment due to absenteeism or presenteeism.[23]

3.1. Physical activity is associated with better physical health

The comprehensive PAGAC (2008) scientific report concluded that physical activity ameliorates many of the risk factors of heart disease, such as obesity and high blood pressure, as well as reducing the incidence of type 2 diabetes, stroke and different forms of cancer (PAGAC 2008). According to the report, there is an inverse association between the level of physical activity performed and coronary heart or cardiovascular disease, independent of gender, for middle-aged or older individuals. Overall, the findings suggest that moderate amounts of activity reduce the risk of cardiovascular disease by about 20 per cent on average, whereas higher levels of intensity reduce the risk by about 30 per cent on average.

22 Note that it is important to reiterate again that much of the evidence discussed in this section is based on two very comprehensive reviews on the state of the evidence in the area of physical activity, the PAGAC scientific reports from 2008 and 2018. Both reports have systematically assessed the current evidence in the literature, including an analysis of all existing systematic reviews and meta-analyses.

23 See Appendix A and Appendix B for more detail on the corresponding analyses.

Furthermore, the PAGAC (2008) scientific report suggests that more physically active individuals tend to have, on average, a 25 to 30 per cent lower risk of stroke than people with low levels of activity or sedentary lifestyles, independent of gender. Increased levels of physical activity are also associated with a decreased risk of developing type 2 diabetes. The evidence suggests that this association tends to hold for both moderate-intensity and vigorous-intensity physical activity and that 30 minutes a day, five days a week, of moderate-intensity physical activity is effective in preventing type 2 diabetes, independent of gender. The systematic review by Reiner et al. (2013) also finds evidence of a negative association between physical activity and the risk of type 2 diabetes.

Moreover, a large body of literature exists on the association between physical activity and the risk of developing different types of cancer, with most evidence stemming from observational studies. The clearest evidence for the association between physical activity and cancer exists for colon and breast cancer (e.g. Rezende et al. 2018). For instance, individuals engaging at least in three to four hours of moderate-intensity exercise have, on average, a 30 per cent lower relative risk of developing colon cancer and, on average, a 20 to 40 per cent lower relative risk of developing breast cancer, compared to individuals living a sedentary lifestyle. There is also some evidence that engaging in physical activity reduces the risk of lung, endometrial and ovarian cancers between 20 to 30 per cent, but generally the evidence for cancers other than colon and breast cancer is associated with some degree of uncertainty (Rezende et al. 2018). There are a set of different mechanisms that may explain the association between physical activity and cancer risks. For instance, increased physical activity reduces adiposity, which may explain reductions in cancers associated with obesity, including breast, colon and endometrial cancer. Another potential mechanism may be through reduced inflammation and improved immune function.

3.2. Physical activity is associated with better mental health

Across the world, mental health problems account for a substantial proportion of the burden of disease, with up to 16 per cent of the world's population affected by a mental disorder (e.g. Rehm & Shield 2019; Whiteford et al. 2013). Individuals with good mental health have a positive state of well-being, with the ability to realise their potential. They experience positive emotions, are able to maintain interpersonal relationships, can better cope with stress and are more productive at work (e.g. Herrman et al. 2005). In contrast, individuals with mental ill health may experience low levels of self-esteem, may have a higher risk of co-existent physical health problems, may be unable to maintain good interpersonal relationships and have a higher risk of communicable and non-communicable diseases than those not experiencing mental ill health (e.g. Prince et al. 2007). The economic consequences of mental ill health have been estimated to cost the global economy up to US$16 trillion by 2030, with a big majority of the cost driven by lower productivity in terms of higher levels of absenteeism and presenteeism (Bloom et al. 2011).

Existing systematic reviews conclude that physical activity is associated with better mental health and well-being, especially with reduced risk for depression and anxiety (e.g. White et al. 2017). Both of the PAGAC scientific reports concluded that physical activity is associated with lower risks of the onset of depression symptoms and major depressive disorders (PAGAC 2008, 2018). The evidence suggests that even relatively low amounts of physical activity (e.g. less than 150 minutes of moderate-intensity activity a week) are associated with reduced relative risk of developing depression. There is a dose-response relationship, and more activity is associated with a larger reduced risk. The PAGAC (2018) suggests that engaging in roughly about 30 minutes of physical activity per day could reduce the likelihood of experiencing depression by more than 40 per cent. The systematic review by Mammen and Faulkner (2013), which analysed 30 primary studies, also concludes that promoting physical activity represents an effective strategy in reducing the risk of developing depression. Furthermore, results from randomised controlled trials indicate that participation in physical activity programs reduces depression symptoms in people diagnosed as depressed. Thus physical activity not only tends to be a prevention strategy, but may also be part of a treatment strategy for people with depression. The PAGAC (2018) report concludes that physical activity is an effective treatment option for reducing the levels of anxiety and depression.

Our own empirical analysis, using a large-scale workplace survey covering seven different countries, suggests that individuals who report sufficient levels of physical activity (e.g. reaching the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity) also report, on average, better levels of mental health, even after we adjusted for a large set of potential confounding other factors that may determine mental health beyond physical activity simultaneously.[24] In our statistical analysis, mental health is measured through different variables, such as a better self-reported overall mental health and lower levels of psychological distress, measured by the Kessler Psychological Distress scale.[25] We also find a statistically significant association between physical activity and what is termed subjective well-being (SWB). Overall, we find evidence for an increasing dose-response relationship between physical activity and mental health, with the magnitude of the associations being larger for higher levels of physical activity. This is corroborated by the PAGAC (2018), report which also finds that there is a strong association between greater amounts of physical activity and better self-reported quality of life.

Furthermore, across other domains of health related to the mind or the brain, the available evidence suggests that regular physical activity is associated with reduced risk of dementia and Alzheimer's disease. Reiner et al. (2013) find an effect of physical activity on Alzheimer's disease and dementia. The existing studies suggest that physically active individuals are at a lower risk of developing cognitive impairment and have a higher cognitive ability score. This also holds for activities with relatively low intensity levels, such as walking. Therefore, it is suggested that regular physical activity could be a factor in preventing cognitive decline and dementia in older people who are otherwise in good health.

3.3. Physical activity is associated with better quality of sleep and longer duration of sleep

Sleep is recognised as an important determinant of health and well-being across the lifespan of an individual. Sleep is important for learning, memory, neural development, and emotional regulation, as well as for physical and mental health. Furthermore, there is evidence that adequate

24 See Appendix A, Table A.9, for more details.

25 See e.g. Kim (2008) for a discussion about the Kessler K-6 score.

sleep is positively associated with work performance (e.g. Hafner et al. 2016). The PAGAC (2018) report reviews existing evidence on the association between physical activity and sleep, concluding that regular physical activity is positively associated with better sleep outcomes, including sleep quality and duration. Specifically, regular physical activity is associated with a larger total sleep time, improved sleep efficiency and improved deep sleep.

Our own empirical analysis, using the same large-scale workplace survey covering seven different countries mentioned above, suggests that individuals who report sufficient levels of physical activity (e.g. reaching the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity) also report a better quality of sleep, on average, after we adjusted for a large set of potential confounding other factors that may determine mental health beyond physical activity.[26] We also find evidence for a statistically significant association between physical activity and sleep duration, but the magnitude of the association is relatively small. Each additional MET-hour of physical activity is associated, on average, with 0.09 minutes of sleep, all else being equal.

3.4. Physical activity is associated with lower risk of premature mortality

The PAGAC (2008) report examined in detail the relationship between physical activity and all-cause mortality. It concluded that physically active individuals have about a 30 per cent lower risk of dying during follow-up across cohort-studies, compared with individuals who are not physically active. The PAGAC (2018) report also examined in detail whether there is a dose-response relationship between physical activity and all-cause mortality. The findings of the report suggest that there is an inverse dose-response relationship between activity and mortality and that the largest relative benefits are observed early in the dose-response relationship (e.g. at lower levels of physical activity). The report also suggests that the mortality risk continues to decrease with increased physical activity, up to at least three to five times the amounts of the recommended minimum threshold of physical activity (about 600 MET-minutes). In other words, about 70 per cent of the total potential benefits on all-cause mortality are reached at 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity (Moore et al. 2012).

Our own meta-regression analysis, which includes 74 relevant studies on the association between physical activity and all-cause mortality, suggests that, after taking into account study heterogeneity, across US and European populations, being moderately active (e.g. reaching about 500 to 600 MET-minutes per week) is associated with a 28 per cent lower relative mortality risk for females and a 17 per cent lower relative mortality risk for males, all else being equal. These percentages increase to 34 and 23 per cent for high levels of activity, respectively, compared to individuals who are not active. For Asian populations, the estimates in the literature for relative mortality risk reductions tend to be lower. For instance, for moderate-intensity activity compared to inactivity, the reduction in relative mortality risk is 17 per cent for females and 11 per cent for males. For high levels of activity compared to inactivity, the reduction in mortality risk is

26 See Appendix A, section A.5.3, for more details.

estimated to be 23 per cent for females and 17 per cent for males.[27] We also find that, all else being equal, on average, the mortality risk reduction tends to be somewhat higher for leisure-time physical activity compared to occupational physical activity.[28]

3.5. Physical activity, work performance and productivity

There is evidence that regular physical activity is associated with a better mood, better work attitude and, in general, better work performance of employees. For instance, Coulson et al. (2008) found that employees who undertook physical exercise tended to have a better mood and also better self-reported work performance. They also reported to have better views about themselves, their work tasks and their colleagues. They also reported, on average, a better resilience to stress and a better ability to focus and concentrate at work.

In general, productivity tends to be measured as the output created per unit of input. Thus labour productivity captures the total output per unit of labour input, such as the number of workers in the production process or their number of hours worked. We found no studies that directly investigate the actual level of labour productivity associated with physical activity, but there are studies that examine the association between physical activity and labour income, namely, whether individuals who regularly perform more physical activity earn higher wages, which, in the economic literature, is often treated as a proxy for individual productivity. Indeed, some studies show an association between being more physically active and earned wages, all else being equal. For instance, Kosteas (2012) examined the association between physical activity and the salaries of American employees, and found that, all else being equal, participating regularly in physical activity was associated with between 6 per cent and 10 per cent higher salary earned than individuals not engaging in sufficient physical activity. Very similar results were found in a study by Lechner (2009), in which German individuals who participate regularly in sports activities reported to be more satisfied with their life and earned up to 1,200 euros more than inactive individuals, on average. The findings suggest a wage return associated with physical activity of between 5 per cent and 10 per cent. Lechner and Sari (2014) found a similar effect size on earnings using Canadian data, reporting a 10 per cent increase in earnings, which is the equivalent earnings return of one to two years of schooling. According to Lechner (2009), the pathways from physical activity to a higher wage are manifold. First, individuals who participate in physical activity tend to be healthier and hence are more productive overall. Second, participating in sporting activities could have a positive effect on an individual's network of social relationships.

27 See Appendix B for more detail on the meta-regression analysis on the association between physical activity and all-cause mortality.

28 Note that it is important to emphasise that the risks discussed in this sections are a metric for the relative risk of not being physically active, which is calculated by dividing the risk of the outcome (e.g. mortality) in the group with the exposure (e.g. being physically inactive) by the risk of the outcome observed of the unexposed group (e.g. the physically active population). Because the absolute sizes of the numerators and the denominator are absent, the true effect of exposure is more difficult to assess. For example, while a 30 per cent excess mortality risk from being physically inactive may sound high, the population-attributable fraction of physical inactivity on total mortality in a population tends to be much lower. The population-attributable fraction is the proportion of a population's incidence of a disease, in this case mortality, that is accounted for by the exposure to the risk factor. Lear et al. (2017) estimate that the relative risk of physical activity (engaging in moderate-intensity physical activity versus being inactive) on all-cause mortality is 20 per cent but that the corresponding population-attributable fraction is 8 per cent.

Third, engaging in sports may signal to an employer that the individual is healthy, motivated and competitive. Furthermore, if physical activity, on average, leads to better self-esteem and better satisfaction with oneself, this could also have a beneficial effect on the labour market. For instance, Hamermesh and Biddle (1994) showed that individuals who consider themselves more attractive earn 5 per cent to 10 per cent more than individuals who do not consider themselves attractive.

In many existing studies, especially in the health literature, workplace performance or productivity are measured or examined using levels of absenteeism or presenteeism. Absenteeism refers to productivity losses when individuals do not show up at work due to ill health. Presenteeism refers to productivity losses when they do come to work but function at a sub-optimal level only. Both absenteeism and presenteeism tend to be measured in days lost in the existing literature, which is often based on relatively small sample sizes.[29] For instance, van den Heuvel et al. (2004) show that workers who regularly participate in sports activities tend to take less time off sick and if they do take time off sick, their recovery time (e.g. the amount of time before they are back at work) is shorter than individuals who do not participate in sports. Losina et al. (2017) test the effectiveness of a workplace physical activity intervention wherein financial rewards were offered to a group of employees for tracking their physical activity over time. The findings of the study suggested that the more physically active individuals had lower sickness absence rates than the less physically active employees. Lahti et al. (2012) find that changes in leisure-time physical activity are associated with lower sickness absence rates, both self-certified (about 20 per cent lower risk of absence compared to an inactive individual) and medically certified (about 37 per cent lower risk of absence compared to an inactive individual). With regards to presenteeism, not many studies have examined the association between physical activity and levels of presenteeism. Brown et al. (2013) find higher self-reported presenteeism among sedentary office workers. Other cross-sectional studies applied in a workplace setting also have found an inverse association between physical activity and presenteeism (Burton et al. 2005, 2014; Pronk et al. 2004; VanWormer et al. 2011; Williden et al. 2012). Furthermore, Walker et al. (2017) show that, in a longitudinal data sample of university employees, becoming more physically active is associated with lower levels of presenteeism.

Our own analysis, using data from a large-scale, international workplace survey, suggests that an employee reporting that they engage in the recommended levels of physical activity per week reports, on average, between 1.33 and 1.98 percentage points lower work impairment due to absenteeism and presenteeism compared to a physically inactive employee.[30] Using an average of 230 working days per year, this corresponds to between 3 and 4.5 working days lost per year per individual who is not sufficiently physically active. The majority of these working days are lost to presenteeism (roughly about 80 percent) rather than absenteeism (about 20 percent). This is in line with existing literature, which suggests that the ratio between presenteeism and absenteeism tends to be 5 to 1 (e.g. Burton et al. 2007; EU-OSHA 2012).

29 For example, a few hundred employees in a given company.

30 See Appendix A, section A.5.1, for more detail.

4 Quantifying the economic benefits of a more physically active population

The previous chapter of this report has illustrated that physical inactivity is associated with a number of health conditions, with premature mortality and with lower levels of workplace productivity (e.g. measured through sickness absence or presenteeism). In this chapter, we examine the potential economic benefits of getting people to be more physically active. Our approach for estimating the benefits from improving physical activity focuses on the opportunity cost, or the missed economic benefits, associated with a more physically active population. Our analysis focuses on two types of benefits:

1. **Increased economic output**: Insufficient physical activity can have negative effects on human capital through the association with mortality and morbidity. Hence, improving physical activity levels can have a positive effect on a country's labour force by reducing premature mortality and reducing rates of sickness absence and levels of presenteeism. A healthy population has a positive effect on a country's economic output (e.g. measured as GDP).
2. **Reduced healthcare expenditure**: Physical inactivity is associated with the onset of a number of different diseases, including cardiovascular disease, stroke, diabetes and cancer (e.g. breast or colon). These conditions are a burden to healthcare systems because they impose costs for treatment.

The analysis is conducted for 23 countries and the rest of the world.[31] For the purpose of this analysis, we consider a 30-year time horizon and examine how potential economic benefits of improving physical activity at the population level may evolve in the future, taking into account changes in demographic composition over time. The analyses presented in this chapter relate to different scenarios of physical activity improvements that affect the adult population.[32] The 'status quo', or 'baseline scenario', is compared against different 'what-if' scenarios for which the effects of changes in various parameters are estimated compared to the status quo. For example, the baseline scenario may represent the current economic situation of a country (under current

31 The countries included in the analysis are Argentina, Australia, Austria, Canada, China, Ecuador, France, Germany, Hong Kong, Japan, Malaysia, Netherlands, New Zealand, Pakistan, Philippines, Singapore, South Africa, South Korea, Sri Lanka, Thailand, United Kingdom, United States, Vietnam and 23 countries in the rest of the world. The countries in the rest of the world are combined into one region labelled rest of the world. Note that these 23 countries combined represent two thirds of the global GDP in 2019.

32 We only take into account changes in the physical activity levels of adults age 20 or older and do not model physical activity improvements for children or adolescents.

physical activity levels), and the what-if scenarios may represent corresponding projections of the economic situation into the future under improved physical activity levels.

4.1. The three physical activity improvement scenarios and the key assumptions in the economic analysis

The 'what-if' scenarios applied in the analysis focus on the following three physical activity improvement situations:

Scenario 1: This improves the adult population physical activity level so that everyone reaches at least the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week (or the equivalent of about 600 MET-minutes per week). This scenario set only improves the activity levels of the inactive and the low active.

Scenario 2: This improves the adult population physical activity level of everyone by 20 percent, shifting everyone across the physical activity distribution to be more active. This scenario only improves the activity levels of those currently active and does not improve the activity levels of those performing no physical activity at all.

Scenario 3: This improves the adult population physical activity levels so that everyone below the recommended 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week (or the equivalent of about 600 MET-minutes per week) reaches this threshold and everyone above this threshold improves their physical activity level by 20 per cent. Scenario 3 is essentially a combination of scenarios 1 and 2. It represents a scenario whereby those individuals with a sedentary or low physically active lifestyle become active and those who are already active improve their activity levels as well.

For each scenario set, we assume that the improvements have been made at the outset, and we then follow the corresponding effects of these changes over time. For scenario 1, we draw on the comprehensive physical activity data provided by Guthold et al. (2018), who report the prevalence of insufficient physical activity (e.g. defined according to WHO guidelines as performing less than 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity activity) across a large number of countries.[33] This study includes different types of activity, such as physical activity during leisure time, during work, at home or for transport. The proportions of the male and female adult population with insufficient levels of physical activity are reported in Table 4.1.[34] For scenarios 2 and 3, the data on the prevalence of inactive versus active individuals are not sufficient. Therefore, where possible, we draw on country-specific physical activity distributions.[35]

33 The prevalence of physical inactivity presented in Guthold et al. (2018) relies mostly on self-reported country-specific physical activity data.

34 Note that the proportions for the rest of the world represent a population-weighted average across all countries included in the rest of the world region.

35 A reliable or comparable physical activity distribution was not available for the majority of countries; hence we had to impute them. The calculation is based on applying the shape of a country-specific physical activity distribution and then shifting the distribution by country according to information on the active versus non-active population groups. A more detailed description of the calculation procedure is provided in Appendix C.

Table 4.1: Prevalence of insufficient physical activity, by country and gender

	Male			Female		
	Insufficiently active	***95% CI: Low***	***95% CI: High***	**Insufficiently active**	***95% CI: Low***	***95% CI: High***
Argentina	**37.6%**	*30.4%*	*45.5%*	**45.3%**	*36.6%*	*54.2%*
Australia	**27.0%**	*21.1%*	*34.0%*	**33.6%**	*26.3%*	*41.9%*
Austria	**26.4%**	*21.2%*	*32.3%*	**33.6%**	*26.8%*	*41.1%*
Canada	**25.7%**	*19.7%*	*32.8%*	**31.4%**	*24.1%*	*39.7%*
China	**16.0%**	*11.7%*	*21.4%*	**12.2%**	*8.5%*	*17.3%*
Ecuador	**24.6%**	*18.1%*	*31.1%*	**29.7%**	*21.3%*	*38.1%*
France	**24.3%**	*19.4%*	*29.9%*	**34.0%**	*27.3%*	*41.4%*
Germany	**40.2%**	*34.0%*	*46.7%*	**44.1%**	*36.9%*	*51.6%*
Hong Kong	**16.0%**	*11.7%*	*21.4%*	**12.2%**	*8.5%*	*17.3%*
Japan	**33.8%**	*20.1%*	*50.9%*	**37.0%**	*21.0%*	*56.5%*
Malaysia	**34.6%**	*26.6%*	*43.6%*	**42.8%**	*32.7%*	*53.5%*
Netherlands	**25.3%**	*20.3%*	*31.0%*	**29.0%**	*22.9%*	*36.0%*
New Zealand	**39.3%**	*32.8%*	*46.1%*	**45.3%**	*37.6%*	*53.2%*
Pakistan	**24.4%**	*13.7%*	*35.1%*	**43.3%**	*27.1%*	*59.5%*
Philippines	**30.1%**	*23.4%*	*37.9%*	**49.1%**	*39.1%*	*59.1%*
Singapore	**34.3%**	*20.8%*	*50.9%*	**38.6%**	*22.6%*	*57.5%*
South Africa	**28.5%**	*22.0%*	*35.9%*	**47.3%**	*37.7%*	*57.0%*
South Korea	**29.5%**	*17.3%*	*45.6%*	**41.0%**	*24.4%*	*59.9%*
Sri Lanka	**20.2%**	*14.7%*	*27.2%*	**36.7%**	*27.2%*	*47.5%*
Thailand	**21.8%**	*16.3%*	*28.5%*	**27.2%**	*20.0%*	*36.0%*
United Kingdom	**31.5%**	*25.8%*	*37.8%*	**40.0%**	*32.8%*	*47.7%*
United States	**31.7%**	*25.8%*	*38.3%*	**48.0%**	*40.1%*	*56.1%*
Vietnam	**19.9%**	*14.8%*	*26.1%*	**30.6%**	*22.8%*	*39.6%*
Rest of the world	**23.7%**	*17.2%*	*31.5%*	**34.9%**	*25.5%*	*45.1%*

Sources: Guthold et al. (2018); Bauman et al. (2009).

Notes: Entries represent the country- and gender-specific levels of insufficient physical activity. Physical activity encompasses different domains, including leisure-time, occupational, transport and household activity. Data for Hong Kong were not directly provided by Guthold et al. (2018). Evidence by Bauman et al. (2009) suggests that, on average, insufficient physical activity is somewhat higher in Hong Kong than it is in mainland China, with a similar distribution ratio across the two genders. In order to be conservative in the values we estimate for Hong Kong, we have used the same levels of activity as are given for mainland China.

The analysis presented in this chapter begins with an analysis of the effects of reducing premature mortality and rates of absenteeism and presenteeism associated with physical inactivity on a country's economic output. To that end, we draw on a multi-country macroeconomic model to estimate the potential changes in GDP associated with different scenarios of physical activity improvements at the population level. We focus on GDP as the measure of total output of an economy because it represents a proxy for the health of an economy and because it is often the metric of interest for a variety of policy- and decision makers. The second analysis presented in this chapter represents an estimation of the potential healthcare expenditure savings associated with different scenarios of physical activity improvements. Following a similar methodology as applied by Ding et al. (2016), we focus on the healthcare cost associated with physical inactivity for five disease areas, namely, coronary heart disease, stroke, type 2 diabetes, breast cancer and colon cancer. We present the healthcare expenditure benefits associated with a more physically active population separately from the effects on overall economic output because changes in healthcare expenditure could have very country-specific macroeconomic effects, depending on the prevalent health system in each country (e.g. public or private). As the macroeconomic model used for the analysis does not include a specific health system for each of the countries included, the changes in healthcare expenditure are reported separately. Both analyses, the assessment of healthcare expenditure over time, as well as the assessment of the impact on economic output over time, rely on a population projection for each of the countries or regions included in the computations. For the population projections, we draw on data provided by the UN Population Database and a cohort-component model that is able to project the demographic composition of each country into the future. Appendix D provides more detailed information on the cohort-component model. For each of the scenarios applied, the population projections are altered so that they reflect changes in mortality rates associated with making people more physically active.

Before we present the corresponding findings, we note some simplifying assumptions that have been made:

1. **Physical activity improvements are permanent**: For the purpose of this analysis, we assume that individuals who improve their physical activity level stay at that new, improved level over time. For instance, we assume that an individual who was physically inactive and becomes active (e.g. reaching a threshold of 600 MET-minutes of physical activity per week) will stay active over time. If people's physical activity were to decline over time, the estimated positive effects on GDP or healthcare expenditure would decrease. Furthermore, we assume that the current levels of insufficient physical activity at the population level will stay constant in the baseline scenario. Even though there is some evidence that the current levels of physical inactivity may increase over time, we calculate the counterfactual (or 'what-if') scenarios based on current physical activity levels at baseline. There is some evidence that, at least for some high-income Western countries, the levels of insufficient physical activity may rise in the future (Guthold et al. 2018). An increase in future prevalence of inactivity would lead to an underestimation of the economic benefits presented, whereas a decrease in future prevalence would lead to an overestimation of the economic benefits.
2. **Individuals do not substitute with other health-improving activities**: In the analysis, we assume that individuals do not substitute physical activity with other health-enhancing activities, such as sleep. Individuals are faced with choices on how to spend their time during

the 24 hours available in a day. For many, a large part of this daily time allocation is spent at work. Leisure time is divided into different leisure activities (such as time spent with friends or family, going to the gym, watching TV, or playing video games), some of which may be associated with health benefits. In our analysis, we assume that the extra time spent on physical activity would be taken from non-health-improving leisure activities (e.g. watching TV). Otherwise, if the time were taken from sleep the estimated positive effects on GDP or healthcare expenditure would be lower than reported.[36]

3. **Consumption behaviour is constant**: The macroeconomic model and its underlying behavioural model equations assume constant consumption behaviour. In reality, individuals who improve their physical activity levels may also switch to different types of foods or may buy different types of clothes (e.g. sports fashion), which could change the relative prices of goods from different industries over time. Because we kept the industry structure of the macroeconomic model relatively broad, distinguishing among agriculture, manufacturing, private and public services only, these inter-industry changes in demand are not taken into account in the different scenarios.

In what follows, we report the findings for each analysis. We deliberately keep the discussion on methodology to a minimum. More technical detail is provided in specific appendices for those who are interested.

4.2. Estimating the effects of physical activity improvements on economic output

We begin this section with a brief description of the macroeconomic model applied in the analysis and a description of how improvements in physical activity affect the model parameters. Subsequently, we present the findings of the corresponding analysis.

4.2.1. A short overview of the macroeconomic model

In order to assess the economic implications of changes in physical activity levels for the adult population, we use a multi-country computable general equilibrium model. Such a model simultaneously solves multiple equations that relate to production from firms and household demand, both within a country and between countries, through trade linkages. Within a CGE modelling framework, the current economic projection for each country is computed using the current underlying economic factors (e.g. 'status quo' or 'baseline scenario') and subsequently compared against a 'what-if' scenario in which various parameters are changed. For instance, for the purpose of this analysis, we compare and analyse how the GDP of a country would change relative to the status quo projection in the long term if we hypothetically made people more physically active. In the baseline scenario, the underlying assumption is that the country's

36 Furthermore, it is important to stress that in the analysis, we cannot quantify potential individual utility trade-offs. For instance, an individual receives utility from watching TV, while exercising instead may provide a lower level of utility (or may even provide a disutility), even though engaging in physical activity may improve their health and well-being in the medium to long term.

economy grows under a long-term growth rate,[37] and in the counterfactual, or 'what-if', scenario, we compare by how much this long-term growth is affected if the underlying parameters change (e.g. people become more active).

Specifically in the field of health economics, the application of CGE models and the determination of the lost economic output associated with a health burden have recently become more common due to these models' advantages over more traditional approaches, such as cost of illness (COI) methods (e.g. Bloom et al. 2018). COI is an easy-to-understand method that summarises the direct and indirect cost associated with ill health, taking into account, for instance, the sum of all direct personal medical cost, as well as the indirect cost (e.g. income loss due to absenteeism or premature death). While the approach is relatively straightforward, it does not take into account the potential spill-over effects on other agents or markets in an economy. A CGE modelling framework provides the ability to capture direct and indirect effects of changes in physical activity levels. For instance, if physical activity affects human capital and hence the labour supply of an economy by making people healthier and more productive, then the increased effective labour supply improves the overall production possibilities in an economy. Firms may produce more, consumers may consume more (e.g. due to having more disposable income), and governments may improve their fiscal income, improving welfare overall. In contrast to COI, a general equilibrium model, such as CGE, takes into account these ripple effects on other parts of the economy by reporting how overall economic output is affected. A more detailed description of the model and the underlying economic data used can be found in Appendix E.

Limitations of the model

The application of a CGE modelling framework to assess the different economic implications of improving physical activity levels has several strengths, as outlined above, including the ability to take into account simultaneously direct and indirect effects of important parameter changes. However, there are also some limitations to the application of this modelling framework.

First, we emphasise that the CGE model applied for the economic analysis is not intended to provide a forecast of the economy at a given point in time in the future. The deterministic CGE model does not take into account transitory (stochastic) short-term changes to the overall economic growth path. The aim of the applied modelling framework is to examine the effects of changes across different modelling parameters representing different scenarios and to then compare how the economy of a country would evolve in the medium to long term in the counterfactual scenario compared with the baseline, holding all other factors constant. This is a simplification of how events would affect the economy in reality; however, it allows for the analysis of specific factors (such as changes in health) in isolation (or all else being equal). Second, the scenarios examined within the economic modelling framework depend heavily on input data and parameters based on empirical evidence from other studies and from our own secondary data analysis. In many instances, the applied parameter estimates do not represent causal effects but, rather, associations between two variables (e.g. improvement of sickness absence rates associated with more physical activity).

37 For example, this is determined through an underlying increase in total factor productivity or changes in the labour supply, among others.

How physical activity improvements affect the economy

In our conceptualisation of the economic benefits of a more physically active population, we focus primarily on its impact on an economy's effective labour supply because improving physical activity is associated with lower mortality risk as well as lower levels of sickness absence and presenteeism. In essence, in our model, insufficient physical activity affects the supply of effective labour through three mechanisms:

1. **Reduced mortality risk:** Insufficient physical activity is associated with a higher mortality risk and hence a reduction in the overall size of the labour force, or, in other words, the total number of individuals who provide their labour on the labour market. The literature and analysis highlighted in Chapter 3 suggest that the relative all-cause mortality risk of being physically active compared to being non-active is between 11 and 28 per cent lower. Note that excess deaths due to insufficient physical activity permanently reduce the size of the population, which directly influences not only the current but also the future population. Hence the effects of insufficient physical activity accumulate over time, in that the death of a worker not only affects the year in which the death occurs, but continues to be a part of the costs in subsequent years because it also includes the potential 'death' of all the deceased's future offspring.
2. **Reduced sickness absence (absenteeism):** Adequate levels of physical activity are associated with better physical and mental health. Prolonged periods of ill health and absence from work lead to reductions in the efficiency of labour. That is, the unit of labour (e.g. an individual in the labour force) is less efficient, representing a direct effect on the effectiveness of the working-age population. For instance, the empirical analysis presented in Appendix A suggests that an individual who is not physically active reports, on average, a larger amount of working time lost due to absenteeism (between 0.44 and 0.86 days[38]) compared to an individual who is physically active.[39]
3. **Reduced presenteeism:** Similar to a reduction in sickness absence, a reduction in presenteeism makes each unit of labour more effective, by improving the performance at work. The empirical analysis presented in Appendix A suggests that an individual who is not physically active reports, on average, a larger amount of working time lost due to presenteeism (between 2.6 and 3.71 days[40]) compared to an individual who is physically active.[41]

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38 Assuming 230 working days a year.

39 Note that, using the international workplace survey data (see Appendix A for more detail), we calculate that, overall, roughly about two thirds of the modifiable absenteeism rate is attributable to physical health and about one third to mental health.

40 This assumes 230 working days a year. Note that the ratio magnitude of the association between physical activity and work impairment for presenteeism and absenteeism is about 5 to 1. This is in line with previous research suggesting that the loss associated with ill health overwhelmingly stems from when people show up at work but are not functioning to their best of ability, rather than from when they stay home (e.g. Burton et al. 2005; EU-OSHA 2012)

41 Note that, using the international workplace survey data (see Appendix A for more detail), we calculate that, overall, roughly about 80 per cent of the modifiable presenteeism rate is attributable to mental health and about 20 per cent to physical health.

In the analysis, we apply different estimates for the sickness absence and presenteeism parameter estimates. For both mechanisms, we apply parameters that are adjusted for physical and mental health variables, as well as parameters that are unadjusted for physical and mental health. The unadjusted parameter estimates are larger in magnitude (e.g. suggesting a higher work impairment due to absenteeism or presenteeism for physically inactive individuals) and therefore potentially take into account some of the indirect effects of physical activity on specific health outcomes. For instance, an individual with hypertension likely has a higher level of sickness absence or presenteeism than an individual without hypertension, all else being equal. An individual can have hypertension even though they are generally physically active. But physical activity may also reduce the risk for hypertension and hence physical activity may have a significant indirect effect on sickness absence rates or presenteeism; however, it is difficult to quantify directly these indirect associations. To that end, for each scenario, we apply the higher unadjusted ('High') and the lower adjusted ('Low') parameter estimates for sickness absence and presenteeism parameters associated with physical activity.

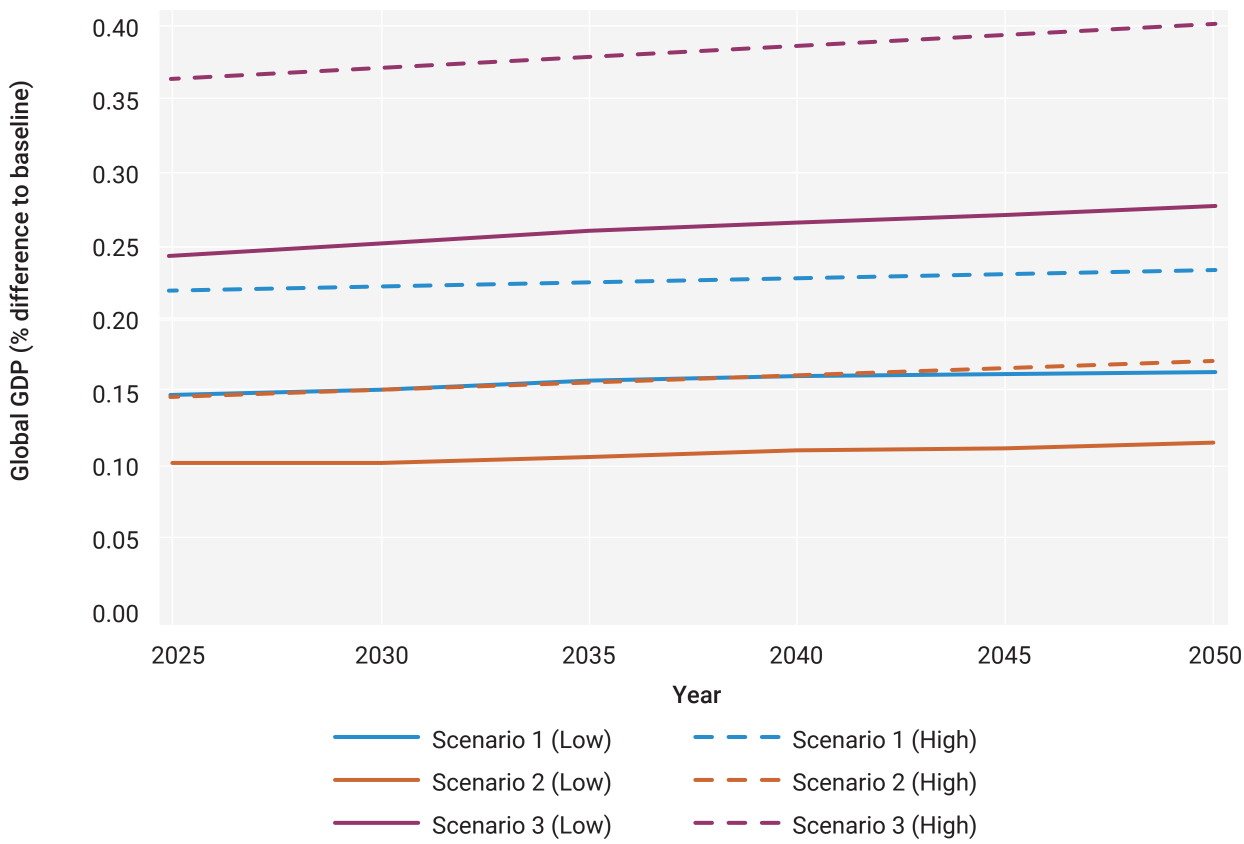
4.2.2. Estimating the effects of physical activity improvements on global GDP

We start the illustration of the simulation results with how the different physical activity improvement scenarios change economic output for the global GDP. The results are presented in a series of figures and tables below. Figure 4.1 illustrates the projected yearly trends in GDP gain (in percentage terms) for each of the different scenarios compared to the baseline scenario (current physical activity levels). The entries reported in Figure 4.1 show a trend of increases in GDP gains over time from making people more physically active.

An increase in the labour force due to less premature deaths compared to the baseline scenario is reflected in all subsequent years of a given scenario. For instance, a worker who is saved from premature death in the current year also provides labour in the next year and, in the long run, may also have offspring, who, over time, may also enter the labour force. Furthermore, an increase in economic production in a given year also creates multiplier effects that may create income for other agents in the economy over time, and that can improve overall investment levels, all else being equal. For instance, Panel A of Table 4.2 reports that under scenario 1 – where it is assumed that all individuals currently not reaching the recommended levels of physical activity per week will reach them – by 2025, global GDP would be between 0.15 and 0.22 per cent higher compared to the baseline scenario with current physical activity levels, depending on whether we apply the sickness absence or presenteeism parameters that take into account only direct effects ('Low') or also potential indirect effects ('High') of physical activity.[42]

42 It is important to keep in mind that in the baseline scenario and throughout all other scenarios, it is predicted that GDP is growing in the long term, but it is also estimated that in each year global GDP could be higher by making people more physically active. In other words, the GDP gains represent a missed economic opportunity from not making people more physically active.

