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Estimating the global economic benefits of physically active populations over 30 years (2020–2050)

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ABSTRACT

Objectives We assess the potential benefits of increased physical activity for the global economy for 23 countries and the rest of the world from 2020 to 2050.

The main factors taken into account in the economic assessment are excess mortality and lower productivity.

Methods This study links three methodologies. First, we estimate the association between physical inactivity and workplace productivity using multivariable regression models with proprietary data on 120 143 individuals in the UK and six Asian countries (Australia, Malaysia, Hong Kong, Thailand, Singapore and Sri Lanka). Second, we analyse the association between physical activity and mortality risk through a meta-regression analysis with data from 74 prior studies with global coverage. Finally, the estimated effects are combined in a computable general equilibrium macroeconomic model to project the economic benefits of physical activity over time.

Results Doing at least 150 min of moderate-intensity physical activity per week, as per lower limit of the range recommended by the 2020 WHO guidelines, would lead to an increase in global gross domestic product (GDP) of 0.15%–0.24% per year by 2050, worth up to US\$314–446 billion per year and US\$6.0–8.6 trillion cumulatively over the 30-year projection horizon (in 2019 prices). The results vary by country due to differences in baseline levels of physical activity and GDP per capita.

Conclusions Increasing physical activity in the population would lead to reduction in working-age mortality and morbidity and an increase in productivity, particularly through lower presenteeism, leading to substantial economic gains for the global economy.

INTRODUCTION

Insufficient physical activity is one of the leading risk factors for death, posing a global public health problem associated with up to 5 million premature deaths every year.^{1 2} Health benefits of increased physical activity include a lower risk for a series of major diseases, such as hypertension and diabetes, to improved mental health^{3 4} and overall quality of life. Despite these well-established health benefits, insufficient physical activity has become increasingly prevalent over the last decades. Globally, it is estimated that about 30% of the population is physically inactive, but the prevalence rate varies across countries⁵; in high-income countries, the share of physically inactive population has increased from 31.6% to 36.8% over the 2001–2016 period. Given finite financial resources and competing health priorities, including resources dedicated to

tackling the COVID-19 pandemic, public health responses to address the problem have been inadequate. Economic analysis can help in this regard to quantify the scale of the problem, increase public, policy and industry engagement and offer data for use in public health advocacy.

Existing studies that analyse the economic burden of insufficient physical activity^{6 7} are typically conducted at the national level and apply the cost-of-illness (COI) approach, varying in costs (eg, direct and indirect) and health conditions considered. Nevertheless, they all find substantial potential savings and health benefits from a more physically active population.^{8–11} A relevant literature review is presented in Ding *et al.*⁷

As Keogh-Brown and colleagues explain in further detail, such COI studies often disregard long-term and second-order effects, limiting the scope of the analysis and thus potentially underestimating the overall costs.¹² For instance, healthier individuals may live longer and may be more productive than non-healthy individuals, earning more income and consuming more over time. The benefits of being healthier then apply not only to the individual themselves but also create positive external effects in the economy (eg, on firms, the government) because they may consume more, save more and pay more taxes for longer.

This study addresses these shortcomings by comprehensively estimating the global macroeconomic cost of physical inactivity using a novel general equilibrium model that captures both long-term and second-order effects and highlighting the potential health and economic benefits associated with increased physical activity, complementing the recent Global Action Plan for Physical Activity 2018–2030.¹³

METHODS

The model used in this study links physical inactivity with the labour supply through excess mortality and reduced productivity and estimates the potential economic benefits of increasing national physical activity levels to the lower bound of the range recommended by the 2020 WHO guidelines.¹⁴ Due to the extent of the analysis, the following text provides a summary of the three methodological approaches used and the corresponding main findings. Full details are available in a free-access technical report that we have recently published.¹⁵ Throughout this study, physical activity is measured using minutes of metabolic equivalents of task



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(MET-minutes). One MET-minute is roughly equivalent to the energy expended when sitting quietly for a minute.