Figure 4.1: Estimated global GDP gain over time relative to baseline scenario with current physical activity levels, per year (per cent difference to baseline)



Notes: Figure entries represent per cent changes in global GDP for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High'). In the baseline scenario, global GDP grows over time, but under scenarios 1 to 3 with physical activity improvements, global GDP per year would be higher compared to the baseline projection.

This corresponds to about US$138 billion to US$203 billion (Panel B of Table 4.2) in 2025.[43] The gains in GDP under scenario 1 are estimated to increase over time and to reach between 0.17 and 0.24 per cent by 2050, or the equivalent of US$314 billion to US$446 billion. It is important to stress that these figures represent annual gains, rather than one-off benefits. As the benefits of getting people to be more active – in terms of lower mortality, sickness absence and mortality rates – continue to accrue over time as the population changes, the annual GDP gains will not be the same year-on-year and will increase over time.

43 To put these figures into perspective, we note that the annual GDP of New Zealand in 2018 was about US$205.9 billion according to the International Monetary Fund.

Table 4.2: Estimated global GDP gain relative to baseline scenario with current physical activity levels, per year

Panel A: Global GDP gain (per cent), per year						
	2025	2030	2035	2040	2045	2050
Scenario 1 (Low)	0.15%	0.15%	0.16%	0.16%	0.16%	0.17%
Scenario 1 (High)	0.22%	0.22%	0.23%	0.23%	0.23%	0.24%
Scenario 2 (Low)	0.10%	0.10%	0.11%	0.11%	0.11%	0.12%
Scenario 2 (High)	0.15%	0.15%	0.16%	0.16%	0.17%	0.17%
Scenario 3 (Low)	0.25%	0.25%	0.26%	0.27%	0.27%	0.28%
Scenario 3 (High)	0.36%	0.37%	0.38%	0.39%	0.40%	0.40%
Panel B: Global GDP gain (US$ billion present value 2019), per year						
	2025	2030	2035	2040	2045	2050
Scenario 1 (Low)	137.5	167.1	198.1	231.9	270.3	313.5
Scenario 1 (High)	203.3	243.1	285.6	332.4	385.7	446.3
Scenario 2 (Low)	93.4	111.5	132.5	156.7	185.0	218.3
Scenario 2 (High)	139.2	166.1	197.3	233.3	275.3	325.0
Scenario 3 (Low)	228.0	274.8	325.9	382.9	448.3	523.7
Scenario 3 (High)	338.3	404.1	476.6	558.1	652.1	760.8

Notes: Table entries represent per cent and absolute changes in global GDP for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for two variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

The estimated GDP gains for scenario 2, where it is assumed that all individuals improve their current physical activity levels by 20 per cent, are lower than for scenario 1. It is estimated that, by 2025, under scenario 2, global GDP would be between 0.1 and 0.15 per cent higher compared to the baseline scenario with current physical activity levels, depending on whether we apply the sickness absence or presenteeism parameters that take into account only direct effects ('Low') or also potential indirect effects ('High') of physical activity. This corresponds to about US$93 billion to US$139 billion. This increases to between 0.12 and 0.17 per cent by 2050, or the equivalent of US$218 billion to US$325 billion.

Across the three scenarios, the GDP gains of making people more physically active are largest for scenario 3, where it is assumed that physically inactive individuals reach at least the recommended threshold of about 600 MET-minutes of activity per week and everyone above this threshold improves their current level of activity by 20 per cent. We estimate that, by 2025, global GDP could be between 0.25 per cent and 0.36 per cent higher compared to the baseline scenario with current physical activity levels. This corresponds to between US$228 billion and US$338 billion by 2025.[44] Similarly to the other two scenarios, the estimated relative GDP gain increases over time. By 2050, global GDP would be between 0.27 and 0.4 per cent higher compared to the baseline scenario with no physical activity improvement, corresponding to between US$523 billion and US$760 billion.

Table 4.3 reports the average global GDP gain over the 30-year time horizon for the three scenarios and the contribution to the overall estimated effect by mechanism (reduced mortality, reduced sickness absence and presenteeism).

Table 4.3: Estimated global GDP gain by mechanism (mortality, absenteeism, presenteeism), average over 30 years

	Global GDP gain (US$ billion present value 2019)			
	Total	Mortality	Absenteeism	Presenteeism
Scenario 1 (Low)	219.7	33.2	28.7	157.8
Scenario 1 (High)	316.1	33.2	55.9	227.0
Scenario 2 (Low)	113.2	9.5	17.7	86.0
Scenario 2 (High)	168.5	9.5	31.4	127.6
Scenario 3 (Low)	363.9	36.3	50.3	277.2
Scenario 3 (High)	531.7	36.3	95.6	399.7

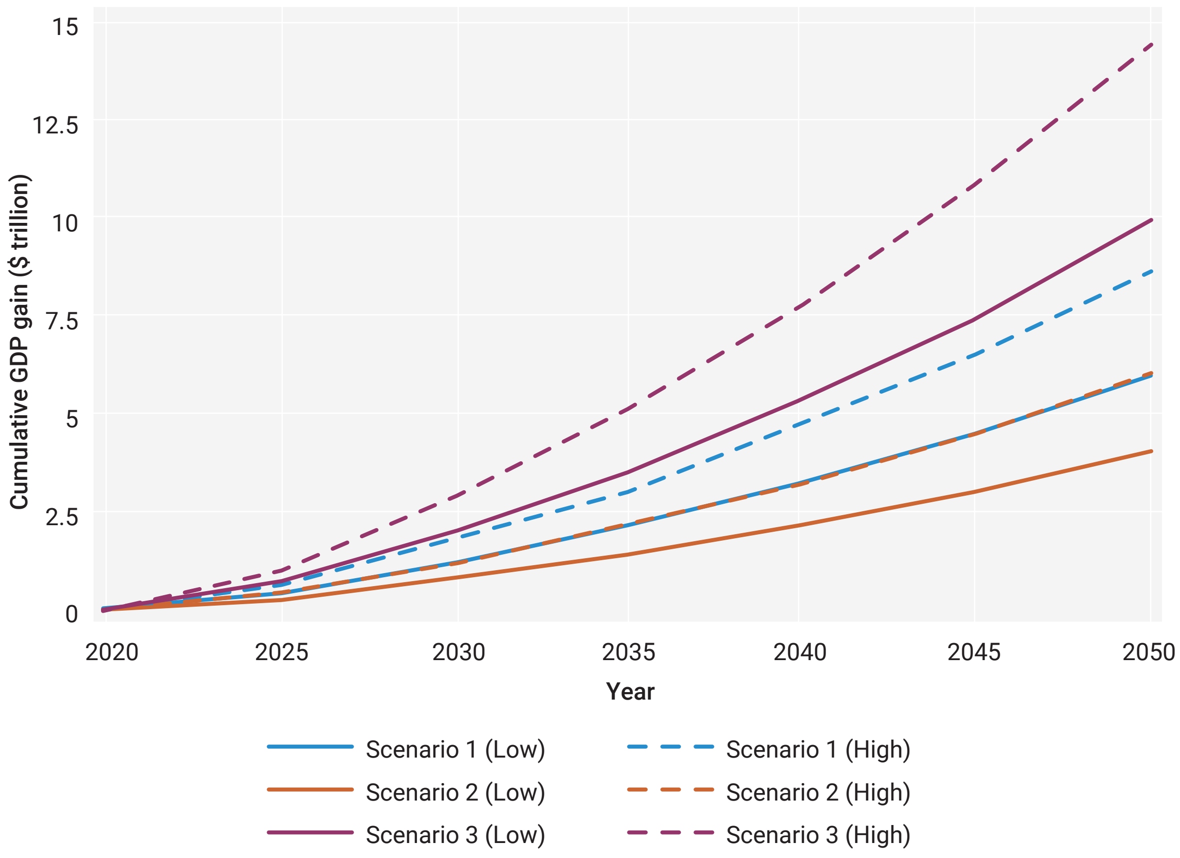
Notes: Table entries represent absolute changes (averaged over 30 years) in global GDP for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Under scenario 1, on average, over a 30-year horizon, the global GDP gain runs between US$220 billion and US$316 billion, of which roughly 15 per cent stems from the increase in the labour force due to a reduction in the mortality risk, about 15 per cent from reduced sickness absence and about 70 per cent from reduced presenteeism.[45] Similar ratios between the three mechanisms apply for scenarios 2 and 3, with the total average global GDP gain by making individuals more physically active estimated to be between US$113 billion and US$168 billion for scenario 2 and between US$364 billion and US$532 billion for scenario 3. Furthermore, given that the benefits of making people more active increase over time in relative terms, it is possible to calculate the cumulative GDP gain. Unlike the annual GDP gains presented above, these represent the total economic benefits over the duration of a given scenario. An illustration of the cumulative global GDP gains over a 30-year time horizon is given in Figure 4.2, with the corresponding numbers provided in Table 4.4.

44 To put this figure into perspective, we note that the annual GDP of Denmark in 2018 was about US$325 billion according to the International Monetary Fund.

45 As reported above, this is in line with other research suggesting that presenteeism tends to incur higher overall cost than absenteeism. For instance, a recent study by the OECD (2019) on the economic cost of obesity also estimated the costs related to presenteeism to be significantly higher than the costs related to absenteeism.

Figure 4.2: Estimated cumulative global GDP gain over 30 years relative to baseline scenario with current physical activity levels (US$ trillion present value 2019)



Notes: Figure entries represent cumulative changes in global GDP over 30 years for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

The cumulative global GDP gain for scenario 1 by 2025 is estimated to be between US$0.4 trillion and US$0.6 trillion, which corresponds to between US$70 and US$104 per adult person.[46] The cumulative global GDP gain rises to between US$6 trillion and US$8 trillion by 2050, corresponding to between US$704 and US$1016 per adult person.

46 Note that in this scenario we improve physical activity levels of adults aged 20 and older only.

Table 4.4: Estimated global cumulative GDP gain over 30 years relative to baseline scenario with current physical activity levels

Panel A: Cumulative global GDP gain (US$ trillion present value 2019), by year						
	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Scenario 1 (Low)	0.4	1.2	2.1	3.2	4.5	6.0
Scenario 1 (High)	0.6	1.7	3.1	4.7	6.5	8.6
Scenario 2 (Low)	0.3	0.8	1.4	2.2	3.0	4.0
Scenario 2 (High)	0.4	1.2	2.1	3.2	4.5	6.0
Scenario 3 (Low)	0.7	2.0	3.5	5.3	7.4	9.9
Scenario 3 (High)	1.0	2.9	5.1	7.8	10.8	14.4
Panel B: Cumulative global GDP gain (US$ present value 2019) per adult person, by year						
	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Scenario 1 (Low)	70.4	185.6	305.1	430.1	561.8	704.9
Scenario 1 (High)	104.2	272.7	445.3	624.8	812.4	1,015.7
Scenario 2 (Low)	47.9	125.2	205.0	289.2	379.1	478.7
Scenario 2 (High)	71.3	186.5	305.3	430.6	564.4	712.6
Scenario 3 (Low)	116.8	306.8	503.2	709.3	927.5	1,166.5
Scenario 3 (High)	173.3	453.6	741.2	1,041.5	1,358.5	1,705.2

Notes: Table entries in Panel A represent cumulative changes in global GDP over 30 years for three physical activity improvement scenarios relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High'). Entries in Panel B represent the cumulative GDP gain per adult person by year, where the cumulative GDP gain is divided by the adult population in a given year.

The cumulative global GDP gain by 2025 for scenario 2 is estimated to be between US$0.3 trillion and US$0.4 trillion, or between about US$48 and US$71 per adult person. The cumulative global GDP gain increases to between US$4 trillion and US$6 trillion by 2050. For scenario 3, the cumulative global GDP gain compared to the baseline scenario is estimated to be between US$0.7 trillion and US$1 trillion, corresponding to between US$117 and US$173 per adult person. For scenario 3, the cumulative GDP gain increases to between US$9.9 trillion and US$14.4 trillion by 2050.[47]

47 To put that figure into perspective, we note that is roughly the current annual GDP of China (according to data from the International Monetary Fund).

4.2.3. Estimating the effects of physical activity improvements on country- or region-specific GDP

The previous sections illustrated the global economic gains of getting people to be more physically active under three different scenarios. In what follows, we break down the estimated GDP gains by country or region. Tables 4.5 to 4.11 report the annual GDP gains by year from 2025 to 2050 for the three different physical activity improvement scenarios as absolute changes in US dollars and percentage changes compared to the baseline scenario of no physical activity improvements. For instance, under scenario 1, the largest estimated annual GDP gain is reported for the United States, which by 2025 could experience a relative increase in GDP of between US$52 billion and US$77 billion (for the low and high estimates, respectively, for the absenteeism and presenteeism rates) compared to a baseline scenario with no physical activity improvements. That corresponds to between 0.25 and 0.38 per cent of US GDP by 2025. This increases to between US$100 billion and US$144 billion by 2050. Under scenario 1, the United Kingdom is estimated to increase its annual GDP by 2025 between US$5.6 billion and US$8.3 billion, corresponding to between 0.16 and 0.24 per cent of UK GDP by 2025. This increases over time to between US$10.5 billion and US$15.3 billion by 2050. For Germany, it is estimated that the potential annual GDP gain by 2025 is between US$7.9 billion and US$11.8 billion, corresponding to between 0.2 and 0.29 per cent of GDP by 2025. This increases to between US$10.9 billion and US$15.8 billion. For Japan, the estimated annual GDP gain by 2025 is between US$6.9 billion and US$10.4 billion, corresponding to between 0.14 and 0.21 per cent of GDP by 2025. Other countries with relative high estimated annual GDP gains under scenario 1 are South Africa (between 0.19 and 0.26 per cent of GDP by 2025), Australia and New Zealand (between 0.16 and 0.23 per cent of GDP by 2025).

Under scenario 3, the estimated annual GDP gains are higher. For instance, it is estimated that the annual GDP of the United States by 2025 would be between US$73 billion and US$108 billion, corresponding to between 0.35 and 0.52 per cent of US GDP by 2025. This increases to between US$137 billion and US$200 billion by 2050. For the United Kingdom, the annual GDP gain under scenario 3 by 2025 is estimated to be between US$8.2 billion and US$12.1 billion, corresponding to between 0.24 and 0.35 per cent of UK GDP by 2025. The estimated annual GDP gain is increasing and by 2050 is between US$15 billion and US$22 billion. Other countries with relative high estimated annual GDP gains under scenario 3 are Germany (between 0.28 and 0.42 per cent of GDP by 2025), Canada (between 0.27 and 0.41 per cent of GDP by 2025), South Africa (between 0.25 and 0.36 per cent of GDP by 2025), as well as Australia and New Zealand (both between 0.27 and 0.41 per cent of GDP by 2025).

Instead of the annual estimated GDP gains, Tables 4.12 to 4.16 report the cumulative GDP gain over a 30-year horizon by year for each of the three scenarios. For instance, under scenario 3, it is estimated that the cumulative GDP gain for the United States by 2025 could be between US$220 billion and US$326 billion or between US$801 and US$1188 per person. For the United Kingdom, the cumulative GDP gain by 2025 is estimated to be between US$24.5 billion and US$36.4 billion or between US$435 and US$649. Other countries with relative large per person gains under scenario 3 are Australia (between US$690 and US$1029 per person by 2025), New Zealand (between US$550 and US$825 per person by 2025), Canada (between US$512 and US$763 per person by 2025), and Germany (between US$466 and US$694 per person by 2025).

Table 4.5: Scenario 1 – estimated GDP gain by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (US$ billion present value 2019) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 1 (Low)						Scenario 1 (High)					
Argentina	0.59	0.77	0.98	1.22	1.51	1.84	0.87	1.12	1.40	1.74	2.14	2.59
Australia	2.69	3.30	3.98	4.75	5.59	6.58	4.02	4.89	5.85	6.96	8.18	9.61
Austria	0.61	0.67	0.72	0.77	0.81	0.87	0.90	0.99	1.06	1.12	1.19	1.26
Canada	2.85	3.19	3.48	3.80	4.13	4.45	4.25	4.70	5.10	5.55	6.01	6.47
China	8.95	13.02	18.20	24.30	31.73	41.35	13.27	19.03	26.36	35.06	45.68	59.33
Ecuador	0.12	0.16	0.20	0.25	0.30	0.37	0.17	0.22	0.28	0.35	0.43	0.52
France	3.89	4.30	4.64	4.93	5.21	5.54	5.79	6.32	6.78	7.19	7.60	8.06
Germany	7.91	8.72	9.27	9.66	10.24	10.85	11.76	12.80	13.53	14.09	14.90	15.75
Hong Kong	0.25	0.29	0.33	0.36	0.40	0.43	0.37	0.42	0.47	0.52	0.56	0.61
Japan	6.94	7.33	7.62	7.78	7.70	7.66	10.36	10.82	11.18	11.36	11.24	11.19
Malaysia	0.46	0.54	0.61	0.67	0.73	0.79	0.69	0.78	0.87	0.95	1.04	1.12
Netherlands	1.19	1.32	1.42	1.51	1.60	1.70	1.77	1.94	2.07	2.20	2.33	2.47
New Zealand	0.41	0.51	0.61	0.73	0.86	1.01	0.62	0.75	0.90	1.07	1.26	1.47
Pakistan	0.58	0.76	0.97	1.21	1.49	1.82	0.86	1.11	1.39	1.72	2.11	2.57
Philippines	0.45	0.59	0.75	0.93	1.15	1.40	0.66	0.85	1.07	1.32	1.62	1.97
Singapore	0.27	0.31	0.35	0.39	0.42	0.46	0.40	0.45	0.50	0.55	0.60	0.65
South Africa	0.77	1.07	1.40	1.75	2.11	2.45	1.08	1.43	1.82	2.24	2.68	3.10
South Korea	2.25	2.55	2.82	3.06	3.28	3.51	3.36	3.75	4.12	4.46	4.76	5.09
Sri Lanka	0.14	0.19	0.24	0.30	0.37	0.45	0.21	0.27	0.34	0.43	0.52	0.64
Thailand	0.63	0.73	0.83	0.92	1.00	1.09	0.94	1.06	1.18	1.30	1.42	1.53
United Kingdom	5.61	6.60	7.55	8.49	9.50	10.55	8.36	9.72	11.05	12.40	13.85	15.36
United States	51.86	61.17	70.00	79.41	89.62	100.37	76.75	89.22	101.31	114.41	128.69	143.82
Vietnam	0.34	0.44	0.56	0.70	0.86	1.05	0.49	0.64	0.80	0.99	1.22	1.48
Rest of the world	37.75	48.56	60.58	74.05	89.63	106.99	55.36	69.83	86.11	104.44	125.70	149.63

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 1 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.6: Scenario 1 – estimated GDP gain in per cent by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (per cent) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 1 (Low)						Scenario 1 (High)					
Argentina	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
Australia	0.16%	0.16%	0.17%	0.17%	0.18%	0.18%	0.23%	0.24%	0.25%	0.26%	0.26%	0.27%
Austria	0.13%	0.14%	0.14%	0.14%	0.14%	0.14%	0.19%	0.20%	0.20%	0.20%	0.21%	0.21%
Canada	0.14%	0.15%	0.15%	0.15%	0.16%	0.16%	0.21%	0.22%	0.22%	0.23%	0.23%	0.23%
China	0.06%	0.07%	0.08%	0.08%	0.09%	0.10%	0.10%	0.11%	0.11%	0.12%	0.13%	0.14%
Ecuador	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
France	0.13%	0.14%	0.14%	0.14%	0.14%	0.14%	0.19%	0.20%	0.20%	0.20%	0.21%	0.21%
Germany	0.20%	0.21%	0.21%	0.22%	0.22%	0.22%	0.29%	0.30%	0.31%	0.31%	0.32%	0.33%
Hong Kong	0.11%	0.12%	0.13%	0.13%	0.14%	0.14%	0.16%	0.17%	0.18%	0.19%	0.19%	0.20%
Japan	0.14%	0.15%	0.15%	0.15%	0.15%	0.16%	0.21%	0.22%	0.22%	0.22%	0.23%	0.23%
Malaysia	0.11%	0.12%	0.13%	0.13%	0.14%	0.14%	0.16%	0.17%	0.18%	0.19%	0.19%	0.20%
Netherlands	0.13%	0.14%	0.14%	0.14%	0.14%	0.14%	0.19%	0.20%	0.20%	0.20%	0.21%	0.21%
New Zealand	0.16%	0.16%	0.17%	0.17%	0.18%	0.18%	0.23%	0.24%	0.25%	0.26%	0.26%	0.27%
Pakistan	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
Philippines	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
Singapore	0.11%	0.12%	0.13%	0.13%	0.14%	0.14%	0.16%	0.17%	0.18%	0.19%	0.19%	0.20%
South Africa	0.19%	0.22%	0.25%	0.27%	0.29%	0.29%	0.26%	0.30%	0.33%	0.35%	0.37%	0.37%
South Korea	0.15%	0.16%	0.16%	0.17%	0.17%	0.18%	0.22%	0.23%	0.24%	0.25%	0.25%	0.26%
Sri Lanka	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
Thailand	0.11%	0.12%	0.13%	0.13%	0.14%	0.14%	0.16%	0.17%	0.18%	0.19%	0.19%	0.20%
United Kingdom	0.16%	0.17%	0.17%	0.17%	0.17%	0.17%	0.24%	0.25%	0.25%	0.25%	0.25%	0.25%
United States	0.25%	0.26%	0.27%	0.27%	0.27%	0.28%	0.37%	0.38%	0.38%	0.39%	0.39%	0.40%
Vietnam	0.12%	0.13%	0.13%	0.14%	0.14%	0.14%	0.18%	0.18%	0.19%	0.19%	0.20%	0.20%
Rest of the world	0.12%	0.13%	0.13%	0.14%	0.15%	0.15%	0.17%	0.18%	0.19%	0.20%	0.20%	0.21%

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 1 three physical activity improvement scenarios relative to a base-line scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.7: Scenario 2 – estimated GDP gain by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (US$ billion present value 2019) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 2 (Low)						Scenario 2 (High)					
Argentina	0.36	0.45	0.55	0.68	0.82	1.00	0.54	0.67	0.82	1.00	1.22	1.48
Australia	2.05	2.45	2.91	3.45	4.04	4.73	3.05	3.66	4.34	5.13	6.02	7.04
Austria	0.47	0.50	0.53	0.56	0.59	0.63	0.69	0.74	0.79	0.83	0.88	0.93
Canada	2.56	2.78	2.99	3.24	3.49	3.74	3.81	4.14	4.45	4.82	5.20	5.57
China	14.59	20.23	27.39	36.00	46.52	59.83	21.73	30.13	40.77	53.58	69.22	89.00
Ecuador	0.07	0.09	0.11	0.14	0.17	0.20	0.11	0.13	0.16	0.20	0.25	0.30
France	2.98	3.19	3.38	3.58	3.78	4.01	4.44	4.75	5.04	5.32	5.62	5.96
Germany	3.50	3.72	3.89	4.05	4.28	4.51	5.21	5.53	5.79	6.03	6.36	6.71
Hong Kong	0.13	0.15	0.16	0.18	0.19	0.21	0.20	0.22	0.24	0.26	0.28	0.30
Japan	2.49	2.56	2.62	2.64	2.62	2.62	3.71	3.82	3.90	3.94	3.90	3.89
Malaysia	0.25	0.27	0.30	0.32	0.35	0.38	0.37	0.41	0.44	0.48	0.52	0.56
Netherlands	0.91	0.98	1.04	1.09	1.16	1.23	1.36	1.45	1.54	1.63	1.72	1.82
New Zealand	0.31	0.38	0.45	0.53	0.62	0.73	0.47	0.56	0.67	0.79	0.92	1.08
Pakistan	0.36	0.44	0.55	0.67	0.81	0.99	0.53	0.66	0.81	0.99	1.21	1.46
Philippines	0.27	0.34	0.42	0.51	0.63	0.76	0.41	0.51	0.62	0.76	0.93	1.12
Singapore	0.14	0.16	0.17	0.19	0.20	0.22	0.21	0.24	0.26	0.28	0.30	0.33
South Africa	0.29	0.35	0.41	0.48	0.56	0.65	0.44	0.52	0.61	0.71	0.83	0.96
South Korea	0.86	0.94	1.03	1.12	1.20	1.29	1.27	1.41	1.54	1.66	1.78	1.92
Sri Lanka	0.09	0.11	0.14	0.17	0.20	0.24	0.13	0.16	0.20	0.25	0.30	0.36
Thailand	0.34	0.37	0.41	0.44	0.48	0.52	0.51	0.56	0.61	0.66	0.71	0.77
United Kingdom	2.65	3.03	3.41	3.81	4.25	4.70	3.95	4.51	5.07	5.67	6.32	7.00
United States	22.41	25.33	28.34	31.75	35.52	39.57	33.40	37.73	42.20	47.26	52.86	58.87
Vietnam	0.20	0.25	0.31	0.38	0.47	0.57	0.31	0.38	0.47	0.57	0.70	0.84
Rest of the world	35.11	42.47	51.03	60.75	72.03	85.04	52.30	63.24	75.98	90.45	107.30	126.74

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 2 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.8: Scenario 2 – estimated GDP gain in per cent by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (per cent) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 2 (Low)						Scenario 2 (High)					
Argentina	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
Australia	0.12%	0.12%	0.12%	0.13%	0.13%	0.13%	0.18%	0.18%	0.18%	0.19%	0.19%	0.20%
Austria	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
Canada	0.13%	0.13%	0.13%	0.13%	0.13%	0.13%	0.19%	0.19%	0.19%	0.20%	0.20%	0.20%
China	0.11%	0.11%	0.12%	0.12%	0.13%	0.14%	0.16%	0.17%	0.18%	0.19%	0.20%	0.20%
Ecuador	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
France	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
Germany	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.13%	0.13%	0.13%	0.13%	0.14%	0.14%
Hong Kong	0.06%	0.06%	0.06%	0.06%	0.07%	0.07%	0.09%	0.09%	0.09%	0.10%	0.10%	0.10%
Japan	0.05%	0.05%	0.05%	0.05%	0.05%	0.05%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
Malaysia	0.06%	0.06%	0.06%	0.06%	0.07%	0.07%	0.09%	0.09%	0.09%	0.10%	0.10%	0.10%
Netherlands	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
New Zealand	0.12%	0.12%	0.12%	0.13%	0.13%	0.13%	0.18%	0.18%	0.18%	0.19%	0.19%	0.20%
Pakistan	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
Philippines	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
Singapore	0.06%	0.06%	0.06%	0.06%	0.07%	0.07%	0.09%	0.09%	0.09%	0.10%	0.10%	0.10%
South Africa	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
South Korea	0.06%	0.06%	0.06%	0.06%	0.06%	0.07%	0.08%	0.09%	0.09%	0.09%	0.09%	0.10%
Sri Lanka	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
Thailand	0.06%	0.06%	0.06%	0.06%	0.07%	0.07%	0.09%	0.09%	0.09%	0.10%	0.10%	0.10%
United Kingdom	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
United States	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%	0.16%	0.16%	0.16%	0.16%	0.16%	0.16%
Vietnam	0.07%	0.07%	0.07%	0.08%	0.08%	0.08%	0.11%	0.11%	0.11%	0.11%	0.11%	0.11%
Rest of the world	0.11%	0.11%	0.11%	0.11%	0.12%	0.12%	0.16%	0.16%	0.17%	0.17%	0.17%	0.18%

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 2 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.9: Scenario 3 – estimated GDP gain by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (US$ billion present value 2019) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 3 (Low)						Scenario 3 (High)					
Argentina	0.94	1.21	1.52	1.88	2.32	2.82	1.39	1.76	2.20	2.72	3.33	4.04
Australia	4.71	5.72	6.85	8.14	9.57	11.23	7.02	8.49	10.13	12.02	14.11	16.55
Austria	1.07	1.16	1.25	1.32	1.40	1.48	1.59	1.72	1.83	1.94	2.05	2.18
Canada	5.38	5.93	6.43	7.00	7.58	8.15	8.02	8.79	9.50	10.32	11.16	11.98
China	23.19	32.77	44.93	59.44	77.12	99.71	34.51	48.48	66.20	87.43	113.33	146.31
Ecuador	0.19	0.24	0.30	0.38	0.46	0.57	0.28	0.35	0.44	0.55	0.67	0.81
France	6.82	7.44	7.97	8.46	8.94	9.49	10.15	11.00	11.74	12.44	13.15	13.94
Germany	11.34	12.36	13.09	13.64	14.44	15.27	16.87	18.22	19.22	20.01	21.15	22.33
Hong Kong	0.38	0.43	0.48	0.53	0.58	0.63	0.56	0.63	0.70	0.76	0.83	0.90
Japan	9.29	9.75	10.10	10.28	10.19	10.14	13.87	14.43	14.87	15.08	14.94	14.87
Malaysia	0.70	0.80	0.89	0.98	1.07	1.16	1.04	1.17	1.29	1.41	1.53	1.66
Netherlands	2.09	2.28	2.44	2.59	2.74	2.91	3.11	3.37	3.59	3.81	4.02	4.27
New Zealand	0.72	0.88	1.05	1.25	1.47	1.72	1.08	1.30	1.55	1.84	2.17	2.54
Pakistan	0.93	1.19	1.50	1.86	2.29	2.79	1.37	1.74	2.18	2.69	3.30	4.00
Philippines	0.71	0.92	1.15	1.43	1.76	2.14	1.05	1.34	1.67	2.07	2.53	3.07
Singapore	0.41	0.46	0.51	0.57	0.62	0.67	0.60	0.67	0.74	0.82	0.88	0.96
South Africa	1.05	1.40	1.79	2.20	2.64	3.06	1.49	1.92	2.39	2.91	3.45	3.99
South Korea	3.05	3.43	3.78	4.11	4.40	4.72	4.54	5.06	5.56	6.01	6.43	6.88
Sri Lanka	0.23	0.30	0.37	0.46	0.57	0.69	0.34	0.43	0.54	0.67	0.82	0.99
Thailand	0.96	1.09	1.22	1.34	1.46	1.58	1.42	1.59	1.76	1.93	2.09	2.27
United Kingdom	8.15	9.49	10.81	12.13	13.57	15.05	12.14	14.04	15.91	17.82	19.90	22.06
United States	73.18	85.26	96.95	109.59	123.38	137.98	108.52	125.11	141.44	159.35	178.95	199.79
Vietnam	0.53	0.69	0.86	1.07	1.32	1.60	0.79	1.00	1.25	1.55	1.90	2.30
Rest of the world	71.96	89.61	109.64	132.24	158.47	188.19	106.56	131.42	159.84	192.01	229.42	272.08

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 3 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.10: Scenario 3 – estimated GDP gain in per cent by country relative to baseline scenario with current physical activity levels, by year

	GDP gain (percent) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 3 (Low)						Scenario 3 (High)					
Argentina	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
Australia	0.27%	0.28%	0.29%	0.30%	0.30%	0.31%	0.41%	0.42%	0.43%	0.44%	0.45%	0.46%
Austria	0.23%	0.23%	0.24%	0.24%	0.24%	0.25%	0.34%	0.35%	0.35%	0.35%	0.36%	0.36%
Canada	0.27%	0.28%	0.28%	0.28%	0.29%	0.29%	0.41%	0.41%	0.42%	0.42%	0.42%	0.42%
China	0.17%	0.18%	0.19%	0.21%	0.22%	0.23%	0.25%	0.27%	0.29%	0.30%	0.32%	0.34%
Ecuador	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
France	0.23%	0.23%	0.24%	0.24%	0.24%	0.25%	0.34%	0.35%	0.35%	0.35%	0.36%	0.36%
Germany	0.28%	0.29%	0.30%	0.30%	0.31%	0.32%	0.42%	0.43%	0.44%	0.45%	0.45%	0.46%
Hong Kong	0.16%	0.18%	0.19%	0.19%	0.20%	0.21%	0.24%	0.26%	0.27%	0.28%	0.29%	0.30%
Japan	0.19%	0.19%	0.20%	0.20%	0.20%	0.21%	0.28%	0.29%	0.29%	0.30%	0.30%	0.30%
Malaysia	0.16%	0.18%	0.19%	0.19%	0.20%	0.21%	0.24%	0.26%	0.27%	0.28%	0.29%	0.30%
Netherlands	0.23%	0.23%	0.24%	0.24%	0.24%	0.25%	0.34%	0.35%	0.35%	0.35%	0.36%	0.36%
New Zealand	0.27%	0.28%	0.29%	0.30%	0.30%	0.31%	0.41%	0.42%	0.43%	0.44%	0.45%	0.46%
Pakistan	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
Philippines	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
Singapore	0.16%	0.18%	0.19%	0.19%	0.20%	0.21%	0.24%	0.26%	0.27%	0.28%	0.29%	0.30%
South Africa	0.25%	0.29%	0.32%	0.34%	0.36%	0.37%	0.36%	0.40%	0.43%	0.45%	0.47%	0.48%
South Korea	0.20%	0.21%	0.22%	0.23%	0.23%	0.24%	0.30%	0.31%	0.32%	0.33%	0.34%	0.35%
Sri Lanka	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
Thailand	0.16%	0.18%	0.19%	0.19%	0.20%	0.21%	0.24%	0.26%	0.27%	0.28%	0.29%	0.30%
United Kingdom	0.24%	0.24%	0.24%	0.24%	0.25%	0.25%	0.35%	0.36%	0.36%	0.36%	0.36%	0.36%
United States	0.35%	0.36%	0.37%	0.37%	0.38%	0.38%	0.52%	0.53%	0.54%	0.54%	0.55%	0.55%
Vietnam	0.19%	0.20%	0.21%	0.21%	0.21%	0.22%	0.28%	0.29%	0.30%	0.30%	0.31%	0.31%
Rest of the world	0.22%	0.23%	0.24%	0.25%	0.26%	0.26%	0.33%	0.34%	0.35%	0.36%	0.37%	0.38%

Notes: Table entries represent per cent estimated changes in country-specific GDP for scenario 3 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.11: Scenario 1 – estimated cumulative GDP gain by country over 30 years relative to baseline scenario with current physical activity levels

	Cumulative GDP gain (US$ billion present value 2019) relative to baseline, by year											
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 1 (Low)						Scenario 1 (High)					
Argentina	1.8	5.2	9.7	15.3	22.3	30.8	2.6	7.7	14.1	22.1	32.0	44.0
Australia	8.1	23.3	41.8	63.9	90.1	121.0	12.0	34.7	61.9	94.5	132.9	178.0
Austria	1.8	5.1	8.6	12.3	16.3	20.5	2.7	7.5	12.6	18.1	23.9	30.1
Canada	8.6	23.8	40.6	59.0	78.9	100.5	12.8	35.3	60.0	86.8	115.9	147.3
China	26.9	83.2	163.1	271.7	414.7	601.2	39.8	122.6	238.8	397.3	603.3	871.2
Ecuador	0.4	1.1	2.0	3.1	4.5	6.2	0.5	1.5	2.8	4.4	6.4	8.8
France	11.7	32.3	54.8	78.9	104.4	131.4	17.4	47.9	80.8	116.0	153.2	192.6
Germany	23.7	65.7	110.9	158.4	208.4	261.5	35.3	97.1	163.3	232.9	305.8	382.8
Hong Kong	0.8	2.1	3.7	5.4	7.3	9.4	1.1	3.1	5.4	7.9	10.6	13.5
Japan	20.8	56.7	94.2	132.7	171.4	209.8	31.1	84.2	139.4	196.1	252.5	308.6
Malaysia	1.4	3.9	6.8	10.0	13.6	17.4	2.1	5.8	9.9	14.5	19.5	25.0
Netherlands	3.6	9.9	16.8	24.2	32.0	40.2	5.3	14.7	24.8	35.5	46.9	59.0
New Zealand	1.2	3.6	6.4	9.8	13.9	18.6	1.9	5.3	9.5	14.5	20.4	27.3
Pakistan	1.8	5.2	9.6	15.2	22.0	30.5	2.6	7.6	14.0	21.9	31.6	43.5
Philippines	1.4	4.0	7.4	11.7	17.0	23.4	2.0	5.8	10.7	16.8	24.3	33.4
Singapore	0.8	2.3	3.9	5.8	7.8	10.0	1.2	3.4	5.8	8.4	11.3	14.5
South Africa	2.3	7.0	13.4	21.4	31.2	42.8	3.2	9.7	18.0	28.4	40.9	55.5
South Korea	6.8	18.9	32.4	47.2	63.2	80.2	10.1	28.0	47.9	69.6	92.8	117.5
Sri Lanka	0.4	1.3	2.4	3.8	5.5	7.6	0.6	1.9	3.5	5.4	7.8	10.8
Thailand	1.9	5.4	9.3	13.7	18.5	23.8	2.8	7.9	13.5	19.8	26.7	34.1
United Kingdom	16.8	47.8	83.6	124.1	169.5	220.1	25.1	70.9	123.4	182.9	249.1	322.9
United States	155.6	442.2	774.1	1,151.8	1,579.0	2,058.8	230.3	650.7	1,132.4	1,678.4	2,292.6	2,980.8
Vietnam	1.0	3.0	5.5	8.7	12.7	17.5	1.5	4.4	8.0	12.6	18.2	25.1
Rest of the world	113.3	333.3	611.1	953.4	1,369.1	1,868.1	166.1	485.0	881.6	1,367.7	1,952.1	2,650.7

Notes: Table entries represent per cent estimated cumulative changes in GDP by country over 30 years for scenario 1 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.12: Scenario 1 – estimated cumulative GDP gain per person over 30 years relative to baseline scenario with current physical activity levels

Cumulative GDP gain (US$ present value 2019) relative to baseline per adult person, by year												
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 1 (Low)						Scenario 1 (High)					
Argentina	49.9	136.7	236.6	351.1	484.1	638.8	73.3	199.9	342.9	506.3	694.3	912.0
Australia	394.0	1,078.6	1,847.2	2,722.6	3,748.7	4,965.0	588.6	1,605.6	2,738.5	4,025.0	5,526.6	7,303.5
Austria	236.0	638.8	1,065.5	1,529.6	2,038.7	2,604.3	350.1	945.0	1,572.7	2,253.4	2,994.9	3,823.2
Canada	271.1	725.8	1,199.9	1,705.9	2,270.7	2,915.6	404.2	1,076.4	1,771.9	2,511.5	3,335.0	4,273.4
China	22.1	65.2	122.6	198.6	300.3	439.5	32.8	96.1	179.4	290.3	436.9	636.9
Ecuador	27.3	73.8	125.2	181.9	244.2	314.7	39.7	106.2	179.8	259.7	346.9	445.5
France	212.0	566.6	934.0	1,315.7	1,731.1	2,181.5	315.4	839.0	1,376.9	1,935.4	2,540.8	3,196.7
Germany	325.2	887.3	1,501.5	2,166.4	2,896.1	3,732.5	483.5	1,312.7	2,210.9	3,184.8	4,248.3	5,465.0
Hong Kong	114.1	317.1	545.0	787.2	1,072.1	1,416.4	168.9	465.2	793.9	1,143.7	1,544.5	2,033.5
Japan	184.0	498.0	832.7	1,201.0	1,615.3	2,068.1	274.6	740.5	1,233.0	1,774.2	2,380.0	3,041.9
Malaysia	54.3	140.7	225.8	308.5	389.8	473.0	80.0	205.8	328.2	445.5	560.8	677.9
Netherlands	241.1	645.7	1,072.7	1,526.1	2,025.7	2,576.9	358.6	957.1	1,581.3	2,245.2	2,972.7	3,776.0
New Zealand	313.1	859.9	1,474.4	2,172.4	2,983.6	3,936.2	470.9	1,277.8	2,182.9	3,208.8	4,399.0	5,785.8
Pakistan	12.4	32.1	52.4	72.4	92.9	114.6	18.2	46.9	76.0	104.5	133.5	163.8
Philippines	17.2	45.2	75.4	106.9	141.0	177.9	25.2	65.9	108.9	154.0	201.8	253.9
Singapore	160.5	432.1	725.2	1,045.3	1,404.6	1,823.6	240.8	640.6	1,061.1	1,516.5	2,029.7	2,624.6
South Africa	50.7	149.9	278.9	443.5	650.1	907.5	71.1	205.7	375.2	588.5	851.5	1,177.8
South Korea	154.2	389.5	610.1	814.6	1,007.6	1,194.9	229.9	578.1	901.2	1,200.1	1,479.7	1,750.3
Sri Lanka	25.8	69.9	121.8	182.8	256.0	343.6	37.5	101.9	175.8	262.8	365.4	488.8
Thailand	31.7	85.1	143.0	206.0	275.4	354.4	46.9	125.1	208.0	298.0	396.6	508.3
United Kingdom	299.7	817.7	1,384.6	2,012.0	2,727.3	3,535.3	446.7	1,213.3	2,044.8	2,965.3	4,008.5	5,185.4
United States	567.8	1,532.8	2,580.4	3,726.1	5,017.8	6,498.5	840.3	2,255.5	3,775.1	5,429.7	7,285.6	9,408.7
Vietnam	13.0	35.7	61.6	91.3	126.3	168.8	19.2	52.5	89.7	131.9	181.3	241.1
Rest of the world	31.6	83.7	139.3	200.6	267.6	341.6	46.4	121.7	201.0	287.7	381.6	484.7

Notes: Table entries represent the cumulative GDP gain per adult person by year, where the cumulative GDP gain is divided by the adult population in a given year.

Table 4.13: Scenario 2 – estimated cumulative GDP gain by country over 30 years relative to baseline scenario with current physical activity levels

Cumulative GDP gain (US$ billion present value 2019) relative to baseline, by year												
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 2 (Low)						Scenario 2 (High)					
Argentina	1.1	3.1	5.7	8.8	12.6	17.2	1.6	4.7	8.4	13.1	18.7	25.6
Australia	6.2	17.6	31.2	47.3	66.3	88.5	9.2	26.2	46.5	70.5	98.8	131.8
Austria	1.4	3.8	6.4	9.1	12.0	15.1	2.1	5.7	9.5	13.6	17.9	22.4
Canada	7.7	21.1	35.6	51.3	68.3	86.5	11.4	31.5	53.1	76.4	101.7	128.7
China	43.8	132.9	254.7	416.5	627.0	898.1	65.2	198.0	379.2	620.1	933.3	1,336.8
Ecuador	0.2	0.6	1.1	1.8	2.5	3.5	0.3	0.9	1.7	2.6	3.8	5.2
France	8.9	24.5	41.0	58.5	77.0	96.5	13.3	36.4	61.1	87.1	114.6	143.7
Germany	10.5	28.6	47.8	67.7	88.6	110.7	15.6	42.6	71.1	100.7	131.9	164.7
Hong Kong	0.4	1.1	1.9	2.8	3.7	4.7	0.6	1.7	2.8	4.1	5.5	6.9
Japan	7.5	20.1	33.1	46.3	59.4	72.5	11.1	30.0	49.3	68.9	88.5	108.0
Malaysia	0.8	2.1	3.5	5.1	6.8	8.6	1.1	3.1	5.2	7.6	10.1	12.8
Netherlands	2.7	7.5	12.6	17.9	23.6	29.6	4.1	11.2	18.7	26.7	35.1	44.0
New Zealand	0.9	2.7	4.8	7.3	10.2	13.6	1.4	4.0	7.1	10.8	15.2	20.2
Pakistan	1.1	3.1	5.6	8.7	12.5	17.0	1.6	4.6	8.4	12.9	18.5	25.3
Philippines	0.8	2.4	4.3	6.7	9.6	13.1	1.2	3.5	6.4	9.9	14.2	19.4
Singapore	0.4	1.2	2.0	3.0	3.9	5.0	0.6	1.8	3.0	4.4	5.8	7.4
South Africa	0.9	2.5	4.4	6.7	9.3	12.4	1.3	3.7	6.6	9.9	13.8	18.3
South Korea	2.6	7.1	12.1	17.5	23.3	29.6	3.8	10.6	18.0	26.1	34.7	44.1
Sri Lanka	0.3	0.8	1.4	2.2	3.1	4.2	0.4	1.2	2.1	3.2	4.6	6.3
Thailand	1.0	2.8	4.8	6.9	9.3	11.8	1.5	4.2	7.2	10.4	13.8	17.6
United Kingdom	8.0	22.3	38.6	56.8	77.1	99.7	11.9	33.3	57.5	84.6	114.8	148.4
United States	67.2	187.9	323.5	475.3	645.1	834.7	100.2	280.0	481.9	707.8	960.7	1,242.7
Vietnam	0.6	1.8	3.2	5.0	7.1	9.8	0.9	2.7	4.8	7.5	10.7	14.6
Rest of the world	105.3	302.4	539.8	823.4	1,160.3	1,558.6	156.9	450.4	803.9	1,226.2	1,727.8	2,321.3

Notes: Table entries represent per cent estimated cumulative changes in GDP by country over 30 years for scenario 2 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.14: Scenario 2 – estimated cumulative GDP gain per person over 30 years relative to baseline scenario with current physical activity levels

Cumulative GDP gain (US$ present value 2019) relative to baseline per adult person, by year												
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 2 (Low)						Scenario 2 (High)					
Argentina	30.5	81.9	138.7	201.9	274.0	357.6	45.4	121.9	205.7	299.6	407.2	531.0
Australia	300.6	813.7	1,378.5	2,015.1	2,756.4	3,631.8	447.3	1,212.9	2,054.1	3,002.0	4,106.8	5,409.8
Austria	181.5	484.5	798.8	1,136.6	1,504.3	1,916.7	269.7	718.5	1,187.7	1,690.0	2,239.0	2,852.1
Canada	243.5	643.8	1,052.8	1,484.5	1,963.7	2,507.7	362.7	959.3	1,568.6	2,211.7	2,924.7	3,734.5
China	36.0	104.1	191.3	304.4	454.0	656.6	53.7	155.1	285.0	453.2	675.9	977.3
Ecuador	16.4	44.3	73.2	104.2	138.1	175.9	24.9	65.4	108.5	154.3	205.0	261.5
France	162.4	428.7	698.2	975.6	1,276.6	1,602.7	242.0	638.6	1,039.9	1,452.3	1,900.2	2,385.3
Germany	143.9	387.1	646.5	925.7	1,231.4	1,580.5	214.1	576.2	962.1	1,377.5	1,832.2	2,351.6
Hong Kong	60.9	167.5	281.4	400.2	536.8	702.9	91.3	248.3	417.7	593.7	797.1	1,043.1
Japan	66.0	176.9	292.7	418.5	559.9	714.8	98.4	263.6	436.1	623.6	834.1	1,064.6
Malaysia	29.3	73.7	115.9	155.5	194.2	233.7	43.3	110.2	173.2	232.3	289.9	348.3
Netherlands	184.4	489.0	801.8	1,131.1	1,493.3	1,892.8	275.6	728.6	1,194.1	1,684.7	2,222.9	2,816.5
New Zealand	239.3	648.5	1,098.3	1,604.4	2,190.9	2,873.9	358.9	965.6	1,634.9	2,391.2	3,263.7	4,279.1
Pakistan	7.5	19.1	30.5	41.5	52.5	64.1	11.2	28.5	45.6	61.8	78.2	95.3
Philippines	10.3	26.9	43.8	61.1	79.5	99.4	15.5	40.0	65.2	91.0	118.3	147.7
Singapore	88.3	231.4	376.4	532.6	705.9	908.2	128.4	340.4	557.3	788.9	1,047.2	1,347.7
South Africa	19.3	53.2	92.3	138.6	194.3	262.8	28.5	79.2	137.3	205.8	287.9	389.1
South Korea	58.5	146.5	227.6	302.1	372.3	440.9	87.1	218.4	338.9	449.5	553.9	656.0
Sri Lanka	15.8	42.3	71.4	105.2	144.8	192.4	23.5	62.3	106.0	156.6	216.3	286.4
Thailand	17.0	44.9	73.7	104.4	137.7	175.4	25.4	67.2	110.3	155.9	205.5	261.6
United Kingdom	141.6	382.1	639.3	921.0	1,240.9	1,601.3	211.0	569.3	951.9	1,371.3	1,847.5	2,384.0
United States	245.4	651.4	1,078.3	1,537.5	2,050.2	2,634.7	365.7	970.5	1,606.3	2,289.8	3,052.9	3,922.6
Vietnam	7.7	21.0	35.7	52.0	71.1	94.2	11.7	31.7	53.7	78.1	106.3	140.3
Rest of the world	29.4	75.9	123.0	173.2	226.8	285.0	43.8	113.0	183.2	258.0	337.7	424.5

Notes: Table entries represent the cumulative GDP gain per adult person by year, where the cumulative GDP gain is divided by the adult population in a given year.

Table 4.15: Scenario 3 – estimated cumulative GDP gain by country over 30 years relative to baseline scenario with current physical activity levels

Cumulative GDP gain (US$ billion present value 2019) relative to baseline, by year												
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 3 (Low)						Scenario 3 (High)					
Argentina	2.8	8.3	15.2	23.9	34.6	47.6	4.2	12.2	22.3	34.8	50.2	68.9
Australia	14.1	40.6	72.5	110.6	155.5	208.2	21.1	60.5	107.7	163.9	230.2	307.9
Austria	3.2	8.8	14.9	21.3	28.2	35.4	4.8	13.1	22.0	31.5	41.6	52.2
Canada	16.2	44.7	75.9	109.7	146.4	186.0	24.1	66.4	112.5	162.4	216.5	274.7
China	69.6	212.9	411.7	678.3	1,026.7	1,477.8	103.5	316.1	609.5	1,001.8	1,514.0	2,176.2
Ecuador	0.6	1.7	3.1	4.8	6.9	9.6	0.8	2.5	4.5	7.0	10.1	13.8
France	20.5	56.4	95.2	136.5	180.2	226.6	30.5	83.7	140.9	201.7	266.0	334.1
Germany	34.0	93.8	157.7	224.8	295.4	370.0	50.6	139.0	233.0	331.5	434.9	544.2
Hong Kong	1.1	3.2	5.5	8.0	10.8	13.9	1.7	4.7	8.0	11.7	15.7	20.1
Japan	27.9	75.7	125.5	176.6	227.7	278.5	41.6	112.6	186.1	261.1	336.0	410.5
Malaysia	2.1	5.9	10.2	14.9	20.0	25.6	3.1	8.7	14.9	21.7	29.1	37.2
Netherlands	6.3	17.3	29.1	41.8	55.2	69.4	9.3	25.6	43.2	61.8	81.4	102.3
New Zealand	2.2	6.2	11.1	17.0	23.9	32.0	3.2	9.3	16.5	25.1	35.3	47.2
Pakistan	2.8	8.2	15.1	23.6	34.2	47.1	4.1	12.0	22.0	34.4	49.6	68.2
Philippines	2.1	6.3	11.6	18.1	26.2	36.1	3.2	9.3	16.9	26.4	38.1	52.3
Singapore	1.2	3.4	5.9	8.6	11.5	14.8	1.8	5.0	8.6	12.5	16.8	21.5
South Africa	3.2	9.4	17.5	27.7	40.0	54.4	4.5	13.2	24.1	37.6	53.8	72.6
South Korea	9.2	25.5	43.7	63.6	85.0	107.9	13.6	37.9	64.7	93.8	125.1	158.6
Sri Lanka	0.7	2.0	3.7	5.9	8.5	11.7	1.0	3.0	5.5	8.5	12.3	16.9
Thailand	2.9	8.1	13.9	20.3	27.4	35.0	4.3	11.9	20.3	29.7	39.8	50.8
United Kingdom	24.5	69.1	120.5	178.4	243.3	315.5	36.4	102.7	178.5	263.7	358.9	464.8
United States	219.5	620.9	1,081.7	1,603.8	2,192.4	2,852.5	325.6	917.0	1,590.7	2,350.8	3,205.4	4,161.7
Vietnam	1.6	4.7	8.7	13.6	19.7	27.1	2.4	6.9	12.7	19.8	28.6	39.2
Rest of the world	215.9	627.1	1,133.6	1,747.9	2,485.9	3,365.3	319.7	925.0	1,665.1	2,558.4	3,628.0	4,900.2

Notes: Table entries represent per cent estimated cumulative changes in GDP by country over 30 years for scenario 3 relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').

Table 4.16: Scenario 3 – estimated cumulative GDP gain per person over 30 years relative to baseline scenario with current physical activity levels

Cumulative GDP gain (US$ present value 2019) relative to baseline per adult person, by year												
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 3 (Low)						Scenario 3 (High)					
Argentina	79.5	216.6	371.2	547.1	750.8	987.1	117.3	318.1	543.0	797.9	1,090.6	1,429.5
Australia	690.2	1,880.7	3,206.3	4,708.7	6,465.2	8,543.1	1,029.5	2,800.9	4,763.5	6,981.9	9,571.8	12,633.3
Austria	414.9	1,113.2	1,851.9	2,651.3	3,524.3	4,499.3	617.2	1,654.6	2,743.0	3,918.5	5,200.1	6,633.3
Canada	512.0	1,362.6	2,241.1	3,174.2	4,212.6	5,395.5	762.8	2,025.4	3,324.0	4,700.4	6,229.5	7,969.6
China	57.3	166.8	309.4	495.7	743.5	1,080.3	85.2	247.7	458.0	732.1	1,096.4	1,590.9
Ecuador	44.4	117.4	196.5	282.6	377.4	484.0	65.5	172.3	287.0	411.0	547.6	700.9
France	371.8	988.3	1,621.0	2,276.3	2,988.8	3,761.1	553.3	1,467.2	2,400.4	3,364.5	4,412.2	5,547.0
Germany	466.3	1,267.1	2,135.4	3,074.4	4,104.0	5,282.7	693.6	1,878.1	3,155.0	4,533.0	6,043.0	7,769.1
Hong Kong	173.5	477.2	813.1	1,169.9	1,585.5	2,090.7	255.6	701.6	1,190.8	1,705.4	2,302.2	3,023.9
Japan	246.4	665.5	1,109.9	1,597.4	2,145.7	2,745.1	367.7	989.9	1,645.6	2,362.0	3,167.0	4,046.7
Malaysia	82.0	211.2	336.4	456.9	575.4	696.4	121.8	311.0	492.7	666.4	836.3	1,009.3
Netherlands	423.5	1,127.4	1,861.8	2,640.8	3,498.1	4,444.1	630.2	1,673.9	2,756.9	3,902.7	5,161.9	6,552.1
New Zealand	549.8	1,494.0	2,547.5	3,748.1	5,137.9	6,761.4	824.7	2,229.0	3,790.3	5,555.8	7,606.7	9,997.2
Pakistan	19.7	50.8	82.1	112.8	144.2	177.2	29.1	74.5	120.0	164.2	209.3	256.4
Philippines	27.1	71.1	117.5	166.1	218.0	274.6	40.0	104.7	172.1	242.2	316.8	397.7
Singapore	242.8	652.0	1,081.3	1,547.2	2,071.0	2,684.6	361.2	958.0	1,585.1	2,262.1	3,019.3	3,896.1
South Africa	69.2	200.4	366.2	574.0	832.7	1,154.4	98.2	280.3	504.4	780.4	1,120.4	1,541.2
South Korea	209.1	526.5	822.7	1,096.8	1,355.4	1,607.1	311.4	781.6	1,217.3	1,618.1	1,995.2	2,361.6
Sri Lanka	40.5	110.1	190.1	283.6	395.8	529.2	59.8	161.6	277.8	413.0	573.8	765.6
Thailand	48.1	128.3	213.4	305.5	406.9	521.7	71.1	188.9	312.8	446.0	591.7	756.9
United Kingdom	435.4	1,183.5	1,996.3	2,893.4	3,914.7	5,067.7	649.0	1,758.6	2,956.8	4,275.6	5,774.9	7,465.5
United States	801.2	2,152.4	3,606.0	5,188.3	6,967.3	9,003.7	1,188.1	3,178.6	5,302.8	7,604.8	10,186.4	13,136.3
Vietnam	20.6	56.4	96.6	142.2	195.7	260.5	30.6	83.1	141.6	207.4	284.5	377.6
Rest of the world	60.3	157.4	258.4	367.7	485.9	615.4	89.3	232.2	379.6	538.2	709.2	896.1

Notes: Table entries represent the cumulative GDP gain per adult person by year, where the cumulative GDP gain is divided by the adult population in a given year.

4.3. Estimating potential savings in healthcare expenditure by getting people to be more physically active

In order to calculate the current and future healthcare expenditure associated with improvements in physical activity levels under the three scenario sets outlined above, we closely follow the methodological approach taken in Ding et al. (2016). That study estimates the healthcare costs attributable to physical inactivity using a population-attributable fraction (PAF) approach in relation to the following five disease areas[48]:

1. Coronary heart disease;
2. Type 2 diabetes;
3. Breast cancer;
4. Colon cancer; and
5. Stroke.

We use the latest data available from the Global Burden of Disease (GBD) database and extract the prevalent cases for all five diseases by year and specific age and gender groups and combine them with the PAF provided in the GBD database to calculate the overall number of cases attributable to physical inactivity. In essence, the PAFs for each disease can be interpreted as the proportion of disease (or mortality) that would not exist in the absence of physical inactivity. We then use the per case healthcare costs for the five disease areas as reported by Ding et al. (2016) to calculate the current estimated healthcare expenditure reductions under three different physical activity improvement scenarios. We further project these costs into the future, keeping the current prevalence of the diseases constant but not the underlying population.[49] That is, we use the population projections by country and estimate how future healthcare costs associated with physical activity would evolve over time using future demographic trends. For instance, with an ageing population, overall healthcare costs are expected to rise, all else being equal.[50] More detail on the analysis is provided in Appendix C.

Tables 4.17 to 4.19 report the estimated potential annual healthcare expenditure that could be avoided by getting people to be more physically active under the three scenarios: (1) every adult reaches at least the recommended 600 MET-minutes per week; (2) every adult 20 per cent more active; or (3) every adult who does not reach the recommended levels reaches at least the recommended 600 MET-minutes per week and getting everyone who exceeds 600 MET-minutes to improve their current level by 20 per cent.

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48 These disease areas were selected by Ding et al. (2016) according to the best available empirical evidence on the relative risks associated with physical inactivity for each of the five disease areas.

49 It is important to stress that we chose to keep the prevalence and the associated cost per case of the disease constant over the years for parsimonious reasons. If the prevalence rates were to increase over time, then the estimated future healthcare expenditure savings by making people more physically active would be underestimated. Conversely, if the prevalence rates were to decrease over time, the expenditure savings would be overestimated. This would also apply if the per case medical costs were to decrease over time. As it is not a priori clear in which directions future prevalence rates and medical costs will evolve, we have kept them constant. Hence, the projected future healthcare expenditure savings are driven by population changes only.

50 The population projections are based on the demographic cohort-component model, which is described in more detail in Appendix D.

Table 4.17: Scenario 1 – estimated potential healthcare cost savings, by year

Direct healthcare cost savings (US$ million present value 2019), by year							
	2020	2025	2030	2035	2040	2045	2050
Global	8,733.0	10,921.5	12,654.8	14,223.9	15,494.6	16,230.9	16,495.4
Argentina	33.2	41.1	47.1	52.6	57.3	60.8	63.4
Australia	54.8	68.0	78.4	88.2	95.7	99.7	101.4
Austria	24.2	29.2	32.6	35.1	36.4	37.2	37.5
Canada	80.4	99.4	114.5	129.0	140.0	144.8	144.1
China	598.5	823.9	1,023.5	1,219.2	1,397.0	1,524.9	1,574.6
Ecuador	1.9	2.5	3.0	3.5	4.0	4.5	4.9
France	90.4	104.9	113.0	120.4	126.0	125.4	121.8
Germany	200.8	243.3	267.5	276.9	281.9	285.4	282.1
Hong Kong	5.0	6.9	8.6	10.2	11.7	12.8	13.2
Japan	844.8	985.5	1,052.5	1,084.8	1,073.2	1,013.1	950.1
Malaysia	18.5	25.7	32.1	38.6	44.9	50.7	55.9
Netherlands	86.9	108.0	122.5	134.3	141.4	141.4	137.9
New Zealand	6.4	7.9	9.1	10.1	10.8	11.2	11.2
Pakistan	16.1	22.0	27.3	32.8	38.4	44.2	50.3
Philippines	9.6	13.4	16.9	20.5	24.2	27.5	30.5
Singapore	21.0	28.4	35.2	42.2	48.8	53.1	54.9
South Africa	39.5	53.6	66.9	80.0	92.7	104.7	115.4
South Korea	125.1	166.7	200.8	232.0	259.4	280.1	290.7
Sri Lanka	4.3	5.8	7.1	8.3	9.2	9.7	10.0
Thailand	26.9	35.8	43.4	50.6	57.2	62.2	64.6
United Kingdom	266.4	319.2	353.2	380.1	395.9	397.2	395.5
United States	4,916.7	6,039.8	6,927.6	7,719.4	8,304.8	8,537.6	8,474.6
Vietnam	11.9	15.4	18.7	22.4	26.4	30.2	32.8
Rest of the world	1,249.5	1,675.2	2,053.3	2,432.6	2,817.2	3,172.5	3,477.9

Notes: Table entries represent the potential healthcare savings associated with making people more physically active under scenario 1.

The estimates reported in Table 4.17 suggest that under scenario 1, about US$8.7 billion of annual healthcare expenditure across the five disease areas globally could be saved by getting people to be more physically active. These estimates increase over time, and the potential savings could reach up to US$16.5 billion per year by 2050. As Table 4.17 suggests, the country-specific savings vary considerably, with the United States responsible for the majority of these potential savings (almost US$5 billion). Other countries with considerable estimated healthcare savings under scenario 1 are Japan (from currently US$845 million to US$950 million),[51] as well as China (US$599 million to US$1,574 million) the United Kingdom (US$266 million to US$396 million) and Germany (US$201 million to US$282 million).

Table 4.18: Scenario 2 – estimated potential healthcare cost savings, by year

Direct healthcare cost reductions (US$ million present value 2019)							
	2020	2025	2030	2035	2040	2045	2050
Global	5,179.6	5,731.5	6,512.6	7,189.6	7,745.6	8,111.6	8,299.9
Argentina	24.1	26.1	29.0	31.7	33.9	35.5	36.7
Australia	70.4	77.0	86.7	95.4	101.8	104.8	105.6
Austria	32.4	34.5	37.7	39.9	40.8	41.2	41.0
Canada	139.7	152.0	170.4	186.3	197.0	199.8	196.6
China	362.3	417.5	487.8	551.6	602.6	635.4	641.1
Ecuador	5.6	6.3	7.4	8.5	9.5	10.4	11.2
France	134.0	137.9	146.3	153.4	158.3	156.3	151.0
Germany	201.1	227.6	261.4	271.7	273.8	273.3	262.6
Hong Kong	3.0	3.5	4.1	4.6	5.1	5.3	5.4
Japan	258.0	262.6	274.5	279.0	273.6	256.8	238.8
Malaysia	7.8	9.1	10.8	12.5	14.1	15.4	16.6
Netherlands	103.5	112.4	124.5	133.5	138.3	136.8	132.5
New Zealand	13.7	15.0	16.9	18.6	19.7	20.1	20.1
Pakistan	4.1	4.7	5.6	6.5	7.4	8.3	9.2
Philippines	4.7	5.4	6.4	7.3	8.1	8.9	9.6
Singapore	8.6	9.9	11.5	13.1	14.4	15.2	15.4
South Africa	20.1	23.0	27.0	31.0	34.7	38.1	41.0
South Korea	47.8	54.2	62.1	68.5	73.5	76.7	77.6
Sri Lanka	2.1	2.3	2.6	2.8	3.0	3.1	3.1
Thailand	10.9	12.1	13.6	15.0	16.1	16.8	17.0
United Kingdom	140.8	149.1	162.2	171.9	177.2	176.7	174.9
United States	1,853.0	1,994.7	2,216.3	2,395.0	2,514.5	2,547.1	2,510.9
Vietnam	7.3	8.2	9.4	10.7	11.9	13.1	13.8
Rest of the world	1,724.6	1,986.4	2,338.4	2,681.1	3,016.3	3,316.5	3,568.2

Notes: Table entries represent the potential healthcare savings associated with making people more physically active under scenario 2.

51 Note that for Japan the overall estimated savings decrease after 2035 due to a decline of the population in the future.

As reported in Table 4.18, for scenario 2, we estimate that the potential global annual healthcare expenditure savings range from US$5.4 billion currently (2020) to US$8.5 billion by 2050, again, with the largest part of these savings for the United States (from US$1.9 billion currently to US$2.5 billion by 2050), followed by Japan (US$258 million to US$238 million), Germany (US$201 million to US$262 million) and the United Kingdom (US$140 million to US$175 million).

Finally, as reported in Table 4.19, for scenario 3, we estimate that the potential global annual healthcare expenditure savings range from US$11.2 billion currently to US$20.6 billion by 2050. For the United States alone, this corresponds to US$4.7 billion to US$7.6 billion.

Table 4.19: Scenario 3 – estimated potential healthcare cost savings, by year

Direct healthcare cost reductions (US$ million present value 2019)							
	2020	2025	2030	2035	2040	2045	2050
Global	11,220.7	13,899.8	15,921.4	17,717.7	19,201.2	20,150.5	20,601.7
Argentina	46.8	57.0	64.3	70.9	76.4	80.7	83.8
Australia	122.8	150.1	170.4	188.9	202.9	209.9	212.3
Austria	55.1	65.6	72.3	77.1	79.3	80.4	80.5
Canada	230.6	280.2	316.7	349.9	373.6	382.1	378.1
China	822.7	1,085.5	1,301.7	1,504.8	1,677.7	1,796.5	1,831.1
Ecuador	7.8	9.9	11.7	13.5	15.2	16.8	18.2
France	205.0	235.5	251.1	264.9	275.0	272.4	263.8
Germany	543.8	668.0	734.4	756.9	764.5	767.6	752.0
Hong Kong	6.9	9.1	10.9	12.6	14.1	15.1	15.4
Japan	748.7	860.8	910.5	932.5	918.9	865.2	808.2
Malaysia	18.9	25.4	31.1	36.8	42.3	47.1	51.4
Netherlands	184.5	225.1	251.7	272.6	284.4	282.7	274.8
New Zealand	22.0	26.9	30.7	33.9	36.2	37.1	37.2
Pakistan	11.8	15.7	19.1	22.7	26.3	29.9	33.7
Philippines	10.1	13.4	16.4	19.3	22.3	25.0	27.4
Singapore	21.4	28.1	33.8	39.5	44.7	48.0	49.1
South Africa	41.4	54.2	65.8	77.0	87.8	97.9	106.6
South Korea	123.1	159.8	188.2	213.0	234.0	249.2	256.0
Sri Lanka	4.4	5.6	6.6	7.5	8.1	8.5	8.6
Thailand	26.6	34.1	40.0	45.4	50.1	53.6	55.0
United Kingdom	313.2	371.3	407.2	434.7	450.4	450.4	447.0
United States	4,722.2	5,709.9	6,439.9	7,068.1	7,518.8	7,680.1	7,601.7
Vietnam	14.4	18.2	21.4	25.0	28.6	31.9	34.3
Rest of the world	2,916.7	3,790.4	4,525.6	5,250.4	5,969.7	6,622.5	7,175.6

Notes: Table entries represent the potential healthcare savings associated with making people more physically active under scenario 3.

4.4. Discussing the findings

Our analytical approach aims to provide estimates for the potential macroeconomic effects of different physical activity improvement scenarios and associated reductions in premature mortality, sickness absence and presenteeism rates. Our reported estimates are based only on improving the physical activity levels of the adult population. This may result in an underestimation of the potential benefits if, for instance, children and adolescents benefit from better health and educational outcomes by becoming more physically active.[52] Furthermore, in our analytical approach, we only take into account reductions in sickness absence and presenteeism rates that are directly associated with individuals in the labour force. However, if, for instance, physical inactivity is associated with a higher risk of certain diseases for older adults, and their relatives need to provide care for them, then that could be associated with additional working days lost of the current labour force, which we do not take into account. Nevertheless, while it is difficult to compare our findings directly with existing studies due to differences in methodologies and data inputs, our estimates tend to be somewhat higher than previous estimates that aimed to look at similar mechanisms in terms of benefits associated with lower mortality and reduced sickness absence and presenteeism rates.

To the best of our knowledge, only one study, for Canada, has assessed the macroeconomic benefits of making people more physically active (Conference Board of Canada 2018). Taking into account reductions in premature mortality, sickness absence and disability, the study estimates that getting 10 per cent of Canadians with suboptimal levels of physical activity to exercise more would increase Canada's GDP by CAN$7.5 billion cumulatively between 2015 and 2040.[53] Our estimates tend to be higher because we are also taking into account potential benefits of reduced presenteeism rates associated with getting people to be more physically active. Furthermore, a recent study by PJM Economics (2019) estimated that the potential benefit of improved productivity (measured as reduced absenteeism and presenteeism among workers) to UK businesses is £6.6 billion per year.[54] While not being in a position to directly calculate the indirect costs associated with lower absenteeism and presenteeism, Ding et al. (2016) suggest that the total global indirect cost of physical inactivity could be between US$27 billion and US$41 billion per year.[55] Our global average benefit of getting people to be more physically active under scenario 1 suggests an average annual GDP gain of between US$220 billion and US$316 billion.

With regards to the estimates presented on the potential savings in direct healthcare cost expenditures associated with different physical activity improvement scenarios, it also has to be highlighted that the estimates are based on improving the adult population only. However, there may also be direct expenditures associated with physical inactivity for children or adolescents.

52 For example, some studies show that adolescents who are physically more active tend to have better grades compared to those who are not, which could translate into better lifetime earnings later on (e.g. Booth et al. 2013; Kari et al. 2017).

53 Using an exchange rate of CAN$1.25/US$1, this corresponds to about US$8.2 billion. We estimate an average GDP gain for the UK of between US$8 billion ('Low') and US$11.8 billion ('High') under scenario 1.

54 The publication by PJM Economics (2019) suggests that their approach is more comparable to our higher scenario variant.

55 Ding et al. (2016) interpolate from information available for the ratio between mortality costs and total indirect costs for cardiovascular disease.

Furthermore, in line with limitations set out by Ding et al. (2016), it has to be highlighted that the estimates reported in section 4.3 are based on only five diseases[56] for which the existing literature suggests moderate to strong evidence for the association with physical activity and that hence these estimates likely represent an underestimation of the potential direct healthcare cost savings associated with different physical activity improvement scenarios.

56 These five diseases are a subset of potentially more than 20 diseases and conditions reported to be associated with physical inactivity, such as hypertension, among others (e.g. PAGAC 2008, 2018).

5 What works in getting people to be more physically active?

There are significant barriers to an individual changing their physical activity. These barriers include a set of personal behaviours and attitudes, the predisposition of the individual to be physically active and the environment in which the individual lives and works. Some researchers point to specific personal barriers, such as limited time, lack of resources, not being predisposed to exercise and the absence of companionship in undertaking exercise (Reichert et al. 2007). Reichert et al. (2007) find that personal barriers may be more significant than wider socio-demographic barriers in specific settings. However, context and demography are important barriers in their own right. Furthermore, there may be a different set of barriers between mid- and high-income countries (see, for instance, Bauman et al. 2012). Multiple studies focus on understanding the barriers for specific groups in the population, including different age groups, individuals with specific health conditions, and ethnic minorities. A recent review of barriers to physical activity of young girls using mostly studies in high-income countries found evidence of the following barriers: lack of motivation; perceptions of competence and body image; physical activity not seen as fun; influence of friends, family and physical education teachers; and the importance of the environment and physical activity opportunities (Martins et al. 2015). A systematic review of barriers to and enablers of individuals taking up physical activity in older populations points to promoting the benefits of physical activity; addressing the individual's fears, individual preferences and social support; and addressing limitations around the physical environment (Baert et al. 2011). While this highlights differences among the older age groups, it is also suggesting that there are important commonalities in barriers across the age range.

Improving physical activity involves understanding the obstacles that individuals confront, all with a view towards helping them circumnavigate those stumbling blocks. Physical inactivity has a multitude of causes, ranging from lack of access to serious health barriers. Thomas et al. (2004), looking at a group of patients in the UK suffering from diabetes, lists a number of barriers, such as difficulty in taking part in exercise, feelings of tiredness, being distracted by something good on television, and lack of facilities. Studies focusing on patient groups suggest that fear of making one's health condition worse could also be a factor. Another factor could be the person's perception of their health situation. In the Britain's Healthiest Workplace (BHW) survey in the United Kingdom, about 70 per cent of respondents (a working age sample) with four or more health risks report being in 'fair' to 'very good' health.[57] This means that in this sample there is a misalignment between the health risks that an individual faces and the general perception they have of their own health. So, from that point of view, we may be overestimating our health and the need to change our behaviour. A review of qualitative studies (Ige-Elegbede et al. 2019) looking at barriers to physical activity of ethnic minority groups in the UK found that lack of awareness, culture, religious practice and traditions, and the inaccessibility of infrastructure were important constraints. Other studies looking at correlates of physical activity point to more emerging factors that contribute to physical activity. Bauman et al. (2012) emphasise the importance of the social and physical environment, such as parks and trails, but also talk about genetic and evolutionary factors that may make an individual more predisposed to be physically active in the first place. Finally, adherence to physical activity remains a problem even if barriers can be overcome. Du et al. (2019) find for a specific population in one location in the United States that, since 2008, adherence to physical activity had remained unchanged but sedentary behaviour had increased. In total, the 60 per cent of the population who were active in this study remained active.[58]. That indicates that for this population, little progress has been made in terms of improving overall physical activity levels.

In addition to access issues, cognitive missteps are a stumbling block to many. Chief among them is optimism bias, which often leads to a problematic misalignment between perception and reality in health, as shown above with the example from the Britain's Healthiest Workplace survey.[59] This rose-tinted view that individuals have of their health points to a need for better education. Despite the fact that there are clear WHO guidelines on physical activity, compliance remains worryingly low, with 28 per cent of the global population – totalling 1.4 billion people – not meeting the WHO-recommended levels of physical activity (Guthold et al. 2018). In the next paragraphs, we will discuss what is known about the effectiveness of programmes and interventions that aim to overcome some of these barriers and make individuals more physically active. We will look at some meta-reviews or systematic reviews at the individual level and in different contexts.

5.1. What can be done to improve physical activity at the individual level?

Empowering an individual to exercise – and instilling the desire to do so in the first place – is an important step. At this level, studies focus mostly on behavioural change approaches and on building more self-efficacy, whereby individuals take more control of their health.

Behaviour change interventions and programmes often look at the use of incentives and the presence of social support. Incentives are a key component of behaviour change, but their thoughtful application is critical to success. Meta-reviews show that conditional incentives,

57 See a description of the survey data in Appendix A. For more findings from Britain's Healthiest Workplace, please see https://www.rand.org/randeurope/research/projects/britains-healthiest-workplace.html (accessed October 2019).