Macroeconomic simulation model

The overall economic impact of increased physical activity is assessed using a multicountry, dynamic, economy-wide computable general equilibrium (CGE) modelling framework, an approach that has recently gained ground in health economics.^{16–18} Our model is broadly based on Lanz and Rutherford¹⁹ and Yerushalmi *et al.*²⁰ and calibrated using the Global Trade Analysis Project V.10 data.²¹ The applied model is implemented in the General Algebraic Modeling System software.²²

The economy of each country is modelled separately, considering a variety of inputs (eg, labour, capital) and outputs (goods and services). Individual countries are linked through international bilateral trade. In all scenarios, economies grow according to their long-term growth rate derived from the total factor productivity growth, which we calibrated using data from the Penn World Tables V.9.1.²³ The model, furthermore, includes a demographic segment, which uses a cohort-component model that projects future country populations.²⁴ Input data for the cohort-component model on mortality, fertility and migration are provided by the UN Population Database, covering the 2020–2100 period.²⁵ The analysis is conducted for 23 countries and the rest of the world and projected forward 30 years from 2020 to 2050 to capture the dynamic demographic effects beyond the productivity benefits of improved physical activity. The countries (Argentina, Australia, Austria, Canada, China, Ecuador, France, Germany, HongKong, Japan, Malaysia, Netherlands, New Zealand, Pakistan, Philippines, Singapore, South Africa, South Korea, Sri Lanka, Thailand, UK, USA, Vietnam; all other countries are combined into ‘rest of the world’) were chosen based on data availability and representativeness of the world as a whole. Additional scenarios are available in Hafner *et al.*¹⁵

The implications of improved physical activity are reflected by an increase in the effective labour supply through a combination of two elements: (1) improved physical activity increases the size of the labour force through a lower mortality risk and (2) improved physical activity raises worker productivity levels by reducing sickness absence and presenteeism.

Two scenarios are considered in the macroeconomic analysis: first, a status quo scenario, where physical activity, mortality and productivity remain at their current real-world levels. Second, a counterfactual scenario, where all people globally achieve at least 150 min of moderate-intensity physical activity per week (equivalent to 600 MET-minutes), that is, lower limit of the range recommended by the 2020 WHO guidelines.¹⁴ In this scenario, all individuals below the recommended activity threshold improve their activity levels to the recommended amount. The baseline physical activity levels by country are obtained from Guthold *et al.*⁵

The analysis relies on the following simplifying assumptions: all changes to physical activity levels in the population are permanent; individuals do not engage in additional physical activity at the cost of other health-enhancing activities such as sleep; and overall consumption patterns remain unchanged. Physical activity levels in the population as well as the productivity and mortality impacts are assumed to take place in the first year of the model’s projection.

The following two sections explain how we link improved physical activity with mortality risk and worker productivity,

which together make up the effective labour supply in the CGE model.

Linking physical activity with mortality

We apply the meta-regression approach established by Doucouliagos and Stanley²⁶ and previously applied in health research by Costa-Font *et al.*²⁷ (The meta-regression analysis follows the Meta-Analysis of Economics Research Network guidelines: www.maer-net.org/). It consists of a systematic review of the relevant empirical literature and assessment of the link between physical activity and mortality. Estimates obtained from the literature are used in a range of statistical methods to synthesise and evaluate the findings, while considering potential publication selection and study design heterogeneity.

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, together with CIs, SEs or *t* statistics. We discarded all summaries, systematic reviews or meta-analyses for this analysis. Furthermore, to obtain comparable estimates, we considered only studies in which physical activity estimates can be transformed into MET-minutes, that is, those that measure activity through a combination of intensity and duration, including through the minutes of moderate-intensity or vigorous-intensity activity as well as directly provided MET-minutes. Finally, we focused only on studies that use inactivity or sedentary lifestyles as their baseline and compare the relative mortality risk of individuals who are active to those who are sedentary or less active. In line with physical activity guidelines, we defined a minimum activity threshold of 500–600 MET-minutes per week. No additional restrictions regarding the date of publication or peer-review status were imposed. Separate studies conducted on the same cohort were included.

This process initially identified 20 135 records, including 12 739 duplicates, which were removed. These were screened on the basis of title and abstract, with 7256 studies excluded at this stage. Finally, the remaining 380 articles were assessed for eligibility based on full-text review: 67 articles were excluded due to insufficient level of information to obtain the equivalent of MET-minute estimates, 191 articles due to focus on non-representative population segments and 48 articles were excluded due to lack of relevant data analysis, with 74 relevant and comparable studies remaining for the analysis. The full list of studies is provided in online supplemental table 7. We tested the extracted estimates for publication bias and obtained corrected results using the precision-effect estimate with standard error regression model.²⁸ To adjust for within-study dependence, random-effect and fixed-effect estimators are applied together with clustered SEs at the study level.