58 In accordance with the definition in US guidelines.

59 For findings from the Britain's Healthiest Workplace survey, please see https://www.rand.org/randeurope/research/projects/britains-healthiest-workplace.html (accessed October 2019).

related to performance, can be effective at promoting increases in physical activity, even among sedentary adults, and that adherence to exercise drops after the incentive is removed, whereas unconditional incentives, such as up-front free gym memberships, are less effective at influencing behaviour (Michell et al. 2013; Mantazri et al. 2015; Mitchell et al. 2019). Similarly, Barte and Wendel-Vos (2017) found in their meta-analysis that unconditional incentives had no impact on physical activity or on any of the other health outcomes they examined. Thus, it is not the presence of a financial incentive that is important but, rather, how that financial incentive is framed. Chokshi et al. (2018) found that loss-framed financial incentives with personalised goal setting significantly increased physical activity among ischemic heart disease patients using wearable devices over the course of a 16-week intervention and that effects were sustained over the 8-week follow-up.

Of equal importance is the ecosystem in which the incentives are placed. A RAND Europe study examined a program that provides members with discounts on their Apple Watch based on their attainment of different levels of physical activity. Leveraging behavioural science concepts of pre-commitment, financial incentives and loss aversion, RAND Europe found that the programme led to an additional 4.8 days of activity per month on average (Hafner et al. 2019).

Social support is also important in promoting behaviour change. A study by Smith et al. (2018) illustrated the impact of family members in helping older adults become more physically active. The creation of ecosystems in which individual efforts can be acknowledged and celebrated creates a positive affirmation loop that can motivate individuals to adhere to a more demanding physical activity regimen over time or to take up physical activity in the first place.

Other studies focus on the psychological state that an individual has to achieve to change their physical activity behaviour. This is often referred to as greater self-efficacy. Systematic reviews that focus on self-efficacy of individuals to look after physical activity show that certain interventions can have a positive impact on self-efficacy. This is particularly the case for interventions that use vicarious experience and feedback on past or others' performance. Interventions that use persuasion, graded mastery (whereby participants are increasingly set more difficult goals), and barrier identification have significantly lower levels of self-efficacy (Ashford et al. 2010).

These findings are confirmed by Michie et al. (2009), who look at behavioural change approaches aimed at increasing physical activity and promoting healthy eating. They find a lot of variability of effect in studies examining 'self-monitoring' approaches. These approaches are more effective if they also include another control component, such as social monitoring, support and goal setting.

These studies highlight the importance of goal setting, support, feedback and monitoring. Technology, with its ability to measure and report back to individuals, serves as an education tool and accountability structure that can distil complex activity data into a resonant measure that members can track over time. The resonance of the measure is critical, because receiving metrics without context makes it less likely that individuals will be able to understand and thus incorporate the data as a driver of their habits. Despite their varied applications, devices are not cure-alls, because, as noted by Patel et al. (2015), they are typically costly and require broader engagement strategies to generate sustained changes in physical activity. In this way, technology can be an enabler when used appropriately.

Empowering individuals to engage with physical activity can use a variety of approaches, and these approaches often have greater effectiveness when used together. It is also important to consider the settings where interventions and programmes are delivered and whether these approaches are mutually reinforcing. For instance, one can incentivise a person to take up physical activity, but this incentive can be blunted without that person having the time to participate, without better societal messaging, or without access to physical activity infrastructure in the workplace or in the community.

5.2. What can be done about workplaces?

As communities in their own right, companies are uniquely positioned to affect the health of their employees, given that 58 per cent of the world's population spend one-third of their adult life at work (WHO 1994). The importance of employer support, through the creation of a culture of health, pans out in the results.

Those programmes with weekly contact with the target group and aimed at younger populations tend to be more effective. A systematic review looking at specific components in programmes aimed to reduce weight show that physical activity programmes in workplace settings are more effective if they include specific environmental components, such as team competitions, family involvement, prompts, walking routes, organisational goals and management commitment (Verwey et al. 2011). Overall, this review, like others, sees a moderate effect associated with programmes. A meta-analysis of workplace physical activity interventions shows that some physical activity interventions can improve physical activity and, in turn, improve selected health outcomes, work culture, and job stress (Conn et al. 2009). Rongen et al. (2013) find that for workplace health promotion programmes aimed at smoking cessation, physical activity improvement and nutrition, those programmes with weekly contact with the target group tend to be more effective.

As at the level of the individual outline above, the use of technology and mobile devices to engage members, verify activities and track progress has been found to be a proven driver of increased activity. A review by To et al. (2013) shows that interventions that use pedometers and apply internet-based approaches are more effective. However, using wearable devices to effectively promote health behaviour change is a complex, multistep process. Patel et al. (2017) examined the uptake of activity trackers from a wellness programme offered across the United States. They found that first the individual must be motivated enough to want a device and be able to afford it.

Employee engagement is the foundation of any successful wellness programme, but employee participation rates in such programmes are often relatively low. A key challenge in workplace settings is awareness and participation. Our data from BHW show that in this working-age population of the UK, awareness of workplace interventions among employees is low, at about 30 per cent of all participating employees, and as a result, participation in workplace interventions is about 7–8 per cent of our sample.[60] There is little evidence that those who are most at risk (the group with the most health risks) participate in the programme. It is a logical conclusion that

60 https://www.who.int/dietphysicalactivity/factsheet_adults/en/ (accessed October 2019).

workplace wellness programs will not be successful at promoting behaviour change if employees are not participating.

As microcosms of society, companies are uniquely positioned to facilitate healthy behaviour change among their staff. Through a sophisticated combination of environment, incentives and technology, and facilitating a culture of health, organisations can bolster the health of their people and of their communities more broadly.

5.3. What can be done at the level of the government?

In public health, studies show that a wide range of approaches may be effective at the level of the government. There are clear overlaps with some of the approaches we highlighted above. A seminal study in *The Lancet* gives a comprehensive global overview of studies conducted between 2001 and 2011 (Heath et al. 2012). Its recommended practices include informational approaches (community-wide and certain mass media campaigns); short physical activity messages targeting key communities and sites; behavioural and social approaches; social support for physical activity within communities and worksites; school-based strategies that encompass physical education and classroom activities; after-school sports; active and different modes of transport; creation and improvement of access to physical activity infrastructure; community urban re-design; land use; and community-wide policies and planning.

Access to infrastructure is a common theme. Sallis et al. (2012) highlight the importance of city, home, and office designs that encourage activity, whether in the form of walkable cities or accessible steps in an office environment. Given the importance of choice architecture in decision making, ensuring that the healthy choice is more natural could help facilitate behaviour change at scale. It is also important to note that these approaches may also target different populations. So, there is a 'horses for courses' argument here. The context matters, and it is obvious that interventions and programmes in different settings may show different results. Cost-effectiveness is an important consideration in how public health programmes and interventions are designed. A study looking at the Australian context finds that mass media campaigns and the use of pedometers are more cost-effective than using more targeted approaches that provide more face-to-face interaction and advice (Cobiac et al. 2009). Because public resources are limited, they need to be deployed as efficiently and effectively as possible.

5.4. Conclusions

Creating enduring change in physical activity is hard. There are significant barriers to change. Nonetheless, decision makers at different levels have a wide array of evidence-based interventions and programmes to consider. We see these, broadly, as sitting in four (not mutually exclusive) areas:

- **Change behaviour and attitudes**. Decision makers could consider approaches that may encourage individuals to shift their behaviour or that may change the attitudes of individuals. Interventions could consist of individual or community messaging, incentives (either gain-framed or loss-framed) to change behaviour, and encouraging a psychological state whereby individuals build efficacy and take more responsibility for their health behaviour. Humans are social animals, and therefore approaches that have a community, social or family dimension tend to be more effective. These approaches make individuals feel part of a group or community that reinforces positive behaviours. A range of goal-oriented approaches that include some feedback or monitoring have some effect on physical activity as well. Technology can be an enabler in the way that these approaches are delivered in different settings.

- **Provide an environment that encourages physical activity**. We see from the studies included here that context matters a great deal. There are a number of examples where individuals have poor access to facilities. Studies focus on community and workplace design and whether local areas and workplaces are set up to encourage physical activity and indeed have the infrastructure required. Certain communities may promote the use of cars over walking and cycling, for instance. Infrastructure may also be intimidating to individuals, and studies speak about ‘safe’ access to infrastructure. Finally, certain environments, such as schools and community centres, are obvious places to provide facilities or physical activity interventions. We find that a range of community-based and school-based strategies can be effective.
- **Promote participation in physical activity programmes and interventions**. Decision makers also need to encourage participation in programmes and interventions. Access to programmes and interventions is one part of the equation. This may affect certain groups more, such as the poor, ethnic minorities and those on low incomes. Certain workplaces may offer certain benefits that encourage physical activity (e.g. gym membership) only to more senior employees or those on higher incomes. Next to access, awareness can be a significant barrier. Awareness of interventions and programmes in different contexts can be low, and, as a result, the participation in such programmes could be limited. One problem is that interventions can be seen as a tick-box exercise by decision makers and that little thought is given to how to create awareness of and drive participation in interventions. In some cases, only the most motivated will participate, typically those who do more in terms of physical activity already. In terms of promoting participation, some of the approaches aimed at behaviour and attitude change could be helpful and effective as well.
- **Build mutually reinforcing approaches to encourage more physical activity across society.** Interventions and programmes can often be quite fragmented and even isolated. Therefore, different interventions may need to sit alongside each other to produce a greater effect. This can be true of a health and well-being programme in the workplace that uses multiple interventions or that leverages a sectoral or national campaign on physical activity to make changes in its offer. Similarly, a community-based approach may require a set of mutually reinforcing interventions that target different barriers to individuals – and perhaps population groups – taking up physical activity. Clusters of interventions may be used to try to change an environment or prevailing culture. Systems may need to be built at different levels, including regulatory approaches, information campaigns, community-based approaches, sectoral approaches, workplace interventions, and individually targeted interventions.

There are also some general and perhaps obvious lessons for decision makers. There can be misalignment between the intervention design and the needs of the group that the intervention is targeting. Specific groups or populations may have specific barriers to taking up physical activity. Programme or intervention design may have to be adjusted for specific groups. Specific populations may have preferences around how the intervention or programme is delivered, for instance, face to face or technology based. The substance of the intervention may also matter. For instance, walking-based interventions seem more effective in some settings than running-based interventions. Adherence is also an issue. Compliance with physical activity programmes and interventions even when individuals decide to participate in the first place can be problematic in certain populations. This finding speaks to carefully considering the needs and preferences of a specific population in programme design and thinking through how involvement can be sustained over time. The risk is always that decision makers will focus on low-hanging fruit, which is associated to who will benefit from a physical activity intervention or programme. Clearly, expense is involved in putting interventions and programmes together. If programmes and interventions mainly encourage the already physically active to become more physically active, are such programmes and interventions really cost-effective for society?

The studies reviewed above show that context matters a great deal. What works in high-income areas may not necessarily work in low-income areas. Workplaces are not all the same. Implementation also can play a part. Some interventions and programmes may be hard to scale up or transfer to other contexts and settings. They can suffer from lack of fidelity to the original design and from limited capacity and resources, for instance.

Finally, wider thought needs to be given to monitoring and evaluation within interventions and programmes to create a better evidence base and feedback loops for those managing interventions and programmes. Many interventions and programmes are not evaluated or monitored. Basic management information on them is not readily available. Therefore decision makers do not always understand what works for whom and in what context.

Our report shows the economic benefits associated with individuals becoming more physically active across a range of countries. It also highlights that there is a growing evidence base on what interventions decision makers can consider in different settings. The challenge remains to create a culture of health that promotes healthy lifestyles across communities, sectors and populations in societies. Our evidence shows that if creating such a culture can be achieved, we can create healthier and more prosperous societies.

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Appendix A. Quantifying the associations between physical activity and a range of health, well-being and workplace performance outcomes

In this appendix, we provide a more detailed overview for the statistical analysis on the associations between physical activity and a range of different health, well-being and workplace performance outcomes. For the purpose of the analysis, we draw on a large-scale, linked employer-employee dataset across seven different countries.

The appendix starts with a description of the dataset and the corresponding variables used in the analysis. This is followed by the relevant empirical findings for the different associations of physical activity and the corresponding outcome variables analysed.

A.1. International linked employer-employee workplace survey data

We use data collected from employers and employees in the United Kingdom, Australia, Malaysia, Hong Kong, Thailand, Singapore and Sri Lanka. The data were collected as part of *Vitality UK's Britain's Healthiest Workplace Survey*, as well as *AIA's Asian Healthiest Workplace Survey*. For the UK, two annual survey waves are included, for the years 2017 and 2018, whereas for the Asian surveys, three annual waves are included (2017, 2018 and 2019).

Both cross-sectional surveys are large, working-age population surveys among the workforces of the UK, Australia, Malaysia, Thailand, Sri Lanka, Singapore and Hong Kong, with the goal to collect information about all aspects of health and well-being and corresponding health-promotion interventions in the workplace. In both the BHW and the AIA survey, employers are surveyed about their provision of health and well-being interventions, while the employee survey covers more than 100 questions related to demographic factors (e.g. age, gender, education, income), lifestyle and health behaviour (e.g. nutrition, smoking habits, physical activity, sleep behaviour), health factors (e.g. mental and physical health indicators, chronic and musculoskeletal conditions), as well as other measures, including workplace productivity and job and life satisfaction.

We discuss in more detail the variables applied in the empirical analysis in the next section. Table A.1 provides the sample sizes for each country included in the two surveys, by year. Overall, the pooled UK cross-sectional sample includes 58,390 individuals across the years 2017 and 2018. Across the six countries involved in the AIA survey, the sample includes 61,753 individuals across three survey waves. For the purpose of the main analysis, we pool the available data across the seven countries and three survey waves.[61]

In addition to the cross-sectional analysis of the BHW and AIA surveys for the years 2017 to 2019, it is possible to follow about one thousand respondents in the UK sample over time between 2017 and 2018. In order to check the robustness of the results stemming from the much larger cross-sectional survey, we also conduct a similar analysis using the smaller longitudinal UK-only data sample.

Table A.1: Number of observations by country and year for the pooled cross-sectional data sample

Country	Year		
	2017	**2018**	**2019**
United Kingdom	31,950	26,460	0
Australia	2,446	2,906	1,319
Malaysia	1,020	2,177	1,169
Hong Kong	5,369	11,551	17,595
Singapore	1,162	0	0
Thailand	0	7,513	4,236
Sri Lanka	0	1,133	2,137
Total	**41,947**	**51,740**	**26,456**

Source: RAND Europe, based on Vitality BHW survey and AIA survey.

A.2. Statistical approach: Multivariate regression analysis

For the purpose of this analysis, we use multivariate regression models to investigate the associations between physical activity and a set of outcome measures, including, for instance, physical and mental health, sleep, subjective well-being and workplace performance. In the statistical analysis, we include physical activity in the regression models in different ways. First, we use them as a binary indicator taking the value one if the individual regularly achieves the recommended level of physical activity per week (e.g. 10 MET-hours per week or the equivalent of 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity[62]), and zero otherwise. Second, we use them as a set of binary indicators taking the value one if the individual regularly performs (1) 10 to 12.5 MET-hours; (2) 12.5 to 15 MET-hours; (3) 15 to 25

61 Where relevant, we also report the findings on a more regional level. Note, however, that all regression analyses presented in this study are adjusted for ethnicity and also include country-fixed effects. They hence take into account only within-ethnicity and within-country variation in physical activity levels when estimating the associations with different outcomes.

62 Both roughly corresponding to about 600 MET-minutes (or 10 MET-hours) per week.

MET-hours; (4) 25 to 35 MET-hours; or (5) more than 35 MET-hours of physical activity per week, and zero otherwise. Third, we used them as a continuous variable measuring the MET-hours of physical activity an individual performs every week.

We primarily apply ordinary least squares (OLS) linear regression analysis to explore associations between physical activity and a number of different variables. In non-technical terms, a linear regression model is a model used to describe the relation between two or more variables in a set of data points with a line. OLS is thus a statistical approach to fitting a model to the observed data by finding the function that most closely approximates (or best fits) the data (Wooldridge 2015). In technical terms, the OLS method is used to fit a straight line through a set of data points so that the sum of the squared vertical distances (called residuals) from the actual data points is minimised. In this way, the best fit is represented by the line that minimises the total distance between the actual data points and the predicted values. Many of the explanatory variables included in the regression analysis are binary indicator variables related to health or lifestyle factors.[63]

For the cross-sectional analysis, we estimate the following model equation:

$$y_{it} = \beta X_{it} + \theta Z_i + \delta PA_{it} + \gamma_t + \varepsilon_{it} \qquad (1)$$

In this equation, the variables are defined as follows:

- y_{it} : represents the outcome variable of interest (e.g. physical or mental health, workplace performance) for individual i in year t;
- X_{it}: is a vector of individual characteristics that can vary over time (e.g. education, job, work environment, becoming a parent);
- Z_i: is a vector of individual characteristics that do not vary over time (e.g. ethnicity, personality traits, paternal background);
- PA_{it}: is a measure of physical activity;
- γ_t: denotes time trends[64]; and
- ε_{it}: denotes an idiosyncratic error term that includes all the time-variant and time-invariant unobserved influences on the outcome variable.

Using cross-sectional data allows us to estimate model equation (1) using a large sample of individuals across seven different countries. However, when estimating equation (1) using cross-sectional data, some considerations have to be taken into account.

First, not-including variables that are correlated with physical activity and the outcome (e.g. a measure of mental health) would lead to a so-called omitted variable bias. For instance, if someone has caring responsibilities for an ill family member, the individual may have less time to spend on physical activity than a person who does not have these responsibilities.

63 In other words, for interpretation purposes, the variables should be interpreted relative to an omitted base or reference category (e.g. for a variable female employee, the omitted category would represent a male employee).

64 Note that we also include company-fixed effects to adjust for company-specific characteristics (e.g. provision of health and well-being interventions), as well as country-fixed effects to examine variation within countries. However, for reasons of parsimony, we have not included the specific subscripts in equation (1).

Simultaneously, the carer's mental health might be differently affected (e.g. due to elevated stress). Hence, from this perspective, it is important to adjust for relevant observed variables that possibly affect both physical activity and the outcome variables. Second, even though the survey data used include a large set of variables about all aspects of an individual's health and well-being, as well as their work and personal work environment, we most likely miss relevant variables in X_{it} and Z_i that affect physical activity but are not directly observed. For instance, the responding individual may have an inherited trait and hence may look after themselves better in terms of physical activity and other areas, such as nutrition or sleep. A specific personality trait may also lead to the individual performing better at work. In the cross-sectional analysis, we try to proxy for some of these personality traits with observed variables included in the data. For instance, respondents in the survey are asked whether they perform voluntary work outside the workplace (e.g. doing leisure-time work for a charity), assuming that caring for others or specific causes might be associated with caring for oneself. Third, when analysing associations in health, almost always the issue of simultaneity arises. For instance, individuals with a high body mass index (BMI) may live a more sedentary lifestyle and hence do less physical activity, while, conversely, doing physical activity is likely associated with a reduction in BMI over time. That is, when we are using cross-sectional data and specific outcomes, such as mental health or BMI, the coefficient δ is most likely biased.

In order to take into account some of the unobserved confounding variables and issues highlighted above, we follow a similar approach taken by Colman and Dave (2013) and estimate equation (1) as first-differences (Δ), meaning that we look at changes over time within the same individual, using the UK longitudinal data sample:

$$\Delta y_{it} = \beta \Delta X_{it} + \delta \Delta PA_{it} + \Delta \gamma_t + \Delta \varepsilon_{it} \qquad (2)$$

In equation (2), differencing removes all time-invariant variables in Z_i, as they do not vary in each year. Following the same individual over time can help reduce the omitted variable problem because it takes into account time-invariant factors associated with individual personality or genetic traits and other invariant factors (e.g. parental background, previous investments in health). It also takes into account contemporaneous changes between variables that are simultaneously associated with each other, such as physical activity and health outcomes (for example, BMI or mental health). However, as Colman and Dave (2013) point out, it is still possible that time-varying factors could influence physical activity and the outcome variable related to health. Take the example of BMI. Physical activity may not only reduce BMI contemporaneously, but also affect future physical activity. That is, a person putting on weight over time may also switch to a more sedentary job or generally perform less physical activity in the future. Or in other words, prior obesity affects the current level of physical activity as well. To account for this, we also estimate the following model equation using the UK longitudinal data sample:

$$\Delta y_{it} = \rho y_{it-1} + \beta \Delta X_{it} + \delta \Delta PA_{it} + \Delta \gamma_t + \Delta \varepsilon_{it} \qquad (3)$$

In comparison to equation (2), equation (3) also includes the lagged outcome variable. This can take into account individual selection into physical activity that depends on the lagged value of the outcome variable. However, while the models in equations (2) and (3) potentially are able to deal with some of the potential biases outlined above, the longitudinal analysis may suffer from a so-called 'attrition bias', whereby some respondents drop out from the survey over time or do not consent to linking their data over time. This is a potential source of bias. It could be that the overall healthier respondents may be more likely to be willing to participate year-on-year than the less healthy or less active individuals. That is, it is important to highlight that, due to these issues and sources of bias, we are not in a position to establish full causality between physical activity and the corresponding outcome measures examined, and hence they should be considered as associations rather than causal effects.

As the survey data are a linked employer-employee dataset, in each regression we include company-fixed effects that adjust for any company-specific factors in the response of individuals, and we cluster standard errors at the company level. All statistical analyses are conducted in STATA 15.[65] Results are reported at the 5 per cent significance level. That means that for statistical significance, we expect the p-value to be less than the significance level ($p<0.05$).[66]

A.3. Variables used in the analysis

In the statistical analysis of this study, we examine the associations between physical activity and a set of outcome variables of interest. In what follows, we describe in more detail the variables used in the analysis, beginning with how physical activity is measured, followed by a description of some of the key covariates and outcome variables. The variables used in the analysis can be divided into the following categories:

- Physical activity;
- Socio-demographic, personal and work environment;
- Lifestyle and health behaviour;
- Sleep;
- Chronic health conditions; and
- Subjective well-being, work engagement and productivity.

A.3.1. Physical activity

While the BHW and the AIA survey are broadly similar with regards to the questions on physical activity, for the purpose of this analysis, only questions which were comparable across both surveys and across years were used, namely:

- How many times per week do you do **moderate-intensity physical activities** for at least 10 minutes that cause light sweating or moderate increases in breathing or heart rate (e.g. carrying light loads, cycling at a normal pace)?
- For about how many minutes do you do these physical activities each time?

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65 https://www.stata.com/.

66 The concept of statistical significance is generally used to determine whether a null hypothesis is to be rejected or retained. For this analysis, the null hypothesis is the default statement that the true association between two variables is zero. P-values represent the probability of observing an effect given that the null hypothesis is true (there is no real association). The null hypothesis is rejected if the p-value is less than the significance level. The significance level therefore represents the probability of rejecting the null hypothesis given that it is true (DeGroot & Schervish 2002).

- How many times per week do you do **vigorous-intensity physical activities** for at least 10 minutes that cause heavy sweating or large increases in breathing or heart rate (e.g. lifting heavy things, digging, aerobics or cycling at a fast pace)?
- For about how many minutes do you do these physical activities each time?

These questions are from the International Physical Activity Questionnaire Short Form (IPAQ-SF)[67] and are often used to measure physical activity in existing research (e.g. Burton et al. 2006; Lenneman et al. 2011; Pelletier et al. 2004; VanWormer et al. 2011).

Following the IPAQ guidelines (IPAQ 2005), we convert the answers to the four questions into the total MET-minutes (or hours)/week, as follows:

1. Moderate MET-minutes/week = 4.0 × moderate-intensity activity minutes × moderate times;
2. Vigorous MET-minutes/week = 8.0 × vigorous-intensity activity minutes × vigorous times; and
3. Total MET-minutes/week = (moderate + vigorous) MET-minutes/week.

In the analysis, we either use a binary indicator to determine the active and non-active survey population, or we also take into account a potential dose-response association for physical activity by including indicator variables for different levels of activity, or we also apply physical activity as the continuous variable. The WHO recommends that adults between 18 and 64 years old do at least 150 minutes of moderate-intensity physical activity or at least 75 minutes of vigorous-intensity physical activity throughout the week, or any equivalent combination of both (WHO 2018). Following the computation described above, this is equivalent to 600 MET-minutes (or 10 MET-hours) per week. We use this threshold to define the active (at least 600 MET-minutes per week) and inactive (fewer than 600 MET-minutes per week) individuals.

Table A.2 provides a summary of the physical activity distribution across three different sample regions, the United Kingdom, Australia and Asia (specifically, Malaysia, Singapore, Thailand, Sri Lanka and Hong Kong).

Table A.2: Summary of total MET-minutes per week, UK, Australia and selected countries in Asia

Regions	Mean	SD	Median	P10	P90
United Kingdom	1,271	1,241	960	60	2,760
Australia	1,221	1,202	960	60	2,640
Malaysia, Singapore, Thailand, Sri Lanka, Hong Kong	731	1,093	360	0	1,880

Notes: p10 and p90 represent the 10th and 90th percentile, respectively, of the MET-minutes per week distribution in the data sample. SD represents the standard deviation.

On average, respondents in the UK survey report about 1271 MET-minutes of physical activity per week, with a corresponding median of 960 MET-minutes. Respondents in Australia report 1221 MET-minutes per week and a median of 960 MET-minutes per week. Respondents from the

67 See http://youthrex.com/wp-content/uploads/2017/06/IPAQ-TM.pdf for more detail.

surveyed Asian countries report on average a lower average MET-minutes of physical activity per week, about 731 MET-minutes, with a corresponding median of 360 MET-minutes.

A.3.2. Socio-demographic, personal and work environment variables

Like other surveys in the area of health and well-being, the BHW and AIA surveys include a number of socio-demographic indicators. We use these indicators as covariates in the analysis. They include:

- **Gender**: The binary variable takes the value one if the respondent is female or zero otherwise.
- **Date of birth**: We calculate current age in years. In addition to the continuous variable age in years, we also create three age categories, namely, (1) age 18 to 30; (2) ages 31 to 50; or (3) ages 51 or older.
- **Education**: This is divided into five different categories according to the highest level of educational degree achieved: (1) primary education only; (2) lower secondary; (3) upper secondary but not university; (4) undergraduate university; (5) postgraduate university.
- **Income**: This is measured in the surveys through a scale of ten different country-specific income categories.[68]
- **Marital status**: This is captured in the surveys through five different categories, namely, (1) married; (2) cohabitating; (3) separated/divorced; (4) never married; (5) widowed.
- **Occupation**: This information is collected in the surveys through various occupational categories, including, among others: manager, professional, technician, clerical support worker, service worker, sales worker, skilled agricultural and fishery worker, craft and related trades worker, plant and machine operator or assembler, elementary occupations, armed forces occupations.
- **Ethnicity**: This comprises four ethnicity-related categories: (1) white; (2) Asian; (3) black; and (4) other ethnic background.
- **Irregular hours**: This is a binary variable taking the value one if an individual reports to work irregular or shift hours and zero otherwise.
- **Bullying**: This is a variable on a five-point Likert scale taking the value 0 if the individual responds having never been subject to bullying in the workplace and 4 if the individual respondents having ‘always’ being bullied.
- **Time pressure**: This is a variable on a five-point Likert scale taking the value 0 if the individual responds never being subject to unrealistic time pressures at work and 4 if the individual responds ‘always’ being under time pressure.
- **Stress**: This is a binary variable taking the value one if an individual reports having felt unwell during the last 12 months due to stress at work and zero otherwise.

68 Income scales have been adapted to each country’s income distribution in the local currency, which roughly correspond to deciles of the work-income distribution.

- **Carer of child**: This is a binary variable taking the value one if an individual reports to be caring for a child in the same household that is below age 18 and zero otherwise.
- **Carer of ill family member or friend**: This is a binary variable taking the value one if an individual reports to be caring for an ill family member or friend and zero otherwise.
- **Volunteering**: This is a binary variable taking the value one if an individual reports to be volunteering or participating in other forms of community or civic participation and zero otherwise.
- **Travel time**: This is the time in minutes from home to work (e.g. commuting time).
- **Hours of work**: This is the number of hours usually worked in a week.
- **Financial concerns**: This is a binary variable taking the value one if an individual reports having financial concerns and zero otherwise.

Table A.3 reports a descriptive summary for each of the socio-demographic, personal and work environment variables, including the sample means and corresponding standard deviations.

Table A.3: Summary of socio-demographic, personal and work environment variables in pooled dataset

Variable	Mean	Standard deviation
Gender: female (yes/no)	0.55	0.50
Age (years)	37.04	10.62
Ethnicity: white (yes/no)	0.44	0.50
Ethnicity: Asian (yes/no)	0.34	0.47
Ethnicity: black (yes/no)	0.01	0.08
Bullying (yes/no)	0.03	0.16
Time pressure (yes/no)	0.14	0.35
Stress (yes/no)	0.10	0.30
Carer of child (yes/no)	0.28	0.45
Carer of ill family member or friend (yes/no)	0.09	0.29
Volunteering (yes/no)	0.31	0.46
Travel time (minutes)	45.29	34.27
Financial concerns (yes/no)	0.15	0.35

Notes: Based on Vitality BHW surveys (2017 and 2018) and AIA surveys (2017, 2018 and 2019). Mean of a binary variable represents the share of individuals within category. To convert shares into per cent, entries need to be multiplied by 100.

In the overall pooled sample, about 55 per cent of respondents are female and the average age is 37. About 44 per cent have white ethnicity, whereas 34 per cent report to be of Asian ethnicity. About 1 per cent reports to be of black ethnicity (with the rest reporting to be of any other ethnicity). About 3 per cent report that they are exposed to bullying frequently, and 14 per cent report to be often under unrealistic time pressure. About 10 per cent report to have been unwell due to stress. About 15 per cent report to have financial concerns, and the average commute time is 45 minutes.

About 28 per cent report to be a carer of a child, whereas about 9 per cent report to be a carer of an ill family member or friend and about one third of respondents report to be volunteering or being engaged in other community or civic participation in their free time.

A.3.3. Lifestyle and health behaviour variables

The BHW and AIA surveys also include a number of relevant variables with relation to individual lifestyle and health behaviour. We include the following variables in the analysis:

- **Physical health**: Respondents are asked about how they rate their overall physical health on a five-point scale (1 very poor–5 very good). We collapse the information into a binary indicator taking the value one if the responded value is above the median and zero otherwise.[69]
- **Body Mass Index (BMI)**: We calculate this using self-reported height and weight. In addition to the continuous BMI variable, we generate four BMI categories: (1) underweight (BMI <18); (2) normal weight (BMI 18–24.99); (3) overweight (BMI 25–29.55) and (4) obese (BMI >30). The BMI is adjusted for waist circumference of the respondent.
- **Smoking**: This is a binary variable taking the value one if the respondent is currently smoking or zero otherwise.
- **Excessive alcohol consumption**: This is measured as a binary variable taking the value one if the individual exceeds the weekly alcohol consumption that is regarded as within the healthy range of 14 units (8mg) and zero otherwise.
- **High blood pressure**: Respondents are asked whether the last time they or somebody else checked their blood pressure it was normal or high, whereby high is measured as a binary variable taking the value one if the respondent has a blood pressure above 120/80 mmHg (UK, Malaysia, Singapore, Hong Kong, Sri Lanka; 140/90 mmHg (Australia) or 135/85mmHg (Thailand) or zero otherwise.
- **High cholesterol**: Respondents are asked whether the last time they or somebody else checked their cholesterol level it was normal or high, whereas high is measured, depending on the country, as binary variable taking the value one if the respondent has a cholesterol level above 5 mmol/L (UK, Malaysia, Singapore), 4.0 mmol/L (Australia); 5.2 mmol/L (Hong Kong), or 200 mg/dl (Thailand and Sri Lanka) or zero otherwise;
- **High glucose**: Respondents are asked whether the last time they or somebody else checked their glucose level it was normal or high, where high is measured as a binary variable taking the value one if the respondent has a random glucose level above 7.8 mmol/L (United Kingdom, Australia, Singapore), 9.0mmol/L (Malaysia, Hong Kong), or 200mg/dl (Thailand, Sri Lanka) or zero otherwise.

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69 Note that the median is 3 ('fair') and the variable takes the value 1 if the respondent responded either 4 ('good') or 5 ('very good').

- **Mental health**: Respondents are asked about how they rate their overall mental health on a five-point scale (1 very poor–5 very good). We collapse the information into a binary indicator taking the value one if the responded value is above the median and zero otherwise.[70]
- **Psychological distress and anxiety**: This is measured through the Kessler Psychological Distress Scale. The six-item scale is a simple measure of psychological distress, involving six questions (each with a five-level response scale) about emotional states. The measure can be used as a brief screen to identify levels of psychological distress, with a higher numeric value suggesting a greater distress. For the majority of the analysis presented in this chapter, we use the binary indicator variable that takes the value one if the Kessler score is equal to or higher than 13, which has been identified in previous literature as the threshold to assess whether an individual is at risk of having mental health issues (e.g. Kim et al. 2016). However, in the longitudinal analysis, we also use the continuous Kessler score as outcome variable.

Table A.4 reports a descriptive summary for each of the lifestyle and health behaviour variables, including the sample means and corresponding standard deviations. In the overall pooled sample, about 72 per cent of respondents say their physical health is either good or very good. About 16 per cent of respondents have a BMI higher than 30, about 10 per cent currently smoke, 16 per cent are not within the healthy range of alcohol consumption and about 23 per cent tend to have high blood pressure. When asked about their mental health, about 68 per cent respond that it is either good or very good, whereas about 7 per cent of respondents have a Kessler score of 13 or higher (out of 24 on the KS-6 scale), suggesting a more severe mental health problem.

Table A.4: Summary of lifestyle and health behaviour variables in pooled dataset

Variable	Mean	Standard deviation
Physical health: good (yes/no)	0.72	0.45
BMI: underweight (yes/no)	0.04	0.20
BMI: overweight (yes/no)	0.03	0.17
BMI: obese (yes/no)	0.16	0.37
Smoking (yes/no)	0.10	0.30
Excessive alcohol consumption (yes/no)	0.16	0.36
High blood pressure (yes/no)	0.23	0.42
High cholesterol (yes/no)	0.04	0.19
High glucose (yes/no)	0.02	0.12
Mental health: good (yes/no)	0.68	0.47
Psychological distress (yes/no)	0.07	0.26

Notes: Based on Vitality BHW surveys (2017 and 2018) and AIA surveys (2017, 2018 and 2019). Mean of a binary variable represents the share of individuals within category. To convert shares into per cent, entries need to be multiplied by 100.

70 Note that the median is 3 ('fair') and the variable takes the value one if the respondent responded either 4 ('good') or 5 ('very good').

A.3.4. Sleep duration and quality

The BHW and AIA surveys also include a number of questions related to sleep health, including self-reported sleep duration and quality. In addition to these two sleep measures, the surveys also ask respondents about their first unit of uninterrupted sleep and their level of daytime fatigue.

In order to take into account short sleep, we generate a binary variable taking the value one if the self-reported hours of sleep per night are less than six hours or zero otherwise. In order to take into account long sleepers as well, we further generate a binary variable taking the value one if the self-reported hours of sleep per night are more than nine hours and zero otherwise.

In addition to sleep duration, the surveys also include questions related to sleep quality. For instance, individuals are asked to rate sleep quality experienced during the past seven days on a five-point scale (1: very poor–5: very good). Included are also three further questions measured on a five-point scale (1: not at all–5: very much) on whether, during the past seven days (1) the sleep was refreshing; (2) the individual had a problem with sleep; or (3) the individual had difficulties falling asleep. Each of these sleep quality items have been recoded so that higher values represent a lower sleep quality. We then create a summary measure to capture overall sleep disturbance by summing up all four binary sleep quality items into a single disturbance composite measure ranging from 4 to 20, with a higher number representing higher levels of sleep disturbance.

In addition to the four sleep quality questions, survey participants are also asked about the self-reported average length of the first uninterrupted sleep period (FUSP) at night. FUSP is the prevalent proxy outcome used for sleep quality in some research literature. Since the majority of essential slow-wave sleep occurs during the first 3–4 hours of sleep, the larger the FUSP, the better the sleep, all else being equal. Hence, in addition to the sleep quality measures described above, our data allows for the examination of the association between physical activity and this additional measure of sleep quality.

Table A.5 reports a descriptive summary for each of sleep quality and duration variables, including the sample means and corresponding standard deviations.

Table A.5: Summary of sleep quality and duration variables in pooled dataset

Variable	Mean	Standard deviation
Sleep disturbance score	10.57	2.17
Poor sleep quality (yes/no)	0.47	0.50
Sleep problem (yes/no)	0.16	0.37
Difficulty falling asleep (yes/no)	0.12	0.33
Sleep was not refreshing (yes/no)	0.28	0.4
First uninterrupted sleep period (hours)	4.34	2.07
Less than 6 hours	0.37	0.48
More than 9 hours	0.01	0.08
Hours of sleep	6.77	1.06

Notes: Based on Vitality BHW surveys (2017 and 2018) and AIA surveys (2017, 2018 and 2019). Mean of a binary variable represents the share of individuals within category. To convert shares into per cent, entries need to be multiplied by 100. FUSP denotes first uninterrupted sleep period in hours.

In the overall pooled sample, about 47 per cent of respondents say they experience overall poor sleep quality, with 16 per cent reporting to have problems staying asleep, 12 per cent reporting to have difficulties falling asleep and 28 per cent reporting that their sleep is not refreshing. The average period of first uninterrupted sleep is 4.34 hours, and more than one third report to sleep on average less than six hours. The sample includes only a very short proportion of long sleepers, with only 1 per cent reporting to sleep more than 9 hours. The overall average reported hours of sleep is 6.7 hours.

A.3.5. Chronic health and musculoskeletal conditions

In both surveys, respondents are asked whether they have been diagnosed within the last 12 months with any of the following chronic health conditions:

- Asthma or severe allergies;
- Heart condition or disease;
- Kidney condition or disease;
- Cancer;
- Diabetes;
- Hypertension[71]; or
- Severe mental illness (e.g. schizophrenia, bipolar disorder, major-depressive disorder or post-traumatic stress disorder).

We include these seven variables as binary indicator variables in the analysis, taking the value one if the respondent has been diagnosed with one of the conditions and zero otherwise. We emphasise that it is not possible to distinguish between the types of cancer, heart or kidney diseases from the data. We only know whether one of these conditions has been diagnosed, but not their type or severity. In addition to the diagnosed chronic health conditions, we also have information on the respondents' musculoskeletal conditions. We have a binary indicator variable taking the value one if the respondent has at least one musculoskeletal condition, and a binary indicator variable taking the value one if the respondent suffers from a severe musculoskeletal condition that significantly affects the respondent's life.

Table A.6 reports a descriptive summary for each of the chronic health and musculoskeletal condition variables, including the sample means and corresponding standard deviations.

71 Note that, in contrast to the question on whether a respondent had a relatively high blood pressure, as described in section 3.3.3, in this question, hypertension refers to diagnosed chronic hypertension.

Table A.6: Summary of chronic health and musculoskeletal conditions in pooled dataset

Variable	Mean	Standard deviation
Asthma (yes/no)	0.05	0.23
Cardiovascular disease (yes/no)	0.01	0.11
Cancer (yes/no)	0.00	0.07
Diabetes (yes/no)	0.02	0.14
Hypertension (yes/no)	0.06	0.23
Kidney disease (yes/no)	0.01	0.08
Severe Mental Illness (yes/no)	0.03	0.17
MSK: at least 1 (yes/no)	0.81	0.39
MSK: severe (yes/no)	0.08	0.27

Notes: Based on Vitality BHW surveys (2017 and 2018) and AIA surveys (2017, 2018 and 2019). Mean of a binary variable represents the share of individuals within category. To convert shares into per cent, entries need to be multiplied by 100.

Overall, about 5 per cent of respondents report to have been diagnosed with asthma, 1 per cent with cardiovascular disease, less than 1 per cent with cancer, 2 per cent with diabetes, 6 per cent with hypertension and 1 per cent with kidney disease. About 3 per cent have also been diagnosed with a severe mental health condition, such as depression. More than 80 per cent of respondents report having at least one musculoskeletal condition (e.g. back pain), whereas about 8 per cent report suffering from a severe musculoskeletal condition.

A.3.6. Subjective well-being, workplace satisfaction, engagement and productivity

The surveys also include a question regarding the overall life satisfaction of respondents, measured on an 11-point scale (0: not at all–10: completely). Specifically, the survey asks 'How satisfied are you with your life nowadays?', which is a standard question applied in numerous surveys and studies to measure what is termed subjective well-being (SWB).[72] In addition, both surveys ask respondents about their satisfaction with the current job: 'All in all I am satisfied with my job' is measured on a five-point scale (1: strongly disagree–5: strongly agree). For both measures, life and job satisfaction, we create a binary measure on whether the respondent is satisfied or not. The two binary variables take the value one if the respondent's value given in the answer is above the median or zero otherwise.[73]

Productivity is measured using the Work Productivity and Activity Impairment Questionnaire (General Health) (WPAI-GH). The WPAI-GH was developed in 1993 to assess productivity loss by measuring the effect on work productivity of general health and health symptom severity

72 See, for instance, Blanchflower (2008) for further background on this topic.

73 Note that the median value for life satisfaction is 7 and that for job satisfaction is 4.

(Tang et al. 2011).[74] The instrument consists of six questions with a recall time frame of seven days. The questions ask whether the respondent is employed; the number of hours missed from work; the number of hours actually worked; and the degree to which the respondent feels that a health problem has affected their productivity while at work and their ability to do daily activities other than work. WPAI-GH outcomes are expressed as impairment percentages, where higher percentages indicate greater impairment and lower productivity. We use the following three work-related impairment percentages calculated on the basis of the WPAI-GH scale:

- Per cent work time missed due to ill-health (absenteeism);
- Per cent impairment while working due to ill-health (presenteeism); and
- Per cent overall work impairment due to ill-health (absenteeism and presenteeism).

To measure work engagement, the surveys include questions that build on the Utrecht Work Engagement Scale (UWES), which includes three dimensions of work engagement: vigour, dedication and absorption. The nine questions related to the scale are measured on a seven-point Likert scale (0: never, 1: almost never, 2: rarely, 3: sometimes, 4: often, 5: very often, 6: always):

- At my work, I feel bursting with energy;
- At my job, I feel strong and vigorous;
- I'm enthusiastic about my job;
- My job inspires me;
- When I get up in the morning, I feel I like going to work;
- I feel happy when I'm working intensively;
- I am proud of the work that I do;
- I am immersed in my work; and
- I get carried away when I am working.

In line with previous research (e.g. Schaufeli et al. 2009), we construct the UWES engagement scale by adding the seven-point scale across all nine questions, with a larger value of the scale showing a larger level of engagement (range 0–54). We use this score as the outcome variable, but we also use a binary indicator taking the value one if the score on the engagement scale is among the top quarter of engagement and zero otherwise, which acts as an indicator for relative high work engagement.

Table A.7 reports a descriptive summary for each of the variables, including the sample means and corresponding standard deviations. About 64 per cent of respondents report good life satisfaction overall, and about 48 per cent report good job satisfaction. The average working time lost due to absenteeism and presenteeism is about 10 per cent, of which 2 per cent is due to sickness absence and 8 per cent is related to presenteeism.

74 It was originally established as a self-reported quantitative assessment of the amount of absenteeism, presenteeism and daily-activity impairment attributable to general health (WPAI-GH) or a specific health problem (WPAI-SHP). It has since been used in a wide range of applications, and several versions for specific health problems are now available, as well as several different language versions (Lofland et al. 2004).

Table A.7: Summary of chronic health and musculoskeletal conditions in pooled dataset

Variable	Mean	Standard deviation
Life satisfaction (0: very poor–10: excellent)	6.82	1.93
Life satisfaction: good (yes/no)	0.64	0.48
Job satisfaction (1: very poor–5: very good)	3.22	1.18
Job satisfaction: good (yes/no)	0.48	0.50
Work impairment %: A&P	0.10	0.20
Work impairment %: A	0.02	0.08
Work impairment %: P	0.08	0.17
UWES Engagement scale (0–54)	33.05	8.92
Engagement: high	0.25	0.43

Notes: Based on Vitality BHW surveys (2017 and 2018) and AIA surveys (2017, 2018 and 2019). Mean of a binary variable represents the share of individuals within category. To convert shares into per cent, entries need to be multiplied by 100. A&P represents absenteeism and presenteeism.

A.4. Limitations of the statistical analysis

The analysis of the BHW and AIA survey data has several strengths. The relatively large sample size and comprehensive collection of data on personal, health and job factors allow for an in-depth investigation of the factors associated with physical activity and corresponding outcomes, such as health and well-being, as well as measures of workplace performance. However, there are some limitations to the empirical approach taken.

First, healthier employees are likely to be more motivated in responding to the surveys, and people who are on long-term sick leave are likely to be under-represented in the data, since it is a workplace survey. There is also potential for selection bias of companies into the survey. For instance, 'healthier' companies probably have a greater incentive to register and compete in both surveys. In our analysis, however, we take care of this potential bias by including in each regression analysis individual company-fixed effects, which allows us to compare employees within the same company. Furthermore, while our data are cross-sectional, each regression analysis adjusts for a large set of individual employee characteristics.

Second, it is important to stress that the data are self-reported. This creates potential for the under-reporting of the real prevalence of bad lifestyle habits, such as smoking or alcohol consumption, or for overstating good ones, such as physical activity. It is important to stress, though, that this is a common issue in surveys of this nature. However, if, for instance, an individual under-reports their real smoking habits or over-reports their levels of physical activity, then our estimates would represent a lower bound of the true parameter value and we would be underestimating the true effect rather than overestimating it.

Third, when interpreting the results from the empirical analysis, caution has to be applied with regard to causality. Our statistical regression models capture associations and not necessarily causation. While in the cross-sectional analysis each regression model adjusts for a large set of covariates, there is a possibility that some time-invariant personal factors are not included in the model (e.g. genetic or personality traits). Reverse causality is also an issue. For instance, when we examine the association between physical activity and BMI, being more active may reduce an individual's BMI over time, but at the same time, individuals with a higher BMI may be less active. We aim to check the robustness of these associations using longitudinal data for a subset of the UK survey population for which we observe the same individual over time. This helps us to adjust for time-invariant individual characteristics that are likely associated with physical activity and a specific outcome variable and may also allow us to take into account contemporaneous changes between variables, such as BMI and physical activity. However, using longitudinal data may introduce another type of bias if the healthier or more motivated individuals stay in the survey for longer and the unhealthier respondents drop out over time.

A.5. The associations between physical activity and a set of outcome measures

In what follows, we present the empirical findings for estimating model equations (1) and (3) for the associations between physical activity and a variety of different outcome variables. We begin the analysis for the parameter estimates related to the association between physical activity and work impairment due to absenteeism and presenteeism, as they represent important input parameters to the macroeconomic model. We examine in more detail the association for a variety of different physical activity measures and different subgroups. We also do a sensitivity analysis using the UK longitudinal data. Furthermore, we examine the association between physical activity and other outcome variables, including (1) physical and mental health; (2) sleep quality and duration; and (3) subjective well-being, job satisfaction and work engagement.

A.5.1. Physical activity and the association with work impairment due to absenteeism and presenteeism

Using OLS regressions, Table A.8 reports the estimated association between physical activity and the per cent work impairment due to absenteeism and presenteeism and the association for two different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity; and (b) five different physical activity categories (from 10–12.5 MET to >35 MET-hours per week).

Furthermore, columns (1) and (4) only include control variables related to the socio-demographic background; columns (2) and (5) additionally adjust for work environment variables (e.g. level of time pressure, commuting time, working hours); and columns (3) and (6) additionally adjust for indicators of physical health (e.g. musculoskeletal and chronic health conditions, blood pressure, cholesterol, glucose) and mental health (e.g. diagnosed depression or whether the individual is at risk of having mental health problems) and lifestyle (alcohol consumption, sleep). With the stepwise inclusion of additional control variables, we intend to illustrate how the coefficient for the physical activity variable changes in magnitude with the adjustment to other factors that potentially affect physical activity and work impairment simultaneously.

Table A.8: The association between physical activity and work impairment due to absenteeism and presenteeism

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable:	% Work impairment: Absenteeism and presenteeism					
>= 10 MET-hours	**-0.02543**	**-0.01987**	**-0.01326**			
se	(0.00186)	(0.00165)	(0.00139)			
p-value	0.00000**	0.00000**	0.00000**			
10–12.5 MET-hours				**-0.01544**	**-0.01233**	**-0.00814**
se				(0.00218)	(0.00205)	(0.00191)
p-value				0.00000**	0.00000**	0.00002**
12.5–15 MET-hours				**-0.02213**	**-0.01749**	**-0.01090**
se				(0.00252)	(0.00235)	(0.00221)
p-value				0.00000**	0.00000**	0.00000**
15–25 MET-hours				**-0.02360**	**-0.01777**	**-0.01136**
se				(0.00197)	(0.00177)	(0.00157)
p-value				0.00000**	0.00000**	0.00000**
25–35 MET-hours				**-0.03074**	**-0.02383**	**-0.01614**
se				(0.00250)	(0.00228)	(0.00201)
p-value				0.00000**	0.00000**	0.00000**
>35 MET-hours				**-0.03349**	**-0.02713**	**-0.01839**
se				(0.00238)	(0.00219)	(0.00191)
p-value				0.00000**	0.00000**	0.00000**
Socio-demographic	yes	yes	yes	yes	yes	yes
Work-related	no	yes	yes	no	yes	yes
Physical and mental health	no	no	yes	no	no	yes
Observations	117,240	117,240	117,240	117,240	117,240	117,240
R-squared	0.28456	0.33020	0.35701	0.28508	0.33055	0.35718

*Notes: Based on pooled BHW and AIA samples for the years 2017, 2018 and 2019. Entries represent OLS regression coefficients with corresponding standard error (parentheses) and p-value. Clustered standard errors (se) in parentheses (at company level); ** p<0.01, * p<0.05. In addition to the physical activity variables, the coefficients in columns (1) and (4) are also adjusted for age, gender, education, marital status, ethnicity, whether an individual has financial concerns, whether an individual is a carer for a child or ill family member, whether an individual is engaged in voluntary or civic participation, and country- and time-fixed effects (year as well as month of interview). The coefficients in columns (2) and (5) are additionally adjusted for work-related factors, including working irregular hours, total hours of work per week, main job, income, and whether an individual is bullied or experiences unrealistic time pressure or stress at work. Columns (3) and (6) are additionally adjusted for physical and mental health as well as lifestyle variables, including excessive alcohol consumption; smoking; psychological distress; clinically diagnosed and chronic asthma, cardiovascular disease, kidney disease, cancer, diabetes, hypertension, severe mental illness; non-clinically diagnosed or chronic high blood pressure, high glucose, high cholesterol; sleep quality; whether the individual experiences less than 6 hours or more than 9 hours of sleep; and BMI (underweight, overweight, obese).*

The parameter estimates reported in column (1) of Table A.8 suggest that an individual reporting the recommended 10 or more MET-hours of physical activity reports on average a 2.5 percentage point lower work impairment due to absenteeism and presenteeism.

The inclusion of additional relevant work environment variables reduces the magnitude of the parameter estimate by about 22 per cent, suggesting an average reduction in work impairment of about 1.98 percentage points compared to an individual not performing at least 10 MET-hours per week (column (3)). Adjusting further for physical and mental health variables reduces the parameter estimate to an average reduction of 1.33 percentage of work impairment due to absenteeism and presenteeism. That is, mental and physical health and lifestyle factors have an independent effect on work impairment, but at the same time are correlated with physical activity. As discussed above, there are potentially different pathways on how physical activity can affect absenteeism and presenteeism, either through direct associations or through indirect associations (e.g. by reducing obesity, improving blood pressure, improving sleep or mental health). While it is impossible to determine the associated direct and indirect effects of physical activity on work impairment with the data available, the parameter estimate presented in column (2) is more likely taking into account some of the indirect associations of physical activity on work impairment, whereas the parameter estimate in column (3) is more likely taking into account the direct association only.

The parameter estimates in columns (4) to (6) report the association between work impairment due to absenteeism and presenteeism and different levels of physical activity, suggesting that the magnitude of the association between work impairment and physical activity decreases in magnitude with higher levels of activity.

For instance, an individual reporting 10 to 12.5 MET-hours reports on average between 0.8 (column (6)) and 1.2 (column (5)) percentage points lower work impairment due to absenteeism and presenteeism than an individual reporting less than 10 MET-hours of physical activity a week. However, an individual reporting more than 35 MET-hours a week reports on average between 1.8 (column (6)) and 2.7 (column (5)) percentage points lower work impairment due to absenteeism and presenteeism than an individual reporting less than 10 MET-hours.

While Table A.8 reported the combined association between physical activity and work impairment due to absenteeism and presenteeism, Table A.9 reports the separate associations for absenteeism (Panel A) and presenteeism (Panel B).

Table A.9: The association between physical activity and work impairment due to absenteeism or presenteeism

	(1)	(2)	(3)	(4)
Panel A: % Work Impairment due to absenteeism				
>= 10 MET-hours	**-0.00373**	**-0.00195**		
se	(0.00051)	(0.00049)		
p-value	0.00000**	0.00008*		
10–12.5 MET-hours			**-0.00223**	**-0.0014**
se			(0.00080)	(0.00066)
p-value			0.00522*	0.0068*

	(1)	(2)	(3)	(4)
12.5–15 MET-hours			**-0.00361**	**-0.00185**
se			(0.00066)	(0.00064)
p-value			0.00000**	0.00408*
15–25 MET-hours			**-0.00421**	**-0.00205**
se			(0.00075)	(0.00068)
p-value			0.00000**	0.00258*
25–35 MET-hours			**-0.00435**	**-0.00211**
se			(0.00069)	(0.00075)
p-value			0.00000**	0.00494*
>35 MET-hours			**-0.00471**	**-0.00342**
se			(0.00110)	(0.00108)
p-value			0.00002**	0.00154*
Panel B: % Work Impairment due to presenteeism				
>= 10 MET-hours	**-0.01615**	**-0.01131**		
se	(0.00145)	(0.00120)		
p-value	0.00000**	0.00000**		
10–12.5 MET-hours			**-0.01010**	**-0.00703**
se			(0.00180)	(0.00169)
p-value			0.00000**	0.00003**
12.5–15 MET-hours			**-0.01278**	**-0.00948**
se			(0.00199)	(0.00189)
p-value			0.00000**	0.00000**
15–25 MET-hours			**-0.01416**	**-0.00951**
se			(0.00151)	(0.00133)
p-value			0.00000**	0.00000**
25–35 MET-hours			**-0.01962**	**-0.01403**
se			(0.00198)	(0.00173)
p-value			0.00000**	0.00000**
>35 MET-hours			**-0.02278**	**-0.01635**
se			(0.00205)	(0.00175)
p-value			0.00000**	0.00000**
Socio-demographic	yes	yes	yes	yes
Work-related	yes	yes	yes	yes
P & M health	no	yes	no	yes

Notes: See Table A.8 for relevant information.

Overall, it is evident from the parameter estimates that presenteeism represents roughly about 80 per cent of the overall magnitude of the associations presented in Table A.8, or, in other words, that the coefficient for presenteeism is roughly about five times the size of the coefficient for absenteeism. This magnitude is in line with previous research that suggests that the burden to presenteeism tends to be larger than absenteeism (e.g. Burton et al. 2005; EU-OSHA 2012). For instance, the parameter estimates in columns (1) and (2) suggest that an individual reporting the recommended 10 or more MET-hours of physical activity per week reports on average 0.2 to 0.37 percentage points lower work impairment due to absenteeism compared to an individual reporting less than 10 MET-hours (Panel A), whereas the reduction in work impairment due to presenteeism is between about 1.1 and 1.6 percentage points, depending on adjustment variables.

The association between physical activity and work impairment due to absenteeism and presenteeism for different sample subgroups (gender, age, geography)

So far, we have examined whether being physically active is associated with lower levels of work impairment, all else being equal, for the full sample. In what follows, we test whether we can find statistically significant differences for these associations by gender or age. We also investigate whether there are different effects by region (e.g. comparing Asian countries with the UK and Australia). To that end, we build interaction terms between the physical activity variables and the indicator variables for the specific subgroups under investigation. For instance, we estimate model equation (1) but add an interaction term as follows:

$$y_{it} = \beta X_{it} + \theta Z_i + \delta PA_{it} + \alpha G_{it} + \mu PA_{it} * G_{it} + \gamma_t + \varepsilon_{it} \qquad (4)$$

In this equation, the variables are defined as follows:

- y_{it} : represents the outcome variable of interest (e.g. physical or mental health, workplace performance) for individual i in year t;
- X_{it}: is a vector of individual characteristics that can vary over time (e.g. education, job, work environment, becoming a parent);
- Z_i: is a vector of individual characteristics that do not vary over time (e.g. ethnicity, personality traits, paternal background);
- PA_{it}: is a measure of physical activity;
- G_{it}: is a variable related to either gender, age or sample region (e.g. Asia);
- $PA_{it} * G_{it}$: is an interaction term between PA_{it} and G_{it}. If there is a difference in the association between work impairment and physical activity, all else being equal, between and any of the subgroup variables, then the coefficient μ is statistically significantly different from zero;
- γ_t: denotes time trends[75]; and

75 Note that we also include company-fixed effects to adjust for company-specific characteristics (e.g. provision of health and well-being interventions), as well as country-fixed effects to examine variation within countries. However, for reasons of parsimony we have not included the specific subscripts in equation (1).

- ε_{it}: denotes an idiosyncratic error term that includes all the time-variant and time-invariant unobserved influences on the outcome variable.

Table A.10 reports the parameter estimates for the interaction term coefficient (μ) by gender subgroups and two different physical activity variable specifications: (a) a binary indicator on whether the respondents reports more than 10 MET-hours (600 MET-minutes) per week of physical activity (columns (1) and (2)); and (b) five different physical activity categories, from 10–12.5 MET to >35 MET-hours per week (columns (3) and (4)). The parameter estimates for the interaction terms presented in columns (1) to (4) are not statistically significantly different from zero. That is, the magnitude of the association between active and non-active male respondents and work impairment is not statistically different from the magnitude of the same association between active and non-active female respondents.

Table A.10: The association between physical activity and work impairment due to absenteeism and presenteeism, by gender

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
>= 10 MET-hours	**-0.02084**	**-0.01356**		
se	(0.00213)	(0.00190)		
p-value	0.00000**	0.00000**		
Female	**0.00559**	**0.00459**		
se	(0.00179)	(0.00178)		
p-value	0.00180*	0.01023*		
>= 10 MET-hours*Female (μ)	**0.00172**	**0.00053**		
se	(0.00230)	(0.00225)		
p-value	0.45633	0.81547		
10–12.5 MET-hours			**-0.01147**	**-0.00675**
se			(0.00317)	(0.00302)
p-value			0.00031*	0.02543*
12.5–15 MET-hours			**-0.01450**	**-0.00867**
se			(0.00341)	(0.00326)
p-value			0.00002**	0.00801*
15–25 MET-hours			**-0.01747**	**-0.01097**
se			(0.00228)	(0.00213)
p-value			0.00000**	0.00000**
25–35 MET-hours			**-0.02449**	**-0.01690**
se			(0.00281)	(0.00255)
p-value			0.00000**	0.00000**

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
>35 MET-hours			**-0.02873**	**-0.01922**
se			(0.00264)	(0.00238)
p-value			0.00000**	0.00000**
Female			**0.00563**	**0.00461**
se			(0.00179)	(0.00178)
p-value			0.00168*	0.00997*
10–12.5 MET-hours*Female (μ)			**-0.00151**	**-0.00239**
se			(0.00391)	(0.00387)
p-value			0.69989	0.53638
12.5–15 MET-hours*Female (μ)			**-0.00531**	**-0.00747**
se			(0.00449)	(0.00440)
p-value			0.23695	0.08978
15–25 MET-hours*Female (μ)			**-0.00060**	**-0.00071**
se			(0.00284)	(0.00280)
p-value			0.83248	0.80152
25–35 MET-hours*Female (μ)			**0.00132**	**0.00161**
se			(0.00349)	(0.00338)
p-value			0.70502	0.63400
>35 MET-hours*Female (μ)			**0.00406**	**0.00229**
se			(0.00313)	(0.00303)
p-value			0.19464	0.45005

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) and (3) are adjusted for socio-demographic and work-related factors, and estimates reported in columns (2) and (4) are additionally adjusted for physical health, mental health and lifestyle factors.

Table A.11 reports the parameter estimates for the interaction term coefficient (μ) by three age subgroups (young age: 18–30; medium age: 31–50; older age: 51 plus)[76] and two different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity (columns (1) and (2)); and (b) five different physical activity categories, from 10–12.5 MET to >35 MET-hours per week (columns (3) and (4)). Similar to the gender subgroups presented above, the parameter estimates for the interaction term with age presented in columns (1) to (4) are not statistically significantly different from zero. That is, the magnitude of the association between active and non-active older and medium-aged individuals and work impairment is not statistically different from the magnitude of the same association between active and non-active young respondents.

76 Note that all parameter coefficients are relative to the base category young age.

Table A.11: The association between physical activity and work impairment due to absenteeism and presenteeism, by age group

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
>= 10 MET-hours	**-0.01866**	**-0.01273**		
se	(0.00255)	(0.00238)		
p-value	0.00000**	0.00000**		
Medium age	**-0.00720**	**-0.00897**		
se	(0.00209)	(0.00206)		
p-value	0.00060*	0.00001**		
Older age	**-0.02465**	**-0.02883**		
se	(0.00304)	(0.00306)		
p-value	0.00000**	0.00000**		
>= 10 MET-hours*Medium age (μ)	**-0.00266**	**-0.00205**		
se	(0.00263)	(0.00258)		
p-value	0.31192	0.42719		
>= 10 MET-hours*Older age (μ)	**0.00264**	**0.00473**		
se	(0.00333)	(0.00329)		
p-value	0.42837	0.15064		
10–12.5 MET-hours			**-0.01274**	**-0.00891**
se			(0.00390)	(0.00381)
p-value			0.00111*	0.01941*
12.5–15 MET-hours			**-0.01509**	**-0.01135**
se			(0.00404)	(0.00397)
p-value			0.00020*	0.00433*
15–25 MET-hours			**-0.01805**	**-0.01193**
se			(0.00300)	(0.00284)
p-value			0.00000**	0.00003**
25–35 MET-hours			**-0.02189**	**-0.01506**
se			(0.00346)	(0.00323)
p-value			0.00000**	0.00000**
>35 MET-hours			**-0.02359**	**-0.01615**
se			(0.00321)	(0.00303)
p-value			0.00000**	0.00000**
Medium age			**-0.00713**	**-0.00889**
se			(0.00209)	(0.00205)
p-value			0.00066*	0.00002**

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
Older age			**-0.02498**	**-0.02901**
se			(0.00304)	(0.00306)
p-value			0.00000**	0.00000**
10–12.5 MET-hours*Medium age (μ)			**0.00107**	**0.00138**
se			(0.00455)	(0.00447)
p-value			0.81403	0.75813
12.5–15 MET-hours*Medium age (μ)			**-0.00548**	**-0.00465**
se			(0.00485)	(0.00474)
p-value			0.25858	0.32633
15–25 MET-hours*Medium age (μ)			**-0.00071**	**-0.00055**
se			(0.00332)	(0.00327)
p-value			0.83099	0.86692
25–35 MET-hours*Medium age (μ)			**-0.00338**	**-0.00251**
se			(0.00384)	(0.00371)
p-value			0.37830	0.49835
>35 MET-hours*Medium age (μ)			**-0.00696**	**-0.00561**
se			(0.00360)	(0.00357)
p-value			0.05361	0.11667
10–12.5 MET-hours*Older age (μ)			**-0.00095**	**0.00017**
se			(0.00566)	(0.00554)
p-value			0.86618	0.97497
12.5–15 MET-hours*Older age (μ)			**0.00400**	**0.00650**
se			(0.00597)	(0.00596)
p-value			0.50256	0.27566
15–25 MET-hours*Older age (μ)			**0.00559**	**0.00673**
se			(0.00393)	(0.00391)
p-value			0.15486	0.08547
25–35 MET-hours*Older age (μ)			**0.00073**	**0.00292**
se			(0.00487)	(0.00478)
p-value			0.88085	0.54123
>35 MET-hours*Older age (μ)			**0.00238**	**0.00587**
se			(0.00477)	(0.00470)
p-value			0.61759	0.21201

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) and (3) are adjusted for socio-demographic and work-related factors, and estimates reported in columns (2) and (4) are additionally adjusted for physical health, mental health and lifestyle factors.

Table A.12 reports the parameter estimates for the interaction term coefficient (μ) for the Asian countries subgroup and two different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity (columns (1) and (2)); and (b) five different physical activity categories, from 10–12.5 MET-hours to >35 MET-hours per week (columns (3) and (4)). The parameter estimates for the interaction terms presented in columns (1) to (4) are not statistically significantly different from zero. That is, the magnitude of the association between active and non-active respondents across non-Asian countries and work impairment is not statistically different from the magnitude of the same association between active and non-active respondents in Asian countries, all else being equal.

Table A.12: The association between physical activity and work impairment due to absenteeism and presenteeism, by geographic region

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
>= 10 MET-hours	**-0.02251**	**-0.01422**		
se	(0.00239)	(0.00210)		
p-value	0.00000**	0.00000**		
Asia	**-0.01515**	**-0.01943**		
se	(0.03284)	(0.02336)		
p-value	0.64466	0.40579		
>= 10 MET-hours*Asia (μ)	**0.00560**	**0.00203**		
se	(0.00347)	(0.00335)		
p-value	0.10676	0.54343		
10–12.5 MET-hours			**-0.01370**	**-0.00878**
se			(0.00276)	(0.00251)
p-value			0.00000**	0.00049*
12.5–15 MET-hours			**-0.01934**	**-0.01130**
se			(0.00232)	(0.00207)
p-value			0.00000**	0.00000**
15–25 MET-hours			**-0.02029**	**-0.01446**
se			(0.00316)	(0.00298)
p-value			0.00000**	0.00000**
25–35 MET-hours			**-0.02519**	**-0.01602**
se			(0.00300)	(0.00271)
p-value			0.00000**	0.00000**
>35 MET-hours			**-0.02977**	**-0.01943**
se			(0.00305)	(0.00277)
p-value			0.00000**	0.00000**

	(1)	(2)	(3)	(4)
Outcome variable:	**% Work impairment: Absenteeism and presenteeism**			
Asia			**-0.01587**	**-0.01992**
se			(0.03325)	(0.02344)
p-value			0.63321	0.39550
10–12.5 MET-hours*Asia (μ)			**0.00235**	**0.00124**
se			(0.00421)	(0.00404)
p-value			0.57690	0.75845
12.5–15 MET-hours*Asia (μ)			**0.00645**	**0.00406**
se			(0.00497)	(0.00486)
p-value			0.19425	0.40389
15–25 MET-hours*Asia (μ)			**0.00301**	**-0.00052**
se			(0.00380)	(0.00365)
p-value			0.42868	0.88704
25–35 MET-hours*Asia (μ)			**0.00257**	**-0.00114**
se			(0.00504)	(0.00494)
p-value			0.61028	0.81690
>35 MET-hours*Asia (μ)			**0.00711**	**0.00311**
se			(0.00459)	(0.00453)
p-value			0.12175	0.49217

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) and (3) are adjusted for socio-demographic and work-related factors, and estimates reported in columns (2) and (4) are additionally adjusted for physical health, mental health and lifestyle factors.

The association between physical activity and work impairment due to absenteeism and presenteeism using a continuous physical activity measure

So far, we have been using physical activity as binary indicator variables, either as a cut-off of 10 MET-hours or more per week or for different levels of physical activity (from 10–12.5 MET-hours to more than 35 MET-hours per week). In this section, we also use physical activity measured in MET-hours per week as a continuous variable and, further, check whether the association between physical activity and work impairment decreases linearly with the level of activity or whether there is potentially a non-linear relationship, e.g. low levels of activity are associated with higher levels of work impairment, as well as very high levels of activity (e.g. which may increase the risk of injuries). To that end, we include second- and third-degree polynomials of the continuous physical activity variable in the regression models. Table A.13 reports the corresponding parameter estimates, where columns (1) to (6) all adjust for variables related to socio-demographic background.

Table A.13: The association between continuous physical activity measure and work impairment due to absenteeism and presenteeism

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	% Work impairment: Absenteeism and presenteeism					
MET-hours	**-0.00043355**	**-0.00029070**	**-0.00074574**	**-0.00050049**	**-0.00100281**	**-0.00065019**
se	(0.00003672)	(0.00003131)	(0.00006837)	(0.00005389)	(0.00009487)	(0.00007720)
p-value	0.0000000**	0.0000000**	0.00000000**	0.0000000**	0.0000000**	0.0000000**
MET-hours^2			**0.00000091**	**0.00000064**	**0.00000762**	**0.00000469**
se			(0.00000002)	(0.0000001)	(0.00000125)	(0.000000965)
p-value			0.00000001**	0.00000008**	0.00000001**	0.00001367**
MET-hours^3					**-0.00000001**	**-0.00000001**
se					-0.00000008	(0.00000005)
p-value					0.1012698	0.10909073
Socio	yes	yes	yes	yes	yes	yes
Work-related	yes	yes	yes	yes	yes	yes
P & M health	no	yes	no	yes	no	yes
N	117,241	117,224	117,241	117,224	117,241	117,224
R-squared	0.3297	0.3568	0.3302	0.3570	0.3305	0.3571

Notes: See Table A.8 for relevant information.

Columns (1), (3) and (5) additionally adjust for work environment-related variables (e.g. level of time pressure, commuting time, working hours); and columns (2), (4) and (6) additionally adjust for indicators of physical health (e.g. musculoskeletal and chronic health conditions, blood pressure, cholesterol, glucose), mental health (e.g. diagnosed depression or whether the individual is at risk of having mental health problems) and lifestyle (alcohol consumption, sleep).

The parameter estimates in columns (1) and (2) suggest that each MET-hour of physical activity is associated with a reduction in work impairment due to absenteeism and presenteeism of between 0.3 and 0.4 percentage points. The parameter estimates in columns (3) and (4) suggest that the association may not be fully linearly decreasing with each MET-hour of additional physical activity, as the coefficients for MET-hours^2 are positive and statistically significantly different from zero. Furthermore, columns (5) and (6) examine whether the association between physical activity and work impairment takes a cubic form. The coefficients for MET-hours^3 are not statistically significantly different from zero, suggesting that the association between physical activity and work impairment in the data sample is likely better explained by the U-shaped relationship suggested by the parameter coefficients reported in columns (3) and (4).

In addition to the association between the continuous physical activity variable measured in MET-hours of activity per week and the work impairment due to absenteeism and presenteeism, we also provide the parameter estimates separately for absenteeism or presenteeism in Table A.14.

Table A.14: The association between continuous physical activity measures and work impairment due to absenteeism or presenteeism

	(1)	(2)	(3)	(4)
	% Work Impairment: Absenteeism		% Work Impairment: Presenteeism	
MET-hours	**-0.000132687**	**-0.000065571**	**-0.000613050**	**-0.000434920**
se	(0.000017172)	(0.000016602)	(0.000063262)	(0.000049779)
p-value	0.000000000**	0.000083092*	0.000000000**	0.000000000**
MET-hours ^2	**0.000000133**	**0.000000058**	**0.000000749**	**0.000000558**
se	(0.000000022)	(0.000000016)	(0.000000012)	(0.000000096)
p-value	0.000000002**	0.000357814*	0.000000655**	0.000003827**
Socio	yes	yes	yes	yes
Work-related	yes	yes	yes	yes
P & M health	no	yes	no	yes
Observations	117,241	117,224	117,224	117,241
R-squared	0.1038	0.1177	0.3671	0.3853

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) and (3) are adjusted for socio-demographic and work-related factors, and estimates reported in columns (2) and (4) are additionally adjusted for physical health, mental health and lifestyle factors.

The association between physical activity and work impairment due to absenteeism and presenteeism and physical activity using UK longitudinal data

So far, we have only examined the association between different physical activity measures and work impairment due to absenteeism and presenteeism using the pooled cross-sectional data. For the purpose of sensitivity analysis, in this section, we estimate model equation (2) using the longitudinal data sample for the UK only. Table A.15 provides a summary of how the survey respondents in the UK cross-sectional sample compare against those in the longitudinal sample across different variables. We observe that the respondents included in the longitudinal sample tend to be slightly more physically active on average than those included in the cross-sectional sample. For instance, about 74 per cent of respondents in the longitudinal sample respond to perform at least 10 MET-hours per week of physical activity, compared to 67 per cent of respondents in the UK cross-sectional sample. The difference in actual MET-hours is a bit more than 2 MET-hours, respectively. Overall, with regard to the socio-demographic background, the two samples are very similar, with the same gender proportions and very similar average age. The share of individuals reporting to be of white ethnicity is a bit larger in the longitudinal sample (97 per cent) compared to the cross-sectional sample (95 per cent). Also, the share of respondents reporting financial concerns is a bit higher in the cross-sectional sample (8 per cent) than in the longitudinal sample (4 per cent). When looking at some health and lifestyle variables, we observe that the two samples have a very similar average BMI but that the share of smokers is larger in the longitudinal sample (33 per cent) compared to the cross-sectional sample (10 per cent), and that the share of respondents with high blood pressure tends to be a bit higher in the longitudinal sample (29 per cent vs 23 per cent). In contrast, we observe on average a slightly higher share of respondents reporting having been diagnosed by a clinician with a severe mental health problem or reporting having a Kessler score higher than 13, suggesting they are at risk of a more severe mental health issue ('Psychological distress'). They also report on average a higher level of sleep disturbance compared to respondents in the longitudinal sample, but they have a similar average sleep length.