To reflect study heterogeneity, we include a range of moderator variables, such as type of physical activity (eg, leisure-time

vs occupational), publication year, country or region, sample size, cohort size, age range of study cohort (eg, whole population vs elderly only) and whether the underlying estimates are unadjusted or adjusted for age, gender, income, alcohol consumption, smoking, body mass index, chronic health conditions. Further information about that analytical process is provided in Hafner *et al.*¹⁵

Linking physical activity with productivity at work

Links between physical activity and productivity at work are assumed to manifest through sickness absence and presenteeism, generally defined as showing up for work when one is ill.²⁹ We use proprietary data from employers and employees in the UK, Australia, Malaysia, Hong Kong, Thailand, Singapore and Sri Lanka collected through Vitality's Britain's Healthiest Workplace Survey (see www.rand.org/randeurope/research/projects/britains-healthiest-workplace.html for more information) and AIA Group Vitality's Asian Healthiest Workplace Survey (see www.rand.org/randeurope/research/projects/asia-s-healthiest-workplace.html for more information). We include two annual survey waves (2017–2018) for the UK and three (2017–2019) for the Asian countries, covering a total of 120 143 individuals (UK: 58 410; Asia: 61 733). The surveys are open to all organisations with 20 or more employees from any sector in the economy. Participating organisations self-select to the survey and distribute the survey links to their employees. There is no fee for participation or a selection process for participants. All employees aged 18+ are allowed to complete the survey, yet their participation is voluntary, and results are anonymised. The surveys collect responses on a range of personal, workplace and broader organisational themes. A more comprehensive description of the survey data is provided in Hafner *et al.*,¹⁵ Stepanek *et al.*³⁰ and Hafner *et al.*³¹

We analyse the data using a set of multivariable generalised linear regression models (GLMs) with Gaussian distribution and identity link. Technical details of the model specifications are provided in Hafner *et al.*¹⁵ Physical activity is measured using the International Physical Activity Questionnaire (IPAQ)³² and transformed into MET-minutes per week according to the IPAQ guidelines, that is, with moderate activity equivalent to four METs and vigorous activity equivalent to eight METs. Absence and presenteeism are measured using the Work Productivity and Activity Impairment (WPAI) questionnaire³³ with a 7-day recall period. WPAI assesses the number of hours missed from work, the number of hours worked and the degree to which respondents feel that a health problem affected their productivity while at work. WPAI outcomes are expressed as impairment percentages due to absence, presenteeism or both, where a higher percentage indicates greater work impairment and lower productivity. All information is self-reported.

All regression models were adjusted for sociodemographic, health and work-related factors. In order to account for heterogeneity in workplace environments, we included company identifier dummy variables in all GLMs and therefore only exploit variation across employees within the different organisations participating. Further included are dummy variables for the week, month and year of the survey response given. SEs are clustered at the organisational level and statistical significance was assessed at a significance level of 0.05. All statistical analyses were conducted in STATA V.16 (StataCorp, College Station, Texas, USA).

Table 1 Physical activity and all-cause mortality risk

Gender	Region	Physical activity level	
		Moderate	High
Female	USA and Europe	0.72 (0.68 to 0.76)	0.66 (0.61 to 0.70)
	Asia	0.83 (0.79 to 0.88)	0.77 (0.72 to 0.82)
Male	USA and Europe	0.78 (0.74 to 0.82)	0.71 (0.67 to 0.76)
	Asia	0.89 (0.85 to 0.94)	0.83 (0.79 to 0.88)

All-cause relative risk estimates are compared with physically inactive individuals (less than 500–600 MET-minutes per week, baseline RR=1) which is taken as baseline. Moderate=500–1500 MET-minutes per week. High=more than 1500 MET-minutes per week. 95% CIs in parentheses. MET, metabolic equivalents of task.

RESULTS

Physical activity and mortality risk

The systematic literature review process identified 74 relevant and comparable studies, providing 1124 estimates of relative all-cause mortality risk (RR) associated with insufficient physical activity. Descriptive statistics for the meta-sample is provided in online supplemental table 8. **Table 1** summarises the meta-regression estimates by gender and geographical region. The presented meta-regression estimates for RRs compare individuals with moderate and high levels of physical activity to the baseline low-activity group and are based on estimates adjusted for age, underlying health conditions and lifestyle factors.