Table A.15: Summary statistics on the difference between UK cross-sectional and longitudinal survey respondents

	Cross-sectional		Longitudinal	
	Mean	*Standard deviation*	Mean	*Standard deviation*
Physical activity: >=10 MET-hours (yes/no)	0.67	*0.47*	0.74	*0.44*
Physical activity: MET-hours	21.18	*20.68*	23.47	*20.51*
Gender: female (yes/no)	0.50	*0.51*	0.50	*0.50*
Age (years)	39.02	*11.40*	40.42	*9.96*
Ethnicity: white (yes/no)	0.91	*0.29*	0.95	*0.22*
Ethnicity: Asian (yes/no)	0.04	*0.20*	0.02	*0.15*
Ethnicity: black (yes/no)	0.01	*0.12*	0.01	*0.10*
Carer of child (yes/no)	0.27	*0.44*	0.27	*0.44*
Carer of ill family member or friend (yes/no)	0.03	*0.17*	0.02	*0.15*
Volunteering (yes/no)	0.25	*0.44*	0.27	*0.45*
Travel time (minutes)	42.07	*31.23*	41.60	*30.57*
Financial concerns (yes/no)	0.08	*0.28*	0.04	*0.19*
BMI	26.21	*5.20*	25.92	*4.56*
Smoking (yes/no)	0.10	*0.30*	0.33	*0.47*
Blood pressure: high (yes/no)	0.23	*0.42*	0.29	*0.45*
Cholesterol: high (yes/no)	0.02	*0.15*	0.03	*0.16*
Glucose: high (yes/no)	0.01	*0.11*	0.01	*0.09*
Asthma (yes/no)	0.08	*0.27*	0.06	*0.24*
Cardiovascular (yes/no)	0.01	*0.11*	0.02	*0.13*
Cancer (yes/no)	0.00	*0.07*	0.00	*0.04*
Diabetes (yes/no)	0.02	*0.13*	0.01	*0.11*
Hypertension (yes/no)	0.05	*0.22*	0.04	*0.20*
Kidney (yes/no)	0.01	*0.08*	0.00	*0.06*
Severe mental health problems (yes/no)	0.04	*0.21*	0.03	*0.16*

	Cross-sectional		Longitudinal	
	Mean	*Standard deviation*	Mean	*Standard deviation*
Psychological distress (yes/no)	0.07	*0.25*	0.02	*0.14*
Sleep disturbance score	10.65	*2.19*	7.07	*5.06*
Sleep: hours	6.91	*0.98*	6.99	*0.85*

Notes: Based on Vitality BHW surveys (2017 and 2018) using cross-sectional data and Vitality BHW individual longitudinal information from survey participants for whom we have information over the time horizon of 2017 to 2018 and who gave their consent to link their data over time.

Table A.16 reports the parameter estimates for estimating model equation (2) using OLS. For the UK cross-sectional sample, a respondent who reaches at least 10 MET-hours reports on average between 1.4 and 2.2 percentage points lower work impairment due to absenteeism and presenteeism than an individual reporting less than 10 MET-hours a week (Panel A, columns (1) and (2)). The parameter estimates for the longitudinal sample are overall somewhat smaller but of relative similar magnitude to the estimates for the cross-sectional sample. For instance, we find that a respondent reaching at least 10 MET-hours reports on average between 1.4 and 1.8 percentage points lower work impairment due to absenteeism and presenteeism than an individual reporting less than 10 MET-hours per week (columns (3) and (4)).

Table A.16: The association between physical activity measure and work impairment due to absenteeism and presenteeism – comparing UK cross-sectional and UK longitudinal sample

	(1)	(2)	(3)	(4)
	%-Change work impairment: Absenteeism and presenteeism			
	UK: Cross-sectional		*UK: Longitudinal*	
Panel A: Change in performing at least 10 MET-hours per week (yes/no)				
>= 10 MET-hours	**-0.02092**	**-0.01466**	**-0.01838**	**-0.01404**
se	(0.00249)	(0.00202)	(0.00870)	(0.00639)
p-value	0.00000**	0.00000**	0.04639*	0.0446*
Observations	56,127	56,127	1,766	1,766
Panel B: Change in MET-hours per week (continuous)				
MET-hours	**-0.00048**	**-0.00034**	**-0.00047**	**-0.00033**
se	(0.00005)	(0.00004)	(0.00020)	(0.00015)
p-value	0.00000**	0.00000**	0.01613*	0.01723*
Observations	56,127	56,127	1,766	1,766
Socio-demographic	yes	yes	yes	yes
Work-related	yes	yes	yes	yes
Physical and mental health	no	yes	no	yes

Notes: Entries represent OLS (first-differences) regression coefficients. See Table A.8 for more relevant information.

In Panel B of Table A.16, we also report the parameter estimates for the continuous physical activity measure. As reported in columns (1) and (2), on average one additional MET-hour of physical activity is associated with between 0.034 and 0.048 percentage points reduction in the reported work impairment due to absenteeism and presenteeism. The coefficients for the longitudinal sample are somewhat smaller but of relative similar magnitude, suggesting that one additional MET-hour of physical activity is associated with between 0.033 and 0.047 percentage points lower work impairment due to absenteeism and presenteeism.

A.5.2. Physical activity and the associations with physical and mental health

Using OLS regressions, Tables A.17 and A.18 report the estimated associations between physical activity and physical and mental health, using four different outcome measures: (1) whether the respondent reports good overall physical health; (2) whether they have a BMI above 30; (3) whether the respondent reports good overall mental health; and (4) whether they report a Kessler score above 13, which represents a threshold for more severe mental health issues. For each outcome measure in Table A.17 and A.18, we report the association for three different physical activity variable specifications: (a) a binary indicator on whether the respondents reports more than 10 MET-hours (600 MET-minutes) per week of physical activity; (b) five different physical activity categories (from 10–12.5 MET-hours to >35 MET-hours per week); (c) continuous MET-hours per week.

The parameter estimate reported in column (1) of Table A.17 suggests that an individual reporting more than 10 MET-hours per week of physical activity reports on average a 16 percentage point larger probability of being in good physical health than an individual who reports less than 10 MET-hours per week. The parameter estimates in column (2) suggest that the probability of reporting good physical health increases with the reported level of physical activity. For instance, an individual performing 10–12.5 MET-hours a week reports on average a 9 percentage point higher likelihood of being in good physical health.

Table A.17: The association between physical activity and physical health using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Physical health: good (yes/no)**			**BMI: obese (yes/no)**		
>= 10 MET-hours	**0.15932**			**-0.05408**		
se	(0.00428)			(0.00279)		
p-value	0.00000**			0.00000**		
10–12.5 MET-hours		**0.09127**			**-0.02814**	
se		(0.00488)			(0.00414)	
p-value		0.00000**			0.00000**	
12.5–15 MET-hours		**0.11260**			**-0.03717**	
se		(0.00633)			(0.00477)	
p-value		0.00000**			0.00000**	

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Physical health: good (yes/no)**			**BMI: obese (yes/no)**		
15–25 MET-hours		**0.14493**			**-0.05289**	
se		(0.00459)			(0.00348)	
p-value		0.00000**			0.00000**	
25–35 MET-hours		**0.19777**			**-0.06159**	
se		(0.00531)			(0.00400)	
p-value		0.00000**			0.00000**	
>35 MET-hours		**0.22974**			**-0.07916**	
se		(0.00537)			(0.00368)	
p-value		0.00000**			0.00000**	
MET-hours			**0.00376**			**-0.00132**
se			(0.00010)			(0.00007)
p-value			0.00000**			0.00000**
Observations	117,991	117,992	117,992	117,991	117,992	117,992
R-squared	0.22164	0.22789	0.21882	0.10141	0.10254	0.10118

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except BMI for estimates presented in columns (4) to (6)).

Performing more than 35 MET-hours is associated with a 23 percentage point higher likelihood of being in good physical health. Column (3) confirms that physical activity is associated with reporting a better physical health overall. The likelihood of reporting good physical health increases on average by about 0.38 percentage points for each MET-hour of physical activity.

Columns (3) to (6) report the association between physical activity and whether an individual reports a BMI that is higher than 30. The parameter estimate reported in column (4) suggest that an individual reporting more than 10 MET-hours of physical activity reports on average a 5 percentage point lower likelihood of having a BMI larger than 30, compared to an individual reporting less than 10 MET-hours a week. As reported in column (5), this association tends to decrease with the level of physical activity performed. For instance, an individual reporting 10 to 12.5 MET-hours a week reports on average a 2.8 percentage point lower likelihood of being obese, whereas an individual reporting more than 35 MET-hours a week reports on average an 8 percentage point lower likelihood of being obese compared to an individual reporting less than 10 MET-hours. The parameter estimate reported in column (6) suggests that each MET-hour of physical activity is associated with a reduction in the likelihood of being obese by about 0.13 percentage points.

The parameter estimate reported in column (1) of Table A.18 suggests that an individual reporting more than 10 MET-hours per week of physical activity reports on average a 5 percentage point larger probability of being in good mental health than an individual who reports less than 10 MET-hours per week.

Table A.18: The association between physical activity and mental health using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Mental health: good (yes/no)**			**Kessler score: medium to high risk (yes/no)**		
>= 10 MET-hours	**0.05183**			**-0.01129**		
se	(0.00296)			(0.00153)		
p-value	0.00000**			0.00000**		
10–12.5 MET-hours		**0.02842**			**-0.00662**	
se		(0.00450)			(0.00260)	
p-value		0.00000**			0.01113*	
12.5–15 MET-hours		**0.04269**			**-0.00925**	
se		(0.00519)			(0.00309)	
p-value		0.00000**			0.00279*	
15–25 MET-hours		**0.04814**			**-0.01302**	
se		(0.00354)			(0.00183)	
p-value		0.00000**			0.00000**	
25–35 MET-hours		**0.06383**			**-0.01373**	
se		(0.00458)			(0.00227)	
p-value		0.00000**			0.00000**	
>35 MET-hours		**0.07206**			**-0.01173**	
se		(0.00422)			(0.00229)	
p-value		0.00000**			0.00000**	
MET-hours			**0.00119**			**-0.00021**
se			(0.00007)			(0.00004)
p-value			0.00000**			0.00000**
Observations	117,991	117,992	117,992	117,991	117,992	117,992
R-squared	0.32523	0.32576	0.32484	0.16181	0.16185	0.16162

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except the Kessler score medium to high risk binary indicator variable for estimates presented in columns (4) to (6)).

The parameter estimates in column (2) suggest that the probability of reporting good mental health increases with the reported level of physical activity. For instance, an individual performing 10–12.5 MET-hours a week reports on average a 3 percentage point higher likelihood of being in good mental health. An individual performing more than 35 MET-hours reports a 7 percentage point higher likelihood of being in good mental health. Column (3) confirms that physical activity is associated with reporting better mental health overall. That is, the likelihood of reporting good mental health increases on average by about 0.12 percentage points for each MET-hour of physical activity.

Columns (3) to (6) report the association between physical activity and whether an individual reports a Kessler score that is higher than 13, being the threshold for more severe mental health problems. The parameter estimate reported in column (4) suggest that an individual reporting more than 10 MET-hours of physical activity reports on average a 1 percentage point lower likelihood of having a Kessler score larger than 13, compared to an individual reporting less than 10 MET-hours a week. As reported in column (5), this negative association tends to increase in magnitude with the level of physical activity performed. For instance, an individual reporting 10 to 12.5 MET-hours a week reports on average a 0.6 percentage point lower likelihood of having more serious mental health issues, whereas an individual reporting more than 35 MET-hours a week reports on average an 1.1 percentage point lower likelihood of having more severe mental health problems compared to an individual reporting less than 10 MET-hours.[77] The parameter estimate reported in column (6) suggests that each MET-hour of physical activity is associated with a reduction in the likelihood of having more severe mental health problems of about 0.02 percentage points.

A.5.3. Physical activity and the association with sleep quality and duration

Using OLS regressions, Tables A.19, A.20 and A.21 report the estimated associations between physical activity and sleep quality and duration. For each outcome measure, we report separately the association for three different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity; (b) five different physical activity categories (from 10–12.5 MET-hours to >35 MET-hours per week); (c) continuous MET-hours per week.

Table A.19 reports the associations between physical activity and the sleep disturbance score (columns (1) to (3)) and the first uninterrupted sleep period measured in hours until first awakening (columns (4) to (6)). Overall, the parameter estimate reported in column (1) suggests that an individual performing the recommended equal to or more than 10 MET-hours per week reports on average a 13.5 per cent lower sleep disturbance than an individual with less than 10 MET-hours per week of physical activity. The parameter estimates reported in column (2) suggest further that the magnitude of the negative association between physical activity and sleep disturbance increases with the level of activity. For instance, an individual reporting to perform 10 to 12.5 MET-hours a week reports on average a 6 per cent lower sleep disturbance compared with an individual performing less than 10 MET-hours, whereas an individual performing more than 35 MET-hours reports on average a 26 per cent lower sleep disturbance score. Furthermore, the parameter estimate in column (3) of Table A.19 suggests that each MET-hour of physical activity is associated with a 0.35 per cent decrease in the sleep disturbance score.

77 However, it is important to note that the parameter estimates reported in column (5) for the lower levels of physical activity are only statistically significant at the 5 per cent level.

Table A.19: The association between physical activity and a sleep disturbance score and the first uninterrupted sleep period using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**(Log) Sleep disturbance score**			**FUSP (hours)**		
>= 10 MET-hours	**-0.14535**			**0.06347**		
se	(0.01301)			(0.01349)		
p-value	0.00000**			0.00000**		
10–12.5 MET-hours		**-0.06050**			**0.03965**	
se		(0.02175)			(0.02432)	
p-value		0.00550*			0.10341	
12.5–15 MET-hours		**-0.12569**			**0.02635**	
se		(0.02715)			(0.02813)	
p-value		0.00000**			0.34920	
15–25 MET-hours		**-0.13876**			**0.06081**	
se		(0.01642)			(0.02176)	
p-value		0.00000**			0.00534*	
25–35 MET-hours		**-0.15494**			**0.07540**	
se		(0.02242)			(0.02119)	
p-value		0.00000**			0.00040*	
>35 MET-hours		**-0.22815**			**0.08055**	
se		(0.01982)			(0.01848)	
p-value		0.00000**			0.00002**	
MET-hours			**-0.00355**			**0.00140**
se			(0.00033)			(0.00037)
p-value			0.00000**			0.00014*
Observations	117,991	117,992	117,992	91,904	91,904	91,904
R-squared	0.19407	0.19439	0.19404	0.11188	0.11193	0.11185

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except any of the sleep disturbance score variables for estimates presented in columns (1) to (6)).

Column (4) reports the parameter estimate comparing the first uninterrupted sleep period (FUSP) for individuals performing more than 10 MET-hours compared to those who do not reach this recommended level of physical activity. The estimate suggests that reaching the recommended activity guidelines is on average associated with a 3.6 minute longer uninterrupted sleep period (or about 1.4 per cent of the average FUSP). As the parameter estimates in column (5) suggest, the association between physical activity and the length of the first uninterrupted sleep period increases with the levels of reported physical activity but the association is only statistically significantly different from zero for medium to relative large levels of activity (15 MET-hours or above) per week. Furthermore, on average, every MET-hour of activity is associated with an increase in the FUSP of about 0.06 minutes.

Table A.20 reports the associations between the likelihood of reporting poor sleep quality or not feeling refreshed after waking up and the level of reported physical activity. The parameter estimate reported in column (1) suggests that an individual performing the recommended 10 or more MET-hours per week reports on average a 5 percentage point lower likelihood of reporting poor sleep quality than an individual with less than 10 MET-hours per week of physical activity.

Table A.20: The association between physical activity and the likelihood of reporting poor sleep quality or not feeling refreshed after sleep using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Sleep quality: poor (yes/no)**			**Not feeling refreshed (yes/no)**		
>= 10 MET-hours	**-0.048**			**-0.04569**		
se	(0.00304)			(0.00302)		
p-value	0.00000**			0.00000**		
10–12.5 MET-hours		**-0.0241**			**-0.03469**	
se		(0.00499)			(0.00449)	
p-value		0.00000**			0.00000**	
12.5–15 MET-hours		**-0.0425**			**-0.03791**	
se		(0.00673)			(0.00576)	
p-value		0.00000**			0.00000**	
15–25 MET-hours		**-0.0479**			**-0.04279**	
se		(0.00391)			(0.00392)	
p-value		0.00000**			0.00000**	
25–35 MET-hours		**-0.0552**			**-0.05289**	
se		(0.00493)			(0.00469)	
p-value		0.00000**			0.00000**	
>35 MET-hours		**-0.0655**			**-0.05730**	
se		(0.00456)			(0.00390)	
p-value		0.00000**			0.00000**	
MET-hours			**-0.0011**			**-0.00093**
se			(0.00008)			(0.00007)
p-value			0.00000**			0.00000**
Observations	117,991	117,992	117,992	117,991	117,992	117,992
R-squared	0.17925	0.17961	0.17894	0.16208	0.16226	0.16136

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except any of the sleep disturbance score variables for estimates presented in columns (1) to (6)).

Furthermore, the parameter estimates reported in column (2) suggest that the magnitude of the negative association between physical activity and poor sleep quality increases with the level of activity. For instance, an individual reporting to perform 10 to 12.5 MET-hours a week reports on average a 2.4 percentage point lower likelihood of reporting poor sleep quality compared with an individual performing less than 10 MET-hours, whereas an individual performing more than 35 MET-hours has on average a 6.5 percentage point lower likelihood of reporting poor sleep quality. Furthermore, the parameter estimate in column (3) of Table A.20 suggests that each MET-hour of physical activity is associated with a 0.11 percentage point decrease in the likelihood of reporting poor sleep quality.

Column (4) reports the parameter estimate comparing the likelihood of reporting that sleep is not refreshing of an individual reporting more than 10 MET-hours of physical activity per week with an individual performing less than this level of activity. The estimate suggests that reaching the recommended activity guidelines is on average associated with a 4.6 percentage point reduction in the likelihood of reporting sleep that is not refreshing. Furthermore, the magnitude of this negative association tends to be larger for higher levels of physical activity. For instance, an individual performing 35 MET-hours a week reports on average almost a 6 percentage point lower likelihood of not experiencing refreshing sleep compared to an individual with less than 10 MET-hours, whereas individuals with 10 to 12.5 MET-hours report on average a 3.4 percentage point lower likelihood. And each MET-hour of physical activity is associated with a 0.09 percentage point decrease in the likelihood of reporting sleep that is not refreshing (column (5)).

Besides the two separate sleep quality measures reported in Table A.20, in Table A.21, we also report the association between physical activity and the likelihood of reporting difficulties falling asleep or having problems with staying asleep.

Overall, there is some evidence that physical activity is associated with a lower likelihood of reporting difficulties falling asleep (compared to being less physically active), but the coefficients are relatively low in magnitude and are mostly not statistically significantly different from zero. For instance, the parameter estimate in column (1) suggests that performing more than 10 MET-hours a week is associated with a 0.5 percentage point reduction in the likelihood of reporting difficulties falling asleep. The parameter estimates reported in columns (2) and (3) also suffer from a lack of statistical significance. In contrast, we find some relevant negative association between physical activity and the likelihood of reporting problems staying asleep. For instance, an individual reporting 10 MET-hours or more reports on average a 1.1 percentage point lower likelihood of having problems staying asleep. This negative association also increases in magnitude with higher levels of physical activity reported. For instance, an individual reporting more than 35 MET-hours a week has on average a 1.6 percentage point lower likelihood of reporting problems staying asleep compared to an individual reporting less than 10 MET-hours a week. This compares to a 0.05 percentage point lower likelihood for individuals reporting 10 to 12.5 MET-hours; however, this estimate is not statistically significantly different from zero. Furthermore, each MET-hour of physical activity is associated with a 0.02 percentage point lower likelihood of reporting problems staying asleep.

Table A.21: The association between physical activity and the likelihood of reporting difficulties falling asleep or problems staying asleep using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Difficulties falling asleep (yes/no)**			**Problems staying asleep (yes/no)**		
>= 10 MET-hours	**-0.00508**			**-0.01122**		
se	(0.00206)			(0.00228)		
p-value	0.01381*			0.00000**		
10–12.5 MET-hours		**-0.00278**			**-0.00560**	
se		(0.00362)			(0.00403)	
p-value		0.44238			0.16431	
12.5–15 MET-hours		**-0.00135**			**-0.00792**	
se		(0.00458)			(0.00511)	
p-value		0.76767			0.12190	
15–25 MET-hours		**-0.00602**			**-0.01045**	
se		(0.00268)			(0.00407)	
p-value		0.02511*			0.01037*	
25–35 MET-hours		**-0.00389**			**-0.01224**	
se		(0.00336)			(0.00300)	
p-value		0.24764			0.00005*	
>35 MET-hours		**-0.00818**			**-0.01648**	
se		(0.00289)			(0.00328)	
p-value		0.00476*			0.00000**	
MET-hours			**-0.00008**			**-0.00022**
se			(0.00005)			(0.00005)
p-value			0.09067			0.00003**
Observations	117,991	117,992	117,992	117,991	117,992	117,992
R-squared	0.17925	0.17961	0.17894	0.16208	0.16226	0.16136

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except any of the sleep disturbance score variables for estimates presented in columns (1) to (6)).

Table A.22 reports the associations between the likelihood of reporting short sleep (less than 6 hours) or long sleep (more than 9 hours), both of which have been associated with negative health outcomes. The parameter estimate reported in column (1) suggests that an individual performing the recommended 10 or more MET-hours per week has on average a 2 percentage point lower likelihood of reporting short sleep, whereas the parameter estimate reported in column (4) suggests that an active individual also has on average a 2 percentage point lower likelihood of reporting more than 9 hours of sleep. For both short and long sleep, we find some evidence that the likelihood decreases with the reported amount of physical activity (see parameter estimates reported in columns (2), (3), (5) and (6)).

Table A.22: The association between physical activity and the likelihood of reporting short or long sleep using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable:	**Sleep duration: less than 6 hours**			**Sleep duration: more than 9 hours**		
>= 10 MET-hours	**-0.02141**			**-0.00194**		
se	(0.00313)			(0.00051)		
p-value	0.00000**			0.00017*		
10–12.5 MET-hours		**-0.01112**			**-0.00067**	
se		(0.00460)			(0.00088)	
p-value		0.01586*			0.44677	
12.5–15 MET-hours		**-0.01754**			**-0.00124**	
se		(0.00668)			(0.00101)	
p-value		0.00874*			0.22096	
15–25 MET-hours		**-0.01982**			**-0.00254**	
se		(0.00465)			(0.00070)	
p-value		0.00002**			0.00032*	
25–35 MET-hours		**-0.02672**			**-0.00265**	
se		(0.00387)			(0.00060)	
p-value		0.00000**			0.00001**	
>35 MET-hours		**-0.02779**			**-0.00271**	
se		(0.00530)			(0.00105)	
p-value		0.00000**			0.00977*	
MET-hours			**-0.00013**			**-0.00003**
se			(0.00006)			(0.00003)
p-value			0.045231*			0.26668
Observations	117,991	117,992	117,992	117,991	117,992	117,992
R-squared	0.16691	0.16701	0.16653	0.02850	0.02856	0.02843

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (6) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors (except any of the sleep duration variables for estimates presented in columns (1) to (6)).

A.5.4. Physical activity and the association with subjective well-being

Table A.23 reports the estimated association between physical activity and subjective well-being, measured through the question on how satisfied an individual is with his or her current life overall.

We report separately the association for three different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity; (b) five different physical activity categories (from 10–12.5 MET-hours to >35 MET-hours per week); (c) continuous MET-hours per week.

Table A.23: The association between physical activity and subjective well-being using pooled cross-sectional sample for all countries

	(1)	(2)	(3)
Outcome variable:		**Satisfied with life (yes/no)**	
>= 10 MET-hours	**0.05570**		
se	(0.00306)		
p-value	0.00000**		
10–12.5 MET-hours		**0.03518**	
se		(0.00483)	
p-value		0.00000**	
12.5–15 MET-hours		**0.05436**	
se		(0.00378)	
p-value		0.00000**	
15–25 MET-hours		**0.05839**	
se		(0.00464)	
p-value		0.00000**	
25–35 MET-hours		**0.05975**	
se		(0.00596)	
p-value		0.00000**	
>35 MET-hours		**0.07140**	
se		(0.00428)	
p-value		0.00000**	
MET-hours			**0.00115**
se			(0.00007)
p-value			0.00000**
Observations	117,991	117,992	117,992
R-squared	0.23905	0.23932	0.23815

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (3) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors.

Column (1) of Table A.23 suggests that an individual meeting or exceeding the recommended 10 MET-hours per week reports on average a 5.5 percentage point higher likelihood of being happy with his or her current life, compared to an individual reporting less than 10 MET-hours per week, all else being equal. The parameter estimates reported in column (2) suggest that the magnitude of this association increases with the level of physical activity reported. For instance, an individual reporting 10 to 12.5 MET-hours per week reports on average a 3.5 percentage point higher likelihood of being happy with his or her current life than an individual reporting less than 10 MET-hours, whereas an individual reporting more than 35 MET-hours a week reports on average a 7.1 percentage point higher likelihood of being happy. Furthermore, each MET-hour of physical activity reported among the sample population is associated with an increase in the likelihood of reporting being happy by about 0.11 percentage points, all else being equal.

A.5.5. The association between physical activity and job satisfaction and work engagement

Table A.24 reports the estimated associations between physical activity, job satisfaction and work engagement. We use two different outcome measures: (1) whether the respondent reports good job satisfaction[78] and (2) whether the respondent reports a relative high work engagement.[79] We report separately the association for three different physical activity variable specifications: (a) a binary indicator on whether the respondent reports more than 10 MET-hours (600 MET-minutes) per week of physical activity; (b) five different physical activity categories (from 10–12.5 MET-hours to >35 MET-hours per week); (c) continuous MET-hours per week.

The parameter estimate reported in column (1) suggests that an individual reporting 10 MET-hours or more of physical activity per week reports on average a 1.8 percentage point higher likelihood of being satisfied with his or her current job, compared to an individual not reaching the recommended 10 MET-hours per week. The parameter estimates reported in column (2) suggest that the magnitude of the estimated association increases with the level of physical activity reported. For instance, an individual reporting 10 to 12.5 MET-hours per week reports on average a 1.4 percentage point higher likelihood of being happy with the current job, compared to an individual performing less than 10 MET-hours, whereas an individual reporting more than 35 MET-hours reports on average a 2.4 percentage point higher likelihood. Furthermore, column (3) suggests that each MET-hour is associated with a 0.03 percentage point higher likelihood of reporting good job satisfaction.

With regards to work engagement, the parameter estimate reported in column (4) suggests that an individual reporting at least 10 MET-hours per week of physical activity reports on average a 4 percentage point higher likelihood of being highly engaged at work, compared to an individual reporting less than 10 MET-hours. The parameter estimates reported in column (5) suggest that the association between physical activity and work engagement increases in magnitude with higher levels of physical activity. For instance, an individual reporting 10 to 12 MET-hours per week reports on average a 2.6 percentage point higher likelihood of reporting high work

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78 This is a binary variable taking the value 1 if the reported level of job satisfaction is above the sample median and zero otherwise.

79 This is a binary variable taking the value 1 if the reported level of Utrecht work engagement score (0–54) is in the highest quarter of the sample-wide work engagement score distribution and zero otherwise. Note that we also used the continuous score as outcome variable, which provided similar results with regards to the direction of the association between physical activity and work engagement.

engagement, compared to an individual reporting less than 10 MET-hours, whereas an individual reporting more than 35-MET-hours reports on average a 6.6 percentage point higher likelihood of being highly engaged at work. Furthermore, column (6) suggests that each MET-hour of physical activity is associated with a 0.1 percentage point higher likelihood of reporting high work engagement, all else being equal.

Table A.24: The association between physical activity, job satisfaction and work engagement using pooled cross-sectional sample for all countries

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	**Job satisfaction: good (yes/no)**			**Work engagement: high (yes/no)**		
>= 10 MET-hours	**0.01830**			**0.04174**		
se	(0.00282)			(0.00258)		
p-value	0.00000**			0.00000**		
10–12.5 MET-hours		**0.01444**			**0.02620**	
se		(0.00472)			(0.00440)	
p-value		0.00224*			0.00000**	
12.5–15 MET-hours		**0.01652**			**0.03363**	
se		(0.00407)			(0.00349)	
p-value		0.00005*			0.00000**	
15–25 MET-hours		**0.01862**			**0.04079**	
se		(0.00399)			(0.00597)	
p-value		0.00000**			0.00000**	
25–35 MET-hours		**0.02140**			**0.04298**	
se		(0.00473)			(0.00478)	
p-value		0.00001**			0.00000**	
>35 MET-hours		**0.02426**			**0.06649**	
se		(0.00641)			(0.00403)	
p-value		0.00016*			0.00000**	
MET-hours			**0.00032**			**0.00112**
se			(0.00007)			(0.00007)
p-value			0.00001**			0.00000**
Observations	117,992	117,992	117,992	117,992	117,992	117,992
R-squared	0.26896	0.26899	0.26883	0.15380	0.15436	0.15408

Notes: See Table A.8 for relevant information. Parameter estimates in columns (1) to (3) are adjusted for socio-demographic factors (e.g. age, gender, ethnicity), work-related factors (e.g. time pressure, stress) as well as relevant physical health, mental health and lifestyle factors.

A.5.6. Using UK longitudinal data to examine the associations between physical activity, BMI, mental health, sleep quality and sleep duration

In this section, we examine the associations between physical activity, BMI, mental health, and sleep quality and duration using longitudinal data for the UK, where we can follow the same individual over time. In essence, we estimate model equation (3) using OLS.[80]

Table A.25 reports the findings using the change in BMI and the change in the Kessler Psychological Distress score over time for two physical activity measures: (1) respondents who report reaching at least 10 MET-hours per week; and (2) the change in MET-hours over time. We find that the inverse association between physical activity and BMI also holds in the longitudinal analysis. For instance, every MET-hour of additional activity reduces the reported BMI by 0.009 points over the course of a year (column (2)). Furthermore, we find that each additional MET-hour of activity reduces the reported Kessler score by 0.22 per cent.

Table A.25: The association between physical activity and BMI and physical activity and psychological distress within the same individual over time using UK longitudinal data

	(1)	(2)	(3)	(4)
Outcome variable:	**Change in BMI**		**Change in (log) Kessler score**	
>= 10 MET-hours	**-0.29991**		**-0.01864**	
se	(0.10265)		(0.00949)	
p-value	0.038781*		0.04599*	
Change MET-hours		**-0.00914**		**-0.00224**
se		(0.00364)		(0.00084)
p-value		0.01591*		0.01099*
Observations	1,829	1,829	1,829	1,829
R-squared	0.09532	0.09911	0.28074	0.28371

*Notes: Based on UK longitudinal data sample. Entries represent OLS (first-differences) regression coefficients with corresponding standard error (parentheses) and p-value. Clustered standard errors (se) in parentheses (at company level); ** p<0.01, * p<0.05. In addition to the physical activity variables, the coefficients in columns (1) to (4) are also adjusted for (one-year) changes in age, education, marital status, whether an individual has financial concerns, whether an individual is a carer for a child or ill family member, whether an individual is engaged in voluntary or civic participation, whether an individual is working irregular hours, total hours of work per week, main job, (log) income, whether an individual is bullied or experiences unrealistic time pressure or stress at work, as well as time-fixed effects (year as well as month of interview). Additionally they are adjusted for changes in physical health as well as lifestyle variables, including excessive alcohol consumption; smoking; clinically diagnosed and chronic asthma, cardiovascular disease, kidney disease, cancer, diabetes, hypertension; non-clinically diagnosed or chronic high blood pressure, high glucose, high cholesterol; sleep quality; and sleep duration (hours). We also include the one-year lag of the outcome variable in each model specification presented in columns (1) to (4).*

Table A.26 reports the findings using the change in the (log) sleep disturbance score and the change in the reported hours of sleep over time for two physical activity measures: (1)

80 See section A.2 for more detail.

respondents who report reaching at least 10 MET-hours per week; and (2) the change in MET-hours over time. We confirm the inverse association between physical activity and sleep disturbance that we found using the cross-sectional data. Overall, respondents who become more physically active tend to report lower levels of sleep disturbance, all else being equal (columns (1) and (2)). Overall, we also find that they tend to increase their overall sleep duration a bit. For instance, each additional MET-hour of physical activity is associated on average with 0.09 minutes of additional sleep, all else being equal.[81]

Table A.26: The association between physical activity and sleep quality within the same individual over time using UK longitudinal data

	(1)	(2)	(3)	(4)
Outcome variable:	**Change in (log) sleep disturbance score**		**Change in sleep length (hours)**	
>= 10 MET-hours	**-0.08224**		**0.09181**	
se	(0.01935)		(0.04676)	
p-value	0.023058		0.049913*	
MET-hours		**-0.00041**		**0.00145**
se		(0.00017)		(0.00069)
p-value		0.02099*		0.046634*
Observations	1,829	1,829	1,829	1,829
R-squared	0.96087	0.97961	0.22342	0.22145

Notes: See Table A.25 for relevant information.

81 Calculated by multiplying 0.00145 (coefficient in column (4)) by 60.

Appendix B. The association between physical inactivity and elevated mortality risk

Many studies have investigated the relationship between physical activity and mortality, finding that being physically active can significantly reduce an individual's relative premature mortality risk. This appendix revisits existing empirical evidence examining the associations between physical activity and all-cause mortality. A handful of systematic reviews and meta-analyses exist in this research area, generally finding that insufficient physical activity and a sedentary lifestyle are associated with elevated mortality risks. One drawback of many existing meta-analyses is that they do not take into account potential selection bias that could be prevalent in the empirical literature. Another drawback is that most of them do not take into account in a comprehensive manner potential heterogeneity in study design and approach across different studies.[82] The aim of the analysis presented in this appendix is to determine the relative mortality risk of insufficient physical activity in the wider population, based on existing empirical research, by taking into account potential publication selection and study design heterogeneity. To that end, we apply the meta-regression approach established by Doucouliagos and Stanley (2009) and recently introduced into health research by scholars such as Costa-Font et al. (2013). In what follows, we describe in more detail the empirical approach adopted for this analysis and report the corresponding findings.

B.1.What is meta-(regression-)analysis?

Meta-analysis is a form of systematic review employing a range of statistical methods to synthesise and evaluate specific empirical literature. It helps to better understand the existing research findings on a given empirical effect of interest (Stanley & Doucouliagos 2012). In contrast to narrative literature reviews, systematic reviews aim to include all research results by following an explicit and comprehensive search strategy which should be replicable by independent researchers. Meta-regression-analysis (MRA) is a form of meta-analysis designed to investigate empirical research (Stanley 2001).

In essence, MRA is designed to model the effects of observed statistical regression specifications and heterogeneity in study designs analysing a specific phenomenon (e.g. mortality effects of physical inactivity). The reported estimates of applied statistical studies are often just a small subset of a large number of different specification choices the researchers made during

82 For example, existing studies are based on different sample populations or on samples of different sizes.

the research process. Often, there is no reliable way to know which model specification is the correct one. To that end, MRA can accommodate potential misspecification bias and correct for publication selection biases within applied statistical studies. For instance, the aforementioned studies look at mortality outcomes for individual subsamples (e.g. all, elderly, female or male only), apply a range of different datasets and, most importantly, report a variety of relative mortality risk effect sizes. It is crucial to understand the extent to which these findings are driven by differences in study design and whether there is a 'true' underlying effect, once we control for the variance in study design factors and potential publication selection bias. Publication selection has been documented and is a widely accepted fact in medical and social sciences, with a potentially detrimental effect on published empirical findings (e.g. Card & Krueger 1995). In essence, publication bias arises when researchers, editors or reviewers use their prior belief about how the relationship between two variables should be or they use statistical significance in statistical estimates as a model selection criterion. Publication bias can arise when research findings are selected as a result of their statistical significance, leading to potential exaggerations of their size. Card and Krueger (1995) list corresponding reasons why publication bias may emerge:

1. Reviewers and editors of academic journals may be predisposed to accept only articles consistent with the predominant conventional view in the area of research;
2. Researchers may use the presence of conventionally expected results as a model-selection test; and
3. Researchers, reviewers and editors may just have a natural predisposition to treat statistically significant results more favourably.

In summary, the real problem of publication selection is not its existence per se, but, rather, the potential biases it imposes on summaries of existing empirical research. The research landscape analysing the links between physical activity and mortality is complex and is characterised by large study heterogeneity. The multidimensional nature of this research makes clear inference more difficult. MRA is a tool to address these challenges and synthesise and evaluate research findings.

As described, MRA is a tool to evaluate existing empirical research; however, like every method, MRA has its limitations and caveats, which should be considered when interpreting the findings of this study:

1. **A meta-study depends on the data that feed into the analysis**: As the data inputs into an MRA are estimates from existing empirical studies, the approach cannot fully overcome the potential underlying weakness of the literature it synthesises.
2. **Every meta-analysis is subject to a degree of subjectivity**: While systematic reviews in medical research often make subjective pre-judgments of what is 'good' and 'bad' research at the outset, empirical meta-analysis aims to be more conclusive and to include all studies as long as they meet some minimal inclusion/exclusion criteria. However, as some empirical studies include a larger number of different estimates, there might be a discourse on what estimates from each study could be included. One way to circumvent this caveat is for researchers to be aligned from the outset of the data extraction process on what type of estimates should be included.

B.2. MRA for the relationship between physical activity and all-cause mortality

We apply meta-regression-analysis to assess the relationship between physical activity and all-cause mortality (taking into account publication selection bias and study heterogeneity) and to identify the 'genuine' relative mortality risk of being physically inactive, net of potential publication selection.

B.2.1. The meta-sample: Systematic review and data collection

We performed a systematic literature search up to May 2019 by searching on PubMed, Embase, Scopus, Web of Science and PsycInfo. Keywords for the search of titles and abstracts included various combinations of:

> "physical activity" OR "lifestyle activity" OR "leisure time activity" OR "occupation* activity" OR "energy expenditure" OR "energy metabolism" OR exercise OR "active commute" OR sport OR walk* OR "metabolic equivalent" OR cycling OR "physical inactivity" OR sedentary*
>
> AND
>
> "all cause mortality" OR "all-cause mortality"
>
> AND
>
> "hazard ratio" OR "relative risk" OR "odds ratio"

To be included in the review, a study needed to contain a new empirical estimate of the relationship between physical activity and all-cause mortality. We discarded all summaries, systematic reviews or meta-analyses. In addition, the study needed to include a prospective design,[83] and the reported estimated effects in the studies needed to provide confidence intervals or standard errors or t-stats. Furthermore, in order to have estimates that are to some extent comparable with each other, we only included estimates that measure physical activity in such a way that they can be transformed into MET-minutes. That is, we included estimates that measure activity through a combination of the intensity and duration, including, for instance, through the minutes of moderate- or vigorous-intensity activity, as well as directly provided MET-minutes. Furthermore, we only focus on studies that use inactivity or sedentary lifestyles as their baseline and compare the relative mortality risk of individuals who are active with that of those are not or less active. In line with physical activity guidelines, we defined a minimum activity threshold of 500 to 600 MET-minutes per week.

This process identified 74 relevant and comparable studies. In order to accommodate potential publication bias, standard errors of the estimates are required (see Egger et al. 1997; Stanley & Doucouliagos 2012). The studies included in the sample mainly provided confidence intervals for the relevant estimates. We use the formula proposed by the *Cochrane Handbook* to calculate the standard errors for the relative mortality risk (RR) estimates – based on confidence intervals.[84]

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83 A prospective study design examines specific outcomes over a longer time period (e.g. mortality) and aims to relate the outcome to other factors, such as lifestyle risks (e.g. smoking, BMI).

84 SE = (upper limit – lower limit) / 3.92. See Higgins & Green 2011.

The next step in the data collection process was to extract relevant estimates and information on different dimensions of the study, including, for instance, the year of publication of the study, how physical activity is measured, whether the estimates in the study are adjusted for control variables and the total number of observations. In line with the MAER-NET guidelines, we extracted multiple estimates per study.[85] Overall, our initial meta-sample contains 1,124 relevant estimates of the relative all-cause mortality risk of insufficient physical activity. A full list of publications and corresponding numbers of estimates included in the analysis can be found in Table B.1.

Table B.1: Authorship, publication date and number of estimates of the studies included in the meta-analysis data sample

Authors	Year	Number of estimates
Alvarez-Alvarez, Ismael, Itziar Zazpe, Javier Pérez de Rojas, Maira Bes-Rastrollo, Miguel Ruiz-Canela, Alejandro Fernandez-Montero, María Hidalgo-Santamaría & Miguel A. Martínez-González	2018	6
Andersen, L. B., P. Schnohr, M. Schroll & H. O. Hein	2000	32
Arem, Hannah, Ruth M. Pfeiffer, Eric A. Engels, Catherine M. Alfano, Albert Hollenbeck, Yikyung Park & Charles E. Matthews	2015	42
Autenrieth, C. S., J. Baumert, S. E. Baumeister, B. Fischer, A. Peters, A. Doring & B. Thorand	2011	8
Barengo, N. C., G. Hu, T. A. Lakka, H. Pekkarinen, A. Nissinen & J. Tuomilehto	2004	6
Beddhu, S., B. C. Baird, J. Zitterkoph, J. Neilson & T. Greene	2009	2
Bellocco, R., C. Q. Jia, W. M. Ye & Y. T. Lagerros	2010	8
Bertram, Lisa A. Cadmus, Marcia L. Stefanick, Nazmus Saquib, Loki Natarajan, Ruth E. Patterson, Wayne Bardwell, Shirley W. Flatt, Vicky A. Newman, Cheryl L. Rock, Cynthia A. Thomson & John P. Pierce	2011	5
Besson, H., U. Ekelund, S. Brage, R. Luben, S. Bingham, K. Khaw & N. J. Wareham.	2008	4
Bijnen, F. C. H., E. J. M. Feskens, C. J. Caspersen, N. Nagelkerke, W. L. Mosterd & D. Kromhout	1999	4
Borgundvaag, E., & I. Janssen	2017	36
Boss, H. M., L. J. Kappelle, Y. Van der Graaf, M. Kooistra, F. L. J. Visseren & M. I. Geerlings	2015	9
Brown, W. J., D. McLaughlin, J. Leung, K. A. McCaul, L. Flicker, O. P. Almeida, G. J. Hankey, D. Lopez & A. J. Dobson	2012	20

85 See https://www.maer-net.org/ for more information.

Authors	Year	Number of estimates
Bucksch, J.	2005	38
Cardenas-Fuentes, G., I. Subirana, M. A. Martinez-Gonzalez, J. Salas-Salvado, D. Corella, R. Estruch, M. Fito, C. Munoz-Bravo, M. Fiol, J. Lapetra, F. Aros, L. Serra-Majem, J. A. Tur, X. Pinto, E. Ros, O. Coltell, A. Diaz-Lopez, M. Ruiz-Canela & H. Schroder	2018	6
Davidson, T., B. Vainshelboim, P. Kokkinos, J. Myers & R. Ross	2017	6
Dohrn, Ing-Mari, Michael Sjöström, Lydia Kwak, Pekka Oja & Maria Hagströmer	2018	10
Edwards, M. K., N. Shivappa, J. R. Mann, J. R. Hebert, M. D. Wirth & P. D. Loprinzi	2018	9
Esteban-Cornejo, I., V. Cabanas-Sanchez, S. Higueras-Fresnillo, F. B. Ortega, A. F. Kramer, F. Rodriguez-Artalejo & D. Martinez-Gomez	2019	4
Evenson, K. R., F. Wen & A. H. Herring	2016	1
Fishman, E. I., J. A. Steeves, V. Zipunnikov, A. Koster, D. Berrigan, T. A. Harris & R. Murphy	2016	18
Garcia-Aymerich, J., P. Lange, M. Benet, P. Schnohr & J. M. Anto	2006	6
Gebel, Klaus, Ding Ding, Tien Chey, Emmanuel Stamatakis, Wendy J. Brown & Adrian E. Bauman	2015	9
Glenn, Kimberly R., James C. Slaughter, Jay H. Fowke, Maciej S. Buchowski, Charles E. Matthews, Lisa B. Signorello, William J. Blot & Loren Lipworth	2015	45
Gorczyca, A. M., C. B. Eaton, M. J. LaMonte, J. E. Manson, J. D. Johnston, A. Bidulescu, M. E. Waring, T. Manini, L. W. Martin, M. L. Stefanick, K. He & A. K. Chomistek	2017	6
Gulsvik, A. K., D. S. Thelle, S. O. Samuelsen, M. Myrstad, M. Mowe & T. B. Wyller	2012	8
Holtermann, A., O. S. Mortensen, H. Burr, K. Sogaard, F. Gyntelberg & P. Suadicani	2010	10
Hu, G., J. Eriksson, N. C. Barengo, T. A. Lakka, T. T. Valle, A. Nissinen, P. Jousilahti & J. Tuomilehto	2004	8
Huerta, José M, María Dolores Chirlaque, María José Tormo, Genevieve Buckland, Eva Ardanaz, Larraitz Arriola, Diana Gavrila, Diego Salmerón, Lluís Cirera, Bienvenida Carpe, Esther Molina-Montes, Saioa Chamosa, Noemie Travier, José R. Quirós, Aurelio Barricarte, Antonio Agudo, María José Sánchez, Carmen Navarro, José M. Huerta & José Ma Huerta	2016	18

Authors	Year	Number of estimates
Irwin, M. L., A. W. Smith, A. McTiernan, R. Ballard-Barbash, K. Cronin, F. D. Gilliland, R. N. Baumgartner, K. B. Baumgartner, L. Bernstein, Melinda L. Irwin, Ashley Wilder Smith, Anne McTiernan, Rachel Ballard-Barbash, Kathy Cronin, Frank D. Gilliland, Richard N. Baumgartner, Kathy B. Baumgartner & Leslie Bernstein	2008	4
Jefferis, B. J., T. J. Parsons, C. Sartini, S. Ash, L. T. Lennon, O. Papacosta, R. W. Morris, S. G. Wannamethee, I. M. Lee & P. H. Whincup	2018	15
Jiunn-Horng, Chen, Wen Chi Pang, Wu Shiuan Bei, Lan Joung-Liang, Tsai Min Kuang, Tai Ya-Ping, Lee June Han, Hsu Chih Cheng, Tsao Chwen Keng, Wai Jackson Pui Man, Chiang Po Huang, Pan Wen Han, Hsiung Chao Agnes, Jiunn-Horng Chen, Chi Pang Wen, Shiuan Bei Wu, Joung-Liang Lan, Min Kuang Tsai, Ya-Ping Tai & June Han Lee	2015	12
Karvinen, S., K. Waller, M. Silvennoinen, L. G. Koch, S. L. Britton, J. Kaprio, H. Kainulainen & U. M. Kujala	2015	12
Keegan, T. H. M., R. L. Milne, I. L. Andrulis, E. T. Chang, M. Sangaramoorthy, K. A. Phillips, G. G. Giles, P. J. Goodwin, C. Apicella, J. L. Hopper, A. S. Whittemore & E. M. John	2010	19
Khaw, K. T., R. Jakes, S. Bingham, A. Welch, R. Luben, N. Day & N. Wareham	2006	42
Koolhaas, Chantal M., Klodian Dhana, Josje D. Schoufour, Lies Lahousse, Frank J. A. van Rooij, M. Arfan Ikram, Guy Brusselle, Henning Tiemeier, Oscar H. Franco & Frank J. A. van Rooij	2018	2
Kujala, U. M., J. Kaprio, S. Sarna & M. Koskenvuo	1998	12
Lahti, J., A. Holstila, E. Lahelma & O. Rahkonen	2014	8
LaMonte, M. J., D. M. Buchner, E. Rillamas-Sun, C. Z. Di, K. R. Evenson, J. Bellettiere, C. E. Lewis, I. M. Lee, L. F. Tinker, R. Seguin, O. Zaslovsky, C. B. Eaton, M. L. Stefanick & A. Z. LaCroix	2018	4
Lear, Scott A., Hu Weihong, Sumathy Rangarajan, Danijela Gasevic, Darryl Leong, Romaina Iqbal, Amparo Casanova, Sumathi Swaminathan, R. M. Anjana, Rajesh Kumar, Annika Rosengren, Wei Li, Yang Wang, Chuangshi Wang, Huaxing Liu, Sanjeev Nair, Rafael Diaz, Hany Swidon, Rajeev Gupta & Noushin Mohammadifard	2017	44
Leitzmann, M. F., Y. Park, A. Blair, R. Ballard-Barbash, T. Mouw, A. R. Hollenbeck & A. Schatzkin	2007	72
Liu, Y., X. O. Shu, W. Q. Wen, E. Saito, M. S. Rahman, S. Tsugane, A. Tamakoshi, Y. B. Xiang, J. M. Yuan, Y. T. Gao, I. Tsuji, S. Kanemura, C. Nagata, M. H. Shin, W. H. Pan, W. P. Koh, N. Sawada, H. Cai, H. L. Li, Y. Tomata, Y. Sugawara, K. Wada, Y. O. Ahn, K. Y. Yoo, H. Ashan, K. S. Chia, P. Boffetta, M. Inoue, D. Kang, J. D. Potter & W. Zheng	2018	51
Long, G., C. Watkinson, S. Brage, J. Morris, B. Tuxworth, P. Fentem, S. Griffin, R. Simmons & N. Wareham	2015	6

Authors	Year	Number of estimates
Martinez-Gomez, D., P. Guallar-Castillon, J. Mota, E. Lopez-Garcia & F. Rodriguez-Artalejo	2015	20
Matthews, C. E., S. S. Cohen, J. H. Fowke, X. J. Han, Q. Xiao, M. S. Buchowski, M. K. Hargreaves, L. B. Signorello & W. J. Blot	2014	17
Mengyu, Fan, Yu Canqing, Guo Yu, Bian Zheng, Li Xia, Yang Ling, Chen Yiping, Li Mingqiang, Li Xianzhi, Chen Junshi, Chen Zhengming, Lv Jun, Li Liming, Mengyu Fan, Canqing Yu, Yu Guo, Zheng Bian, Xia Li, Ling Yang & Yiping Chen	2018	72
Mensink, G. B. M., M. Deketh, M. D. M. Mul, A. J. Schuit & H. Hoffmeister	1996	2
Meyerhardt, J. A., S. Ogino, G. J. Kirkner, A. T. Chan, B. Wolpin, K. Ng, K. Nosho, K. Shima, E. L. Giovannucci, M. Loda & C. S. Fuchs	2009	1
Moore, S. C., A. V. Patel, C. E. Matthews, A. Berrington de Gonzalez, Y. Park, H. A. Katki, M. S. Linet, E. Weiderpass, K. Visvanathan, K. J. Helzlsouer, M. Thun, S. M. Gapstur, P. Hartge, I. M. Lee, Steven C. Moore, Alpa V. Patel, Charles E. Matthews, Amy Berrington de Gonzalez, Yikyung Park & Hormuzd A. Katki	2012	51
Moy, M. L., M. K. Gould, I. L. Amy Liu, J. S. Lee & H. Q. Nguyen	2016	2
O'Donovan, G., M. Hamer & E. Stamatakis	2017	4
Ou, S. M., Y. T. Chen, C. J. Shih & D. C. Tarng	2017	2
Pedersen, J. O., B. L. Heitmann, P. Schnohr & M. Gronbaek	2008	8
Ratjen, I., C. Schafmayer, R. di Giuseppe, S. Waniek, S. Plachta-Danielzik, M. Koch, G. Burmeister, U. Noethlings, J. Hampe, S. Schlesinger & W. Lieb	2018	6
Sabia, Séverine, Aline Dugravot, Mika Kivimaki, Eric Brunner, Martin J. Shipley & Archana Singh-Manoux	2012	8
Sadarangani, Kabir P., Mark Hamer, Jenny S. Mindell, Ngaire A. Coombs & Emmanuel Stamatakis	2014	7
Saint-Maurice, P., R. P. Troiano, C. E. Matthews & W. E. Kraus	2018	6
Schmid, D., C. Ricci, S. E. Baumeister & M. F. Leitzmann	2016	29
Schmidt, M. E., J. Chang-Claude, A. Vrieling, P. Seibold, J. Heinz, N. Obi, D. Flesch-Janys & K. Steindorf	2013	3
Schnohr, P., P. Lange, H. Scharling & J. S. Jensen	2006	11
Schoenborn, Charlotte A. & Manfred Stommel	2011	24
Shen, C., S. Y. Lee, T. H. Lam & C. M. Schooling	2016	1

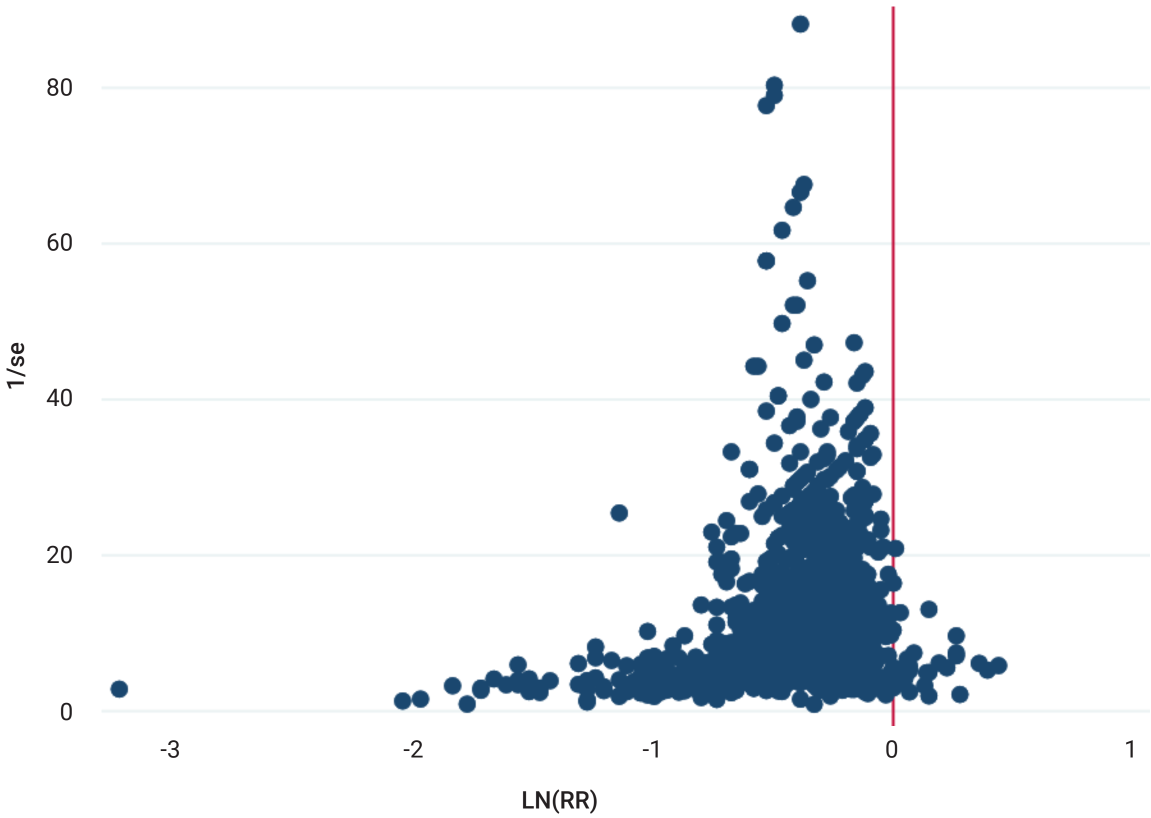
Authors	Year	Number of estimates
Sone, H., S. Tanaka, S. Suzuki, H. Seino, O. Hanyu, A. Sato, T. Toyonaga, K. Okita, S. Ishibashi, S. Kodama, Y. Akanuma & N. Yamada	2013	8
Stamatakis, E., M. Hamer & D. A. Lawlor	2009	24
Stensvold, D., J. Nauman, T. I. L. Nilsen, U. Wisloff, S. A. Slordahl & L. Vatten	2011	4
Sternfeld, B., E. Weltzien, C. P. Quesenberry, A. L. Castillo, M. Kwan, M. L. Slattery & B. J. Caan	2009	27
Stessman, J., Y. Maaravi, R. Hammerman-Rozenberg & A. Cohen	2000	6
Tanasescu, M., M. F. Leitzmann, E. B. Rimm & F. B. Hu	2003	12
Wannamethee, S. G., A. G. Shaper, M. Walker, A. G. Shaper & M. Walker	1998	3
Weller, I., & P. Corey	1998	2
Wen, Chi Pang, Jackson Pui Man Wai, Min Kuang Tsai, Yi Chen Yang, Ting Yuan David Cheng, Meng-Chih Lee, Hui Ting Chan, Chwen Keng Tsao, Shan Pou Tsai & Xifeng Wu	2011	12
Zahrt, Octavia H., & Alia J. Crum	2017	4
Zhao, Guixiang, Chaoyang Li, Earl S. Ford, Janet E. Fulton, Susan A. Carlson, Catherine A. Okoro, Xiao Jun Wen & Lina S. Balluz	2014	3
Zhou, Y., R. Chlebowski, M. J. LaMonte, J. W. Bea, L. H. Qi, R. Wallace, S. Lavasani, B. W. Walsh, G. Anderson, M. Vitolins, G. Sarto & M. L. Irwin	2014	58

B.2.2. Meta-regression-analysis and publication selection bias

The common practice in medical research for detecting publication bias is an informal examination of a so called 'funnel plot' (Sutton et al. 2000). A funnel plot is a simple scatter diagram of an empirical estimate and its corresponding precision (e.g. the inverse of the estimate's standard error: 1/SE). Since a measure of variability of each estimate is placed on the y-axis, the estimates at the bottom have larger corresponding standard errors and, hence, are more widely dispersed. In contrast, the more precisely estimated estimates are more compactly distributed, towards the top. The most accurate estimates can therefore be found at the top of a funnel graph. These estimates should be less affected by publication selection as their high precision makes them less likely to be statistically insignificant. In essence, if no publication selection is prevalent, then the scatter diagram should resemble an inverted funnel. Figure B.1 presents the funnel plot for the estimated relative mortality risks related to insufficient physical activity.

There are some estimates with relatively high precision, which mainly stem from studies that had a large cohort sample available for their analysis. The graph is not fully symmetrical, with more estimates of lower precision gathered in the left lower portion of the graph, which reveals potential selection for lower relative mortality risk for individuals meeting physical activity guidelines. However, it should be noted that simply looking at the graph can be misleading as such graphs are vulnerable to misjudgement and subjective interpretation. To that end, we follow Stanley and Doucouliagos (2012) and apply the Funnel Asymmetry Test (FAT) and the Precision Effect Test (PET) – or FAT-PET. The mechanism of FAT-PET is simple but extremely powerful. With publication selection, researchers with small samples and low precision will be forced to search more intensively for their 'best' model specification, based on their data and statistical regression technique, until they find larger estimates. Otherwise their results will not be statistically significant. Researchers with larger studies, however, do not need to search so hard to find statistical significance in their estimates and will be more likely to be satisfied with lower estimates. In essence, should publication selection be present, the reported effect is, all else being equal, positively correlated with its standard error.

Figure B.1: Funnel plot of relative mortality risks related to short sleep duration



Note: RAND Europe calculations.

Such considerations suggest that the magnitude of the reported estimate depends on its standard error. We depict this more formally in equation (1):

$$effect_i = \beta_0 + \beta_1 SE_i + \varepsilon_i \qquad (1)$$

where $effect_i$ represents an individual estimate of the association between physical activity and relative mortality and SE_i is its corresponding standard error. The term $\beta_1 SE_i$ models publication selection bias, while estimates β_0 serve as estimates corrected for publication bias. However, the error term ε_i is not expected to be independently and identically distributed because the estimated effect is a statistical regression coefficient from a larger sample and hence the variance of $effect_i$ likely varies from one estimate to another. This leads to the fact that estimating equation (1) with OLS will suffer from heteroscedasticity. Stanley and Doucouliagos (2012) suggest estimating and employing a weighted least squares (WLS) approach by weighting the standard errors with the inverse of each estimate's variance (e.g. 1/SE*SE). Equivalently, equation (1) can just be divided by SE_i and estimated as:

$$t_i = \beta_1 + \beta_0(1/SE_i) + v_i \qquad (2)$$

where t_i is the t-statistic of each individual estimated empirical effect or ($effect_i/SE_i$), and $(1/SE_i)$ represents its precision and v_i = ε_i/SE_i makes its variance approximately constant.

A simple test for the presence of publication selection is the funnel-asymmetry test: $H_0: \beta_1 = 0$. This is test shows whether or not publication selection is present. β_0 is the coefficient on precision in equation (2) and testing $H_0: \beta_0 = 0$ is the precision-effect test to identify whether there is a 'genuine' underlying empirical effect net of a potential publication selection bias. Table B.2 reports the estimates for the MRA model depicted in equation (2). As authors in this literature usually report multiple estimates and hence estimates within a study are likely not independent from each other, we have to adjust the WLS estimates for within-study dependence. Following Stanley and Doucouliagos (2012), we apply cluster-robust standard errors and random-effect (RE) and fixed-effect (FE) unbalanced panel estimators.[86]

Table B.2: Testing for publication bias – weighted least squares of meta-regression model (2)

	(1)	(2)	(3)	(4)
Variables	**WLS**	**WLS Cluster**	**RE Panel**	**FE Panel**
1/SE [PET]	0.6431	0.6431	0.6005	0.5932
	(0.006)***	(0.032)***	(0.031)***	(0.032)***
Intercept [FAT]	0.6161	0.6161	1.0750	1.5406
	(0.136)***	(0.287)**	(0.481)**	(0.584)***
Observations	**1,124**	**1,124**	**1,124**	**1,098**

*Notes: Cells report coefficient estimates for equation (2). The dependent variable is the relative mortality risk insufficient physical activity (defined as performing less than the equivalent of 500 to 600 MET-minutes per week). The standard errors are reported in parentheses: *** p<0.01, ** p<0.05, * p<0.10; Standard errors are adjusted for data clustering in columns (2), (3) and (4). FAT represents a test for publication bias. PET is a test for the existence of a difference in mortality risk between being physically inactive or active. RE panel and FE panel represent the random-effects and fixed-effects panel meta-regression model.*

Normally, fixed-effects panel MRA models are the preferred option, as random-effects are likely to be correlated with the MRA independent variables (e.g. $(1/SE_i)$). Applying the Hausman test for

86 Note that while most common panel data are pooled time-series and cross-sectional data, any multidimensional data may de facto be regarded as a panel. In this case we have various effect sizes by study.

choosing between fixed- and random-effects panel models allows us to accept fixed effects as the preferred model specification.[87]

The parameter estimates in Table B.2 reveal that there is statistical evidence of publication selection bias, as the intercept (FAT) is positive and statistically significant across all the three columns. Hence, the hypothesis $H_0: \beta_1 = 0$ is rejected. In addition, we observe a genuine mortality effect of insufficient physical activity, with the parameter estimate between 0.59 and 0.64. Furthermore, as discussed in Stanley and Doucouliagos (2012), the coefficient on precision in equation (2) gives a biased estimate of the empirical effect if there is evidence of publication bias. Stanley and Doucouliagos (2014) therefore offer an improved correction for publication selection using the standard error in the MRA model outlined in equation (2). This estimator is called the precision-effect estimate with standard error, or PEESE. Stanley and Doucouliagos (2012) report that in simulations PEESE provides better estimates of the underlying 'genuine' effect if there is publication bias and there is an effect. The PEESE WLS-MRA model can be written as:

$$t_i = \beta_1 SE_i + \beta_0 (1/SE_i) + v_i \qquad (3)$$

where the standard error is added to equation (2). Table B.3 reports the parameter estimates for PEESE outlined in equation (3).

Table B.3: Correcting for publication bias – weighted least squares of meta-regression model (3)

	(1)	(2)	(3)	(4)
Variables	**WLS**	**WLS cluster**	**RE panel**	**FE panel**
1/SE [PET]	0.6349	0.6349	0.6009	0.5947
	(0.006)***	(0.033)***	(0.034)***	(0.034)***
SE [FAT]	-3.0018	-3.0018	0.2218	0.6653
	(1.127)***	(2.726)	(1.733)	(1.759)
Observations	**1,124**	**1,124**	**1,124**	**1,098**

*Notes: Cells report coefficient estimates for equation (3). The dependent variable is the relative mortality risk insufficient physical activity (defined as performing less than the equivalent of 500 MET-minutes per week). The standard errors are reported in parentheses: *** p<0.01, ** p<0.05, * p<0.10; Standard errors are adjusted for data clustering in columns (2), (3) and (4). PET is a test for the existence of a difference in mortality risk between being physically inactive or active corrected of publication bias. RE panel and FE panel represent the random- and fixed-effects panel meta-regression model.*

The parameter estimates for β_0 reported in columns 1 to 4 in Table B.3 reveal that the PEESE correction for publication bias increases the average relative mortality risk for inactivity between 0.07 to 0.25 per cent in our preferred specifications (columns (3) and (4)). That is, the unadjusted average reduction in mortality risk in the meta-sample of studies included suggests that individuals who are active according to the recommended guidelines of reaching minimum 500 to

87 Chi-square(1) = 0.88; p-value >>0.05.

600 MET-minutes per week reduce their relative mortality risk by almost 40 per cent compared to individuals not reaching the recommended guidelines.

However, it is important to note that the parameter estimates for the relative mortality risk of insufficient physical activity presented in Tables B.2 and B.3 do not reveal whether there are different risks related to different levels of physical activity (e.g. moderate vs high levels compared to inactive). They also do not take into account any differences in the study design. All such factors may affect the parameter estimates and need to be taken into account. To accommodate for study heterogeneity, and hence potential misspecification bias, we turn to multiple MRA.

Taking into account study heterogeneity

In order to accommodate study heterogeneity, the simple MRA model in equation (3) can be expanded as follows:

$$t_i = \beta_1 SE_i + \beta_0(1/SE_i) + \sum \beta_k Z_{ki}/SE_i + v_i \qquad (4)$$

where β_0 is replaced by $\beta_0 + \sum \beta_k Z_{ki}$ and the Z-variables allowing for heterogeneity and misspecification bias. We include the following moderator variables which, for instance, can help us to understand whether there are heterogeneous effects across different sample populations (e.g. female or male) or allow us to adjust for study design characteristics (e.g. follow-up period or the total cohort size):

1. whether estimate is adjusted for socio demographic confounders (e.g. age, gender, income, education);
2. whether estimate is adjusted for lifestyle risk factors (e.g. BMI, drinking, smoking);
3. whether estimate is adjusted for chronic conditions (e.g. diabetes, cholesterol, cancer, hypertension);
4. categories of physical activity (e.g. moderate and high);
5. type of physical activity (e.g. leisure-time vs occupational);
6. gender differences (female vs male);
7. country/region (e.g. Asia);
8. whether estimate is based on sample that includes all ages or only middle-aged or only elderly;
9. follow-up year of effect measured (e.g. below or above 10 years follow-up);
10. year of publication of study; and
11. whether sleep duration is self-reported or based on expert interview.

Table B.4 lists the moderator variables and how they are coded, together with their mean and standard deviation.

Table B.4: Moderator variables for sleep mortality research

Moderator variable	Definition	Mean	SD
SE	is the standard error of estimate	0.09	0.09
Male	=1, if estimate relates to males	0.41	0.49
Female	=1, if estimate relates to females	0.21	0.41
Middle age	=1, if estimate relates to sample with cohort age between 45 and 65	0.25	0.43
Old age	=1, if estimate relates to sample with cohort age between above 65	0.31	0.46
Type	=1, if estimate relates to household or occupational activity	0.27	0.44
Socio	=1, if estimate is adjusted for socio-demographic factors	0.72	0.45
Smoking	=1, if estimate is adjusted for smoking	0.72	0.45
BMI	=1, if estimate is adjusted for Body Mass Index	0.55	0.50
Drinking	=1, if estimate is adjusted for alcohol consumption	0.46	0.50
Chronic	=1, if estimate adjusted for chronic conditions.	0.58	0.49
Asia	=1, if estimate relates to a population sample from an Asian country	0.23	0.42
Pub	Year of publication (normalised to earliest year of 1996)	16.32	5.31
Follow	=1, if follow up year >=10.	0.34	0.47
High	=1, if estimates relates to equal to or more than 1500 MET-minutes	0.60	0.49
Cohort	Total study cohort size	99,970	164,386
Sample	Sample size related to estimate	14,847	26,867

Note: Variable means and standard deviations (SD) reported based on a sample of 1,124 estimates.

Table B.5 reports the parameter estimates for the MRA model outlined in equation (4).

The full set of moderator variables from the random- and fixed-effects panel estimators are reported in columns (1) and (2). Next, to identify the most important research dimensions in this literature, we employed a general-to-specific modelling approach, removing the variables from the specification that had the largest p-value (insignificant variables) until only significant variables remained (all p-values are equal to or below 0.05).

The resulting cluster-robust general-to-specific RE and FE panel models are shown in columns (3) and (4) of Table B.5. Several patterns emerge from this comprehensive MRA of the all-cause mortality risk associated with physical inactivity statistical literature.

Columns 3 and 4 reveal that the following research dimensions affect the magnitude of the reported mortality risk effect:

1. Gender;
2. Amount of physical activity;
3. Type of activity;
4. Adjustment covariates;

5. Region of underlying sample population;
6. Follow-up years; and
7. Cohort and sample size.

Table B.5: Multiple meta-regression-analysis of short sleep duration and mortality risk

	(1)	(2)	(3)	(4)
Moderator variables	**RE panel**	**FE panel**	**G-to-S: RE panel**	**G-to-S: FE panel**
1/SE [PET]	0.5271	0.5449	0.5574	0.5530
	(0.094)***	(0.095)***	(0.014)***	(0.015)***
High	-0.0603	-0.0637	-0.0590	-0.0629
	(0.012)***	(0.012)***	(0.006)***	(0.006)***
Female	-0.0647	-0.0635	-0.0587	-0.0601
	(0.022)***	(0.022)***	(0.008)***	(0.008)***
Male	0.0120	0.0077		
	(0.013)	(0.012)		
Middle age	0.0204	0.0187		
	(0.022)	(0.026)		
Old age	0.0068	0.0104		
	(0.018)	(0.019)		
Type	0.1050	0.1128	0.1066	0.1160
	(0.036)***	(0.034)***	(0.010)***	(0.011)***
Socio	0.0477	0.0465	0.0495	0.0490
	(0.016)***	(0.017)***	(0.010)***	(0.010)***
Smoking	0.0004	0.0004	0.0004	0.0004
	(0.000)***	(0.000)***	(0.000)***	(0.000)***
BMI	0.0218	0.0223	0.0211	0.0204
	(0.013)*	(0.013)*	(0.009)**	(0.009)**
Drinking	0.0005	0.0004	0.0006	0.0005
	(0.000)***	(0.000)**	(0.000)***	(0.000)***
Chronic	-0.0035	-0.0064		
	(0.018)	(0.018)		
Asia	0.1179	0.1357	0.1165	0.1203
	(0.045)***	(0.058)**	(0.014)***	(0.016)***
Pub	0.0007	-0.0009		
	(0.003)	(0.004)		
Follow	0.0890	0.1121	0.0908	0.1109

	(1)	(2)	(3)	(4)
Moderator variables	**RE panel**	**FE panel**	**G-to-S: RE panel**	**G-to-S: FE panel**
	(0.030)***	(0.038)***	(0.014)***	(0.018)***
Cohort	-0.0001	-0.0001	-0.0001	-0.0001
	(0.000)	(0.000)	(0.000)*	(0.000)**
Sample	-0.0002	-0.0002	-0.0003	-0.0002
	(0.000)	(0.000)	(0.000)***	(0.000)***
Observations	**1,098**	**1,098**	**1,098**	**1,098**

*Notes: Provides definitions of the moderator variables. The dependent variable is the relative mortality risk insufficient physical activity (defined as performing less than the equivalent of 500 to 600 MET-minutes per week). The standard errors are reported in parentheses: *** p<0.01, ** p<0.05, * p<0.10. Standard errors are adjusted for data clustering. PET is a test for the existence of a difference in mortality risk between being physically inactive or moderately active. The combination of the coefficients for PET and High would provide an estimate of the reduced mortality risk between being physically inactive and active overall (including being highly active). RE panel and FE panel represent the random-effects and fixed-effects panel meta-regression model.*

Our analysis indicates that estimates that have been conducted on female samples tend to be lower in magnitude, suggesting that the all-cause mortality risk between being inactive vs active is reduced by about 6 percentage points more for female study populations, all else being equal, compared to study populations including all genders or only male individuals (MRA coefficient of about −0.06).

Furthermore, if individuals reporting high levels of activity (e.g. above equivalent of 1500 MET-minutes), the overall all-cause mortality risk would reduce by a further 6 percentage points on average (MRA coefficient of about −0.06). Interestingly, our findings suggest that the type of activity may matter in reducing the all-cause mortality risk, all else being equal. For instance, our findings suggest that compared to leisure physical activity, occupational physical activity reduces the mortality risk less compared to leisure activity, by about 10 to 11 percentage points (MRA coefficients of 0.1066 and 0.1160). Furthermore, we find that adjusting for covariates in the regression models reduces the estimates for the overall reduction of all-cause mortality risk between active and non-active individuals. The MRA coefficients for adjusting for socio-demographic variables, BMI, smoking, drinking and chronic conditions are all positive. That means that the original studies calculating the relative risk of mortality between active and inactive individuals, by adjusting for these factors, take into account that other factors, beyond physical activity explain mortality risk. According to the MRA estimates presented in columns (3) and (4) of Table B.5, estimates for all-cause mortality risk associated with inactivity tend to be larger in magnitude (suggesting lower overall reduction in mortality risk), by about 12 percentage points.

Finally, the longer the follow-up period with participants in the study, the larger the MRA coefficient of the relationship between being inactive and active.

Physical inactivity and the risk associated with all-cause mortality for different subcategories

As the previous section highlighted, there are a handful of factors which contribute to the heterogeneity across different studies in this research area. In Table B.6, we combine the significant dimensions to report the relative mortality risk of physical inactivity, compared to different levels of activity: moderate (500 MET-minutes per week) or high (more than 1500 MET-minutes per week) compared to being inactive (less than 500 MET-minutes per week), separately by gender and region. Table B.7 divides the categories further, into types of physical activity, distinguishing between leisure-time and occupational physical activity. Table B.6 reports that across US and European populations, being moderately active (e.g. reaching at least 500 to 600 MET-minutes per week), all else being equal, is associated with a 28 per cent lower mortality risk for females and a 17 per cent lower mortality risk for males. These increase to 34 and 23 per cent for high levels of activity, respectively. For Asian populations, the estimates in the literature for mortality risk reductions tend to be lower. For instance, for moderate-intensity activity compared to non-active, the reduction in mortality risk for females is 17 per cent and for males 11 per cent. For high levels of activity compared to inactivity, the reduction in mortality risk is estimated to be 23 per cent lower for females and 17 per cent lower for males. Overall, we find that the reduction in mortality risk associated with being active compared to not being active is statistically significant but lower in magnitude than for leisure-time activity, which often includes such activities as running or going to the gym.

Table B.6: Physical inactivity and all-cause mortality risk

		All activity	
Gender	**Region**	**Moderate**	**High**
Female	United States and Europe	0.72 (0.68–0.76)	0.66 (0.61–0.70)
	Asia	0.83 (0.79–0.88)	0.77 (0.72–0.82)
Male	United States and Europe	0.78 (0.74–0.82)	0.71 (0.67–0.76)
	Asia	0.89 (0.85–0.94)	0.83 (0.79–0.88)

Note: Table entries based on linear combination for different research dimensions using parameter estimates of column (3) in Table B.5 (Stata command:lincom).

Table B.7: Physical inactivity and all-cause mortality risk for different activity types – leisure vs occupational

		Leisure-time activity		Occupational-time activity	
Gender	Region	Moderate	High	Moderate	High
Female	United States and Europe	0.69 (0.64–0.73)	0.62 (0.58–0.66)	0.81 (0.75–0.86)	0.74 (0.70–0.80)
	Asia	0.80 (0.76–0.85)	0.74 (0.69–0.79)	0.92 (0.88–0.98)	0.86 (0.81–0.92)
Male	United States and Europe	0.75 (0.71–0.78)	0.68 (0.64–0.73)	0.87 (0.82–0.92)	0.81 (0.76–0.86)
	Asia	0.86 (0.82–0.91)	0.80 (0.76–0.85)	0.98 (0.93–1.03)	0.92 (0.87–0.97)

Note: Table entries based on linear combination for different research dimensions using parameter estimates of column (3) in Table B.5 (Stata command:lincom).

Appendix C. Computing country-specific physical activity distributions and calculating potential healthcare expenditure savings for different physical activity improvement scenarios

This appendix provides a more detailed overview on how the country-specific physical activity distributions have been computed and also reports how the changes in healthcare expenditure associated with different physical activity improvement scenarios have been calculated.

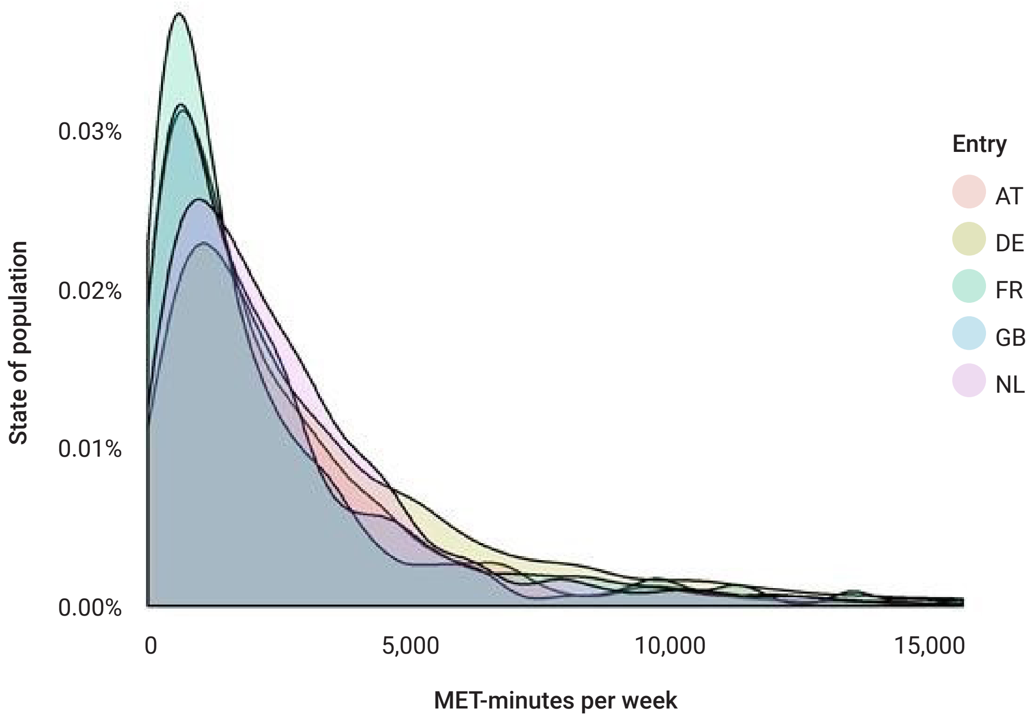
C.1. Computing country-specific physical activity distributions

In the existing literature, there are studies assessing physical activity in the population (see e.g. Bauman et al. 2009; European Commission 2018; Guthold et al. 2018; Hallal 2012; Sjøl et al. 2003). However, these studies often do not cover multiple countries (see e.g. Palacios-Ceña et al. 2011; Stamatakis & Chaudhury 2008) or differ in their study populations, their definition of physical activity, and their time of assessment. For instance, a report by the European Commission (2018) provides data on 'time spent on health-enhancing (non-work-related) aerobic physical activity', whereas the Health Survey for England (HSE Digital 2018) considers all activities causing increased heartrate or heavier breathing, and a report by the European Commission (2013) considers the same set of activities but further distinguishes among work, travel and recreational activities. Country coverage by such surveys varies significantly, with the United States and Europe being covered most frequently and often repeatedly, whereas South American, Asian and African countries are covered least often.

As documented by Guthold et al. (2018), most of the 358 studies covered in their analysis use either the Global Physical Activity Questionnaire (GPAQ) or the International Physical Activity Questionnaire (IPAQ). Both of these consider physical activity at three levels: (1) walking at least 10 minutes at a time; (2) moderate-intensity physical activity, generally defined as activity that causes light sweating or a light increase in breathing or heartrate (e.g. brisk walking, hiking, moderate-intensity cycling, golf, leisure swimming or strength exercises); and (3) vigorous physical activity, defined as activities that causes heavy sweating or a heavy increase in breathing or heartrate (e.g. aerobic, vigorous cycling, football, tennis, climbing hills or vigorous swimming). From the health-improvement perspective, different intensity levels of physical activity contribute unequally towards lowering morbidity and mortality rates, with higher-intensity activities being more beneficial. This is, for instance, documented in the relative risk estimates reported by Stanaway et al. (2018), who use METs as the common denominator across all intensity categories. One MET is defined as 1 kcal/kg/hour and is roughly equivalent to the energy cost of sitting quietly; for comparison, e.g. cycling is estimated to equal 3.5–16 METs and running 6–23 METs, depending on intensity (Shephard 2011). Given that all of such activities are combined into just three categories in the population surveys, in what follows, walking is considered equivalent to 2.5 METs, moderate-intensity physical activity to 4 METs, and vigorous physical activity to 10 METs. Lastly, the publicly available information on physical activity levels by country often reduces to the share of population doing low, moderate-intensity and high levels of activity (see e.g. Bauman et al. 2009), with the exceptions in this regard being particularly the Eurobarometer surveys, which cover the whole European Union and provide access to the underlying microdata. Since understanding the detailed physical activity distribution is crucial for the analysis of improvement, we impute the missing distributions from the existing data.

Specifically, in order to generate country-specific physical activity distribution, we first analyse data from the Eurobarometer 88.4 (European Commission 2018), where we compare the physical activity distribution (in METs per week) for Austria, Germany, France, Netherlands and the United Kingdom (see Figure C.1). It is evident that the shape of the physical activity distributions are remarkably similar, with the majority of individuals doing less than 2000 METs per week and approximately 20 per cent of individuals doing less than the recommended 150 minutes of moderate-intensity physical activity per week, equivalent to 600 METs.

Figure C.1: Physical activity distribution across countries (METs per week)



As Figure C.1 illustrates, the shape of the distribution in each country is very similar, resembling a log-linear distribution. Given the apparent similarities in the physical activity distributions, we use an average of these distributions and apply the shape of the distribution to impute the missing information for other countries. Specifically, for the countries for which we do not have the actual physical activity distribution, we take the estimates on the share of population being inactive vs active from Guthold et al. (2018) and we shift the underlying generic distribution for the remaining countries of interest accordingly. Formally:

$$p_{c,a}^{n} = \left(p_{g}^{n} - p_{g}^{n-1}\right) \times \frac{x_{c,a}^{i}}{x_{g}^{i}} + p_{g}^{n} \qquad (1)$$

where $p_{c,a}^{n}$ the n^{th} percentile in the physical activity distribution in country c and age group a, p_{g}^{n} is the n^{th} percentile in the generic distribution (i.e. the share of population that does a particular level of physical activity or less), and $x_{c,a}^{i}$ and x_{g}^{i} refer to the share of the population doing $i \in \{\text{low; high}\}$ amount of physical activity in country c and age a. This results in a detailed, country-specific physical activity distribution where the total number of individuals doing low and high levels of physical activity corresponds to the distribution provided in Guthold et al. 2018 and the shape of the distribution in between those points corresponds to the generic distribution. This is done for all 5-year age groups from the age of 25. A snapshot of the resulting distribution for the United States is presented in Table C.1.

Table C.1: Distributions of physical activity in the US population, measured using the proportion of population doing less than or equal to the number of METs per week.

	METs per week															
Age group	0	100	200	300	400	600	800	1000	1200	1400	1600	1800	2000	2400-4000	4400-10000	>10,000
25 to 29	9%	14%	20%	28%	33%	37%	41%	44%	47%	49%	51%	55%	56%	73%	92%	100%
30 to 34	10%	14%	22%	30%	35%	40%	44%	47%	51%	53%	55%	59%	61%	78%	99%	100%
35 to 39	10%	15%	22%	30%	35%	40%	45%	48%	51%	53%	55%	59%	61%	79%	100%	100%
40 to 44	10%	15%	22%	30%	35%	40%	45%	48%	51%	53%	55%	59%	61%	79%	100%	100%
45 to 49	10%	15%	22%	31%	36%	41%	46%	49%	52%	54%	57%	60%	62%	80%	100%	100%
50 to 54	10%	16%	23%	32%	38%	43%	48%	51%	54%	57%	59%	63%	65%	84%	100%	100%
55 to 59	11%	16%	25%	34%	40%	45%	51%	54%	58%	60%	63%	67%	69%	89%	100%	100%
60 to 64	12%	18%	27%	37%	43%	49%	55%	58%	62%	65%	68%	73%	75%	97%	100%	100%
65 to 69	13%	19%	28%	39%	46%	52%	58%	62%	66%	69%	72%	77%	79%	100%	100%	100%
70 to 74	13%	20%	30%	42%	49%	55%	62%	66%	70%	73%	76%	82%	84%	100%	100%	100%
75 to 79	14%	20%	30%	42%	49%	56%	62%	66%	71%	74%	77%	83%	85%	100%	100%	100%
80 to 84	14%	21%	31%	43%	50%	57%	63%	67%	72%	75%	78%	84%	86%	100%	100%	100%
85 to 89	14%	20%	31%	43%	49%	56%	63%	67%	71%	75%	78%	83%	86%	100%	100%	100%
90 to 94	14%	20%	31%	42%	49%	56%	62%	67%	71%	74%	78%	83%	85%	100%	100%	100%
95 plus	14%	20%	30%	42%	49%	56%	62%	66%	71%	74%	77%	83%	85%	100%	100%	100%

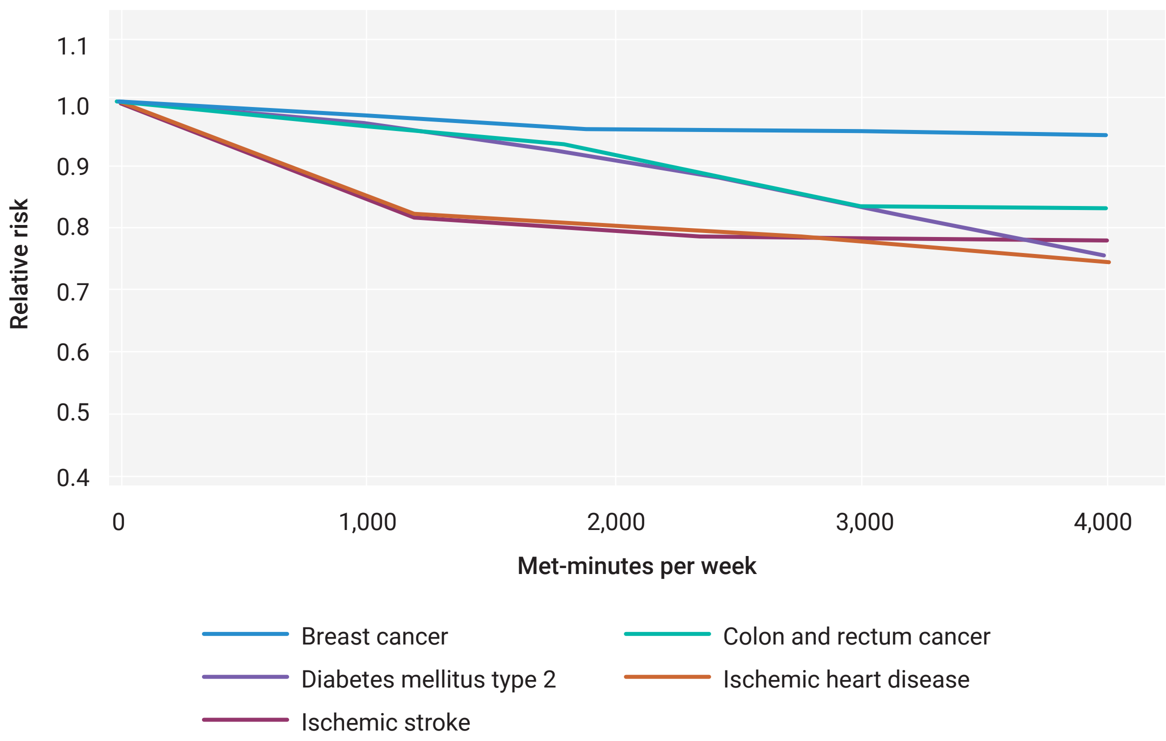
We use the computed physical activity distributions by country to calculate the health (mortality and healthcare costs) and productivity benefits of increasing physical activity levels for the following scenario sets:

- **Scenario 2:** Increase activity by 20 per cent for every point in the distribution except those performing zero activity (e.g. represented by percentiles), meaning there is an increase in the amount of physical activity done by 20 per cent; and
- **Scenario 3:** Increase activity by 20 per cent for every point in the distribution except those performing less than 600 MET-minutes per week.

C.2. Calculating potential healthcare expenditure savings

To estimate the resulting impact of doing additional physical activity on people's health, we utilise the relative risk estimates provided by the Global Burden of Disease (GBD 2018)[88] for all the diseases included in the analysis: breast cancer, colon and rectum cancer, diabetes mellitus type 2, ischemic heart disease and ischemic stroke. These are available in 600-MET categories from 0 METs per week to 33,000 METs per week and range from 0.643 (lowest) to 1 (highest) for ischemic stroke to 0.808 (lowest) to 1 (highest) for breast cancer. That is, the reduction in the relative risk associated with more physical activity is relatively higher for ischemic stroke than for breast cancer. The estimates are equivalent for all age categories and both mortality and morbidity outcomes. In order to better evaluate the change in relative risk within the 600 MET-minutes per week category, we further linearly interpolate between the cut-off points to get a continuous distribution of relative risk, as presented in C.2.

Figure C.2: Relative risk by disease for different MET-minutes per week



Source: Global Burden of Disease (2018).

88 See http://ghdx.healthdata.org/gbd-results-tool for more detail about the GBD data.

Using the physical activity distributions and relative risk estimates, we can calculate the overall relative risk by country and age group as follows:

$$r_{c,a} = \sum_{p=1}^{100} x_{c,a,p} \times r_{c,a,p} \quad (2)$$

where $x_{c,a,p}$ is the population share in country c and age group a doing p MET-minutes per week and $r_{c,a,p}$ is the corresponding relative risk. That is, the combined relative risk is a weighted sum of individual relative risk estimates, with the share of population at each level of physical activity distribution serving as relevant weights. Consequently, we can calculate the improvement, in terms of relative risk change, as a result of doing additional physical activity as:

$$r^{*}_{c,a} = \sum_{p=1}^{100} x_{c,a,p} \times \left(1 - \frac{r^{i}_{c,a} - r^{min}_{c,a}}{r^{max}_{c,a} - r^{min}_{c,a}}\right) \quad (3)$$

where $r^{i}_{c,a} \leq r_{c,a,p}$ is the improved relative risk for the particular population percentile (e.g. the relative risk associated with 120 MET-minutes per week for individuals who do 100 MET-minutes per week at the baseline in the +20 per cent activity scenario); $r^{min}_{c,a}$ is the theoretical minimum relative risk (e.g. 0.643 for ischemic stroke in the example above) and $\mathbf{r^{max}_{c,a}} = 1$ is the maximum theoretical relative risk. In other words, we calculate the improvement as the proportional reduction in relative risk compared to the minimum level of risk achievable.

We then use the relative risk changes to estimate healthcare cost implications of improving physical activity levels under different physical activity improvement scenarios. To do so, we utilise data from Ding et al. (2016) who estimate the healthcare expenditure costs per case of the five diseases as per above (breast cancer, colon and rectum cancer, diabetes mellitus type 2, ischemic heart disease and ischemic stroke) by country. These range (in 2013 prices) from US$347 per case of breast cancer in China (and far lower than that in less developed countries) to US$4,915 per case in the USA and equivalent ranges for other causes of death, up to as much as US$14,644 per case of colon and rectum cancer. To obtain the current annual aggregate healthcare cost estimate, we combine these with prevalence of the diseases, obtained from the Global Burden of Disease database.[89] These are available in the form of total number of cases, per age group, year and country; rate per 100,000 lives; or proportion of population. We use the rate per 100,000 lives estimates and multiply them by the population projections figures and their future projections derived in Appendix D to obtain the total number of projected cases of diseases going forward, assuming that the underlying prevalence rates remain constant over time.

However, only part of the total risk can be prevented by increasing physical activity levels; this is defined by the population-attributable fraction (PAF), determining the total proportion in mortality/morbidity that can, in theory, be eliminated in the population by reducing the associated risk factor. For the selected diseases, this ranges between 1 per cent for breast cancer occurrence among young individuals to 15 per cent for ischemic stroke among individuals aged 80–84. Hence, we can obtain the overall estimates of healthcare cost associated with suboptimal

89 See http://ghdx.healthdata.org/gbd-results-tool for more detail about the GBD data.

physical activity levels by multiplying the prevalence, PAF, population and healthcare cost estimates. Formally:

$$c_{d,c,t} = h_{d,c,t} \times \sum_{a \in A} f_{d,c,t,a} \times PAF_{d,c,t,a} \times x_{d,c,t,a} \quad (4)$$

where $h_{d,c,t}$ is the healthcare cost per case of disease d in country c in year t, a is age group from the set of all age groups A, $f_{d,c,t,a}$ is prevalence per 100,000 lives, $PAF_{d,c,t,a}$ is the PAF estimate, and $x_{d,c,t,a}$ is the population size. Equivalently, we can then calculate the potential savings, on healthcare costs, by improving physical activity levels in the population as:

$$c^*_{d,c,t} = c_{d,c,t} \times r^*_{c,a} \quad (5)$$

using the relative risk improvement $r^*_{c,a}$ reported in equation (3) above.

Appendix D. A cohort-component model for population projections

The analysis on the future economic benefits of changes to physical activity at the population level is based on demographic projections on how the population of each country or region evolves over time. To that end, we generate the demographic projections using input data from the UN[90] and an adapted version of Chapin's cohort-component model (Hunsinger, n.d.), which we implement as five-year projections using Stata.[91]

The cohort-component model starts with the current base population and is categorised for each country region by age, gender and skill level. The base population subsequently evolves by applying assumptions on mortality, fertility and migration rates. The outcome of the model is a projection of the population by (5-year) age, gender and skill groups up to 30 years, applied to each of the 24 countries or regions included in the analysis. In essence, the cohort-component model characterises population change according to a 'natural' increase (births minus deaths) and net-migration (in-migration less out-migration). More formally, the population by age cohort a and gender s at time t can be written as:

$$P(a,s,t_1) = P(a,s,t_o) + B(a,s) - D(a,s) + IM(a,s) - OM(a,s)$$

where $B(a,s)$ represents the total births and $D(a,s)$ total deaths. $IM(a,s)$ and $OM(a,s)$ represent inward and outward migration, respectively. The total births in a given period depends on the size of the population, the age structure and the age-specific fertility rate, which vary across countries. It is important to stress that we assume in our projections that the age-specific fertility rates will follow a similar trend within each country as they have during the last decade.

Similarly, the number of deaths in any given period depends on the population size, the age distribution and the age- and gender-specific mortality rates. We apply the abridged life tables provided by the UN[92] to calculate age- and gender-specific probabilities of surviving from one age group to the next. Specifically, we draw on country-specific data for the demographic model input based on the initial population, net migration and age- and gender-specific fertility and mortality

90 See http://esa.un.org/wpp/ for more information about the detailed population data.

91 See http://www.demog.berkeley.edu/~eddieh/toolbox.html#CohortComponent for more information.

92 See http://esa.un.org/wpp/ for more information.

rates. Within these demographic projections, we define the potential working population as all individuals in the age range from 15 to 65. Furthermore, for each country, we divide the working population into high- and low-skilled according to their educational attainment. This data on employment by education levels stems from the International Labor Organization.[93]

93 See the International Labor Organization's ILOSTAT (2018) for more information: https://ilostat.ilo.org/.

Appendix E. Description of the dynamic computational general equilibrium (CGE) model

The CGE model, applied for the analysis, is a multi-regional model whereby each region has bilateral trade with all other regions, simultaneously. World prices are, therefore, determined globally by the model, and each country/region has an effect on all the other regions. Larger regions will have larger effects compared with smaller regions. This is different from the small-open economy health models, in which countries cannot affect world prices but, rather, take them as given (e.g. Smith et al. 2005). In each country or region, firms produce a single good using a multi-level, differentiable, constant return to scale production function that combines factor inputs (i.e. capital and labour) with intermediate goods. The model uses a constant elasticity of transformation function to split production into domestic production and exports. Then, domestic production is combined with imports to form the final Armington good (Armington 1969). The representative agent in each country/region is assumed to be rational with a locally, non-satiated preference and demand for final Armington goods. Thus, subject to disposable income, the representative agent in each country/region maximises a continuous, multi-level utility function. First, we assume a Ramsey-type utility function, which imposes a fixed share between savings and a consumption bundle (Ramsey 1928). This is an appropriate function for a recursive dynamic model, because agents are assumed to be myopic and do not alter their consumption-savings behaviour in anticipation of the future. Multi-level functions mean that they are a combination of different functions stacked together to form a more complex function. Breaking them into levels makes it simpler to analyse and describe. The Armington assumption allows for cross-hauling, thus allowing for product differentiation between import and exports of similar goods. Second, subject to the net-savings disposable income, the representative agent maximises a typical Cobb-Douglas utility function (Cobb & Douglas 1928). As previously discussed, the government has no active role in the model because of our assumption that the government maintains its current methods (i.e. policies) towards providing the public good. Therefore, the public and private sectors are aggregated together, which simplifies the model, reduces the number of assumptions necessary and increases transparency. Finally, a virtual investment firm 'builds' new capital stock for the next period by demanding some Armington final-inputs in fixed proportion. Capital is accumulated under the assumption of a competitive capital market. This means that the purchase price of one unit of new capital is equal to the rental earnings of that unit, plus the value of the remaining capital sold in the subsequent period (net of depreciation).

E.1. Technical description of model characteristics

In this section, we provide a general overview of the recursive dynamic computable general equilibrium (CGE) multi-regional model. Below, we begin by describing the static element of the model, then we describe its recursive dynamics.

First, the static element is similar to Lanz and Rutherford (2016), who developed a multi-regional CGE model calibrated to the Global Trade Analysis Project (GTAP) data.[94] Each country or region has bilateral trade with all other regions, simultaneously. World prices are determined globally by the model, and each country (or region) has an effect on all the other regions. Larger regions will have larger effects compared with smaller regions. This is different from small-open economy health models, in which countries cannot affect world prices, but, rather, take them as given (e.g. Smith et al. 2005).

To reflect cross-hauling (i.e. cases of imports and exports of the same good), we use the Armington (1969) assumption. In each country, firms produce a single good using a multi-level, differentiable, constant return to scale production function.[95] Production combines factor inputs (i.e. capital and labour) with intermediate inputs, which are either domestically produced or imported. Omitting the time subscript t, firm i's profit maximisation problem is:

$$Max\ p_i y_i - \left(p_{ij} D_{ij}^{INT} + pfx_{ij} M_{ij}^{INT} + rK_i + wL_i\right)$$

$$s.t., y_i = CES[CES_i\left(CES\left(INT_{ij}, M_{ij}, \sigma_1\right), \sigma_2\right), CD(K_i, L_i), \sigma_3]$$

with D_{ij}^{INT} and M_{ij}^{INT} referring to domestic or imported intermediates to sector i from sector j (e.g. apple juice production by industry requires raw apples from agriculture, and apples could be domestically produced or imported). Domestic and imported intermediates are combined with a constant elasticity of production (CES) function, which has a high substitution elasticity σ_1. Next, between different sector types j, σ_2 has a very low substitution elasticity (e.g. to make apple juice, we require a nearly fixed proportion of apples to barrels). Next, for most sectors, we assume a Cobb-Douglas (CD) function between capital and labour. Finally, all components in the value chain are assembled to produce output y_i, with σ_3 a low substitution elasticity. Production is split into domestic use and exports to other countries using a constant elasticity of transformation function.

The representative agent in each country (or region) is assumed to be rational, with a locally non-satiated, additive, separable preference for final Armington goods. Omitting the time and country subscripts, each agent's disposable income Z, is generally of the form $Z = r^K K + wL + taxrev + pU \cdot CA$, given by the effective labour and capital endowment at each point in time, tax revenue and transfers collected, and capital borrowing (lending) abroad. Note that in the full model, we also differentiate between high-skilled and low-skilled workers.

94 Lanz and Rutherford (2016) develop and carefully document their static CGE model, which they implement onto the GTAP database using the computer program GAMS (which stands for general algebraic modelling language; see www.gams.com). Their model analyses two cases: a small-open economy and a multi-regional model. Our model is similar to their multi-regional model.

95 Multi-level functions are a combination of different functions stacked together to form a more complex function. Breaking them into levels makes it simpler to analyse and describe them.

Over time, effective labour supply adjusts (based on our cohort-component population model that considers births, deaths and migration and on the labour efficiency model). This changes the supply of the working age population and the dependency ratio (i.e. the ratio of non-working-age to working-age population). Furthermore, countries accumulate (or lose) capital and amass current account surplus (or deficit), which also includes transportation margins. Finally, agents collect various forms of taxes, such as tariffs on imports and exports, sales taxes, production taxes, input taxes and income taxes.

Given their disposable income, the representative agent in each country maximises a continuous, multi-level utility function. At the top level, we assume a Ramsey-type utility function that imposes a fixed share between savings and a consumption bundle (Ramsey 1928). This is an appropriate function for a recursive dynamic model, because agents are assumed to be myopic and do not alter their consumption-savings behaviour in anticipation of the future.

Next, subject to their net-savings disposable income, the representative agent maximises an additive separable utility function that combines final demands for private and public consumption.

Private consumption: The various types of goods (commodities) are demanded using a Cobb-Douglas utility function. These are then differentiated, in the second level, by being either domestically produced commodities or commodities imported from abroad. We assume a high substitution elasticity between domestic and imported final goods, θ_1, but a Cobb-Douglas utility among the various goods: $U = CD(CES_i(D_i^U, M_i^U, \theta_1^U))$.

Public demand for consumption: This uses a similar approach: The government demands goods, which are either domestically produced or imported, $G = CES(CES_i(D_i^G, M_i^G, \theta_1^G))$, with θ_1^G a high substitution elasticity between the same domestic or imported goods, and θ_2^G a low substitution between different types of bundle of goods. Note that the government has no active policy role in this model. Taxes and transfers are accrued by the representative agent, who allocates them to government consumption.

Finally, a virtual investment firm 'builds' new capital stock for the next period by demanding some final-inputs. Similarly, some of these input goods are domestically produced, while others are imported: $I = CES(CES(D_i^I, M_i^I, \gamma_1)\gamma_2)$.

We now turn to the recursive dynamics of this model that links with the virtual investment firm (as described above). Capital is accumulated under the assumption of a competitive capital market, by

$$K_{t+1} = (1-\delta)K_t + I_t$$

with δ the depreciation rate, K_t the stock of capital and I_t demand for investment.

Assuming a competitive capital market, the purchase price of one unit of new capital $p_{K,t}$ is equal to the rental earnings of that unit r^k, plus the value of the remaining capital sold in the subsequent period (net of depreciation).

$$p_{K,t} = r_t^K + (1-\delta)p_{K,t+1}$$

After some manipulation, the capital accumulation equation yields

$$VK_{t+1} = \frac{1}{1+r}[(1-\delta)VK_t + (r+\delta)p_{K,t+1}I]$$

where $VK = r^K \cdot K$ represents capital earnings (i.e. it equals the rental price of capital times the capital stock), this is the value as provided by the social accounting matrix (SAM).[96] Note that r is the discount rate. (For a detailed explanation, see the supplementary online appendix in Yerushalmi et al. (2020))

E.2. Model input data

The base underlying economic data used for the purpose of this analysis are taken from the Global Trade Analysis Project database. This database has been developed by the Center for Global Trade Analysis at Purdue University since 1993. Overall, GTAP covers 140 countries for 57 GTAP commodities and includes all bilateral trade patterns, production, consumption and intermediate inputs of commodities and services. We use the latest version, GTAP 10, which has a reference year of 2014. From the GTAP database, we extract a social accounting matrix (SAM) for the specific countries and regions included in the analysis. The SAM is a complex table expressed in terms of incomes and expenditures, i.e. a double-entry accounting method. GTAP includes SAMs for individual countries, which are based on national accounts data (e.g. use-supply tables, input-output tables) and information from household survey data and trade data. GTAP collects and coordinates country SAMs from researchers across the world and cleans and standardizes the data. For the purpose of this analysis, we extracted the SAMs for all 23 countries as well as for the rest of the world (RoW). In order to make the model tractable, we aggregate the different sectors into four sectors: agriculture, manufacturing, private services and public services. The data for the underlying population data come from the United Nations' UN Population Database (2019). We divide a country's population into the working-age population and the non-working-age population, whereby the working-age population is defined as that part of the population between age 15 and age 65. Furthermore, we use data from the International Labour Organization on the distribution of educational attainment across countries to divide the working-age population further, into skilled and unskilled labour. The UN Population Database also provides the current mortality rates by age and gender, which we apply to calculate the counterfactual working-age population.

E.3. How improvements in physical activity levels affect the CGE model economy

As outlined previously, in this analysis, we consider improvements in physical activity levels at the population level and how they affect the overall labour supply in an economy. Hence, one element of the model is the focus on changes in the effective labour supply, which is represented as the physical amount of labour (e.g. number of employed people at any given time) augmented by their productivity level (e.g. depending on their health or skill). In a country or region r, output in sector i consists of goods and services Y_{ir}, that are produced by capital K_{ir}, other inputs N_{ijr} (e.g. intermediate inputs from sector j), and effective labour L_{ir} (i.e. a labour input adjusted for

96 The concept of the SAM is described in the next section.

efficiency units). Thus, production is modelled as a function of $Y = F(K, N, L)$, where subscripts i and r are omitted for simplicity.

Similar to the method used by Taylor et al. (2014) in a different context (for the study of antimicrobial resistance), for each time period t, the model assumes that effective labour supply is adjusted for efficiency units by $L_{r,t} = \bar{L}_{r,t} \cdot E_{r,t}$, with the physical supply of labour input $\bar{L}_{r,t}$, and efficiency of labour $E_{r,t}$.

In the model, the changes in effective labour supply are manifested through **three** potential mechanisms:

1. **Reduced mortality risk:** Insufficient physical activity is associated with a higher mortality risk and hence reduces the overall size of the labour force, or in other words, the total number of individuals who provide their labour on the labour market. Note that excess deaths due to insufficient physical activity permanently reduce the size of the population, which influences directly the current but also future population hence the effects of insufficient physical activity accumulate over time. That is, the death of a worker not only affects the year in which the death occurs but continues to be a part of the costs in subsequent years because it also includes the potential 'death' of all future offspring.
2. **Reduced sickness absence:** Adequate levels of physical activity are associated with better physical and mental health. Prolonged periods of ill-health and absence from work lead to reductions in the efficiency of labour. That is, each unit of labour (e.g. an individual in the labour force) is less efficient, representing a direct effect on the effectiveness of the working-age population.
3. **Reduced presenteeism:** Similar to a reduction in sickness absence, a reduction in presenteeism is making each unit of labour more effective, by improving the performance at work.

Thus, in our model, in order to take into account changes to sickness absence and presenteeism days, labour efficiency is based on subtracting a number of days (normalised to a year) from the baseline yearly efficiency level; attributable lost days is for a combination of the adult workers. Simply put, the yearly efficiency of a worker is:

$$E = 1 - Number\ of\ lost\ days\ normalised\ to\ a\ year,$$

where, for example, the onset of a certain health condition or becoming more physically active decreases the number of lost working days. In order to operationalise the different scenarios, we use different parameter estimates for the three mechanisms.

In scenario 1, we apply the parameter estimates for the relative mortality risk provided in Table B.6 for those individuals that have not met the 10 Met-hours per week, and for sickness absence and presenteeism we apply the parameter estimates presented in Table A.9. Specifically, we apply the values in terms of reduced work impairment due to absenteeism for an individual performing 10 to 12.5 MET-hours on average compared to an individual that performs less than 10 MET-hours. For absenteeism we apply a 0.14 ("Low") and 0.22 ("High") percentage point reduction, and for presenteeism we apply a 0.79 ("Low") and 1.01 ("High") percentage point reduction for individuals that performed less than 10 MET-hours per week.

In scenario 2, everyone gets 20 per cent more active. To that end we apply the continuous relative mortality risk function as outlined in PAGAC (2018) and reported by Moore et al. (2012). We use linear interpolation to provide a relative risk change for each part of the physical activity distribution. For absenteeism and presenteeism we apply the continuous function for the association with MET-hours per week as reported in Table A.14.

In scenario 3, we apply the same parameter estimates as described above for scenario 1 for the population that is below 10 MET-hours at baseline and apply the parameter values from scenario 2 for the population above 10 MET-hours.

In addition to the scenarios 1 to 3, for sensitivity analysis we also applied a scenario where every adult person improves his current level of physical activity by 300 MET-minutes per week, relative to a baseline scenario with current physical activity levels. In contrast to scenarios 1 to 3, this represents a more modest physical activity improvement scenario. The corresponding estimated GDP gains are reported in Table E.1. Panel A reports the estimated annual GDP gain by year, whereas Panel B reports the cumulative GDP gain over time.

Table E.1: Estimated global GDP gain for 300 MET-minutes per week improvement relative to a baseline scenario with current physical activity levels, per year

	Panel A: GDP Gain (US$ billion present value 2019), by year					
	2025	2030	2035	2040	2045	2050
Scenario 300 MET-minutes (Low)	68.13	81.10	96.03	113.13	133.05	156.52
Scenario 300 MET-minutes (High)	101.32	120.39	142.32	167.50	196.83	231.41
	Panel B: Cumulative GDP Gain (US$ trillion, 2019), by year					
Scenario 300 MET-minutes (Low)	0.20	0.58	1.03	1.56	2.19	2.92
Scenario 300 MET-minutes (High)	0.26	0.83	1.49	2.28	3.20	4.29

Notes: Table entries represent absolute changes in global GDP for a scenario improving every adult person's current level pf physical activity by 300 MET-minutes per week, relative to a baseline scenario economic projection with no physical activity improvement (status quo). Estimates are shown for two variants of reductions in sickness absence and presenteeism levels ('Low' and 'High'). Panel A reports the annual GDP gain by year and Panel B reports the cumulative GDP gain by year.

E.4. Analytical limitations

The application of a CGE modelling framework to assess the economic benefits of physical activity has several strengths, such as the ability to model the long-term economic benefits taking into account all potential spillovers on other agents in an economy that could occur from physical activity improvements. However, there are some limitations to the modelling approach taken.

First, the CGE model applied for the economic analysis is not intended to provide an exact forecast of the economy at a given point in time in the future. The deterministic model does not take into account transitory (stochastic) short-term changes to the overall economic growth path. The aim of the applied modelling framework is to examine the effects of changes across different modelling parameters representing different scenarios and then compare how the economy of a country would evolve in the medium to long term in the counterfactual scenario compared with the baseline, holding all other factors constant. This is a simplification of how events would affect the economy in reality; however, it allows for the analysis of specific factors in isolation. So, for instance, the model inherently assumes that any transitory shocks to an economy, for instance, to take a recent example, shocks introduced by international trade wars, would affect the baseline and the counterfactual scenario in the same way. And as we calculate the difference between the counterfactual and the baseline scenario, the transitory effect of the trade war on the economy would cancel out in the difference.

Second, the scenarios examined within the economic modelling framework depend heavily on assumptions made about how physical activity improvements affect mortality rates or rates of sickness absence and presenteeism. We aimed, whenever possible, to use robust empirical evidence provided by the existing literature to support the modelling assumptions made. Where there was a lack of existing evidence, we aimed to apply conservative estimates on assumed parameters where possible. Furthermore, the assumptions made during the modelling of this study were made based on the best available evidence from the existing literature or additional economic modelling at the time of the analysis. In the future, it may be possible to amend some assumptions based on better empirical evidence that may emerge.

Finally, the modelling framework is based on a microfoundation of the underlying equations that determine the economic behaviour of the various economic agents. However, some of the microeconomic parameters are fixed and are hence invariant across different scenarios. Such fixed input parameters include, among others, different demand, substitution and income elasticities, as well as parameters relevant to the production technology, such as the relative importance of each of the production inputs. Potentially, any changes in the counterfactual scenario, such as making individuals healthier in the future, could change their economic behaviour. For instance, a healthier person may change their consumption behaviour and become more sensitive to changes in prices for specific goods (e.g. healthy vs unhealthy foods). However, it is not straightforward to make an ultimate judgment call on whether these changes would really occur, and hence we keep the underlying behavioural parameters fixed in the counterfactual scenarios.