Physical activity is associated with lower all-cause mortality. Estimates suggest greater benefits for women than men and residents of the USA and Europe than Asia. Note that the estimates are based on the information provided in the primary studies and do not indicate the underlying reasons for differences by gender or region. We use the relative mortality risk parameter estimates for the moderate activity group by gender and region for the counterfactual scenario in the economic model. (In the economic model, we applied the mortality risk estimates for Asia to the rest of the world group as they tend to be more conservative (lower in magnitude) than the estimates for the USA and Europe.) Applying our counterfactual scenario with increased levels of physical activity and reduced mortality will therefore have a positive effect on size of the labour force in the future.

Physical activity and productivity

The results of the regression analysis assessing the association between improved physical activity and productivity are presented in **table 2**. It summarises the estimated associations across both gender and survey regions for different levels of physical activity, controlling for socioeconomic, work-related, health and lifestyle factors. Additional results differentiated by gender, age and region are reported in Hafner *et al.*¹⁵ (No statistically significant differences in the parameter estimates for the association between physical activity and productivity were found by (a) gender, (b) age (c) or by region of the survey sample (eg, UK vs Asia)). The descriptive statistics for all variables used in the analysis are presented in online supplemental table 5. On average, the survey participants reported doing 975 MET-minutes of activity per week and lost 10% of their work time due to absence (2%) and presenteeism (8%).

As summarised in **table 2**, physical activity is associated with higher levels of workplace productivity, with individuals doing 600–750 MET-minutes of physical activity per week reporting, on average, a 0.8–1.5 percentage point (pp) lower work impairment due to absence and presenteeism than inactive individuals (those performing less than the recommended 600 MET-minutes per week). The productivity loss reduction increases with the level of

Table 2 The association between physical activity and work impairment due to absence and presenteeism (% of work time lost)

	(1)	(2)	(3)
MET-minutes per week			
600–750	–0.015** (–0.011 to –0.019)	–0.012** (–0.008 to –0.016)	–0.008** (–0.004 to –0.012)
750–900	–0.022** (–0.016 to –0.028)	–0.017** (–0.013 to –0.021)	–0.011** (–0.007 to –0.015)
900–1500	–0.024** (–0.02 to –0.028)	–0.018** (–0.14 to –0.22)	–0.011** (–0.007 to –0.15)
1500–2100	–0.031** (–0.025 to –0.037)	–0.024** (–0.02 to –0.28)	–0.016** (–0.012 to –0.02)
>2100	–0.033** (–0.029 to –0.032)	–0.027** (–0.023 to –0.031)	–0.018** (–0.014 to –0.022)
Controls			
Sociodemographic	Yes	Yes	Yes
Work related	No	Yes	Yes
Health and lifestyle	No	No	Yes

**p<0.01, *p<0.05. n=117240. 95% CIs in parentheses. Regression model in column 1 controls for age, gender, education, marital status, ethnicity, financial concerns, being a carer for a child or ill family member, engagement in voluntary or civic activities, and country-fixed and time-fixed effects; column 2 additionally controls for work-related factors, including working irregular hours, total hours of work per week, job position, income and stress at work; column 3 additionally controls for lifestyle, physical and mental health variables, including excessive alcohol consumption, smoking, psychological distress, chronic illnesses, sleep length and body mass index. All model specifications include organisational dummy variables, as well as dummy variables for the week, month and year of the given survey response. Estimates need to be multiplied by 100 to calculate the percentage point change in work impairment due to absenteeism and presenteeism. Results based on Table A.8 in Hafner *et al.*¹⁵ MET, metabolic equivalents of task.

physical activity reported. The specific value estimate depends on the number of correlates considered in the analysis; models with fewer correlates assign higher importance to physical activity. Physical activity is assumed to affect productivity both directly and indirectly, through a range of mediation factors such as improved physical and mental health. More complex models, however, may unintentionally control for some of the indirect effects. As a result, two inputs are considered in the simulation model: a low estimate of 0.8 pp and a high estimate of 1.2 pp reduction in productivity loss, as per columns 2 and 3 in table 2. These two parameter values are applied to all countries and regions analysed in the economic model.

Economic benefits of physical activity

The economic benefits from physical activity improvements are reported in table 3. These are reported in the form of added gross domestic product (GDP)—a measure of the aggregate economic output of a country—in constant prices (ie, disregarding inflation). The ‘low’ and ‘high’ scenarios correspond to the two distinct productivity parameters reported in the previous section. Online supplemental table 6 provides a detailed breakdown by country, and further information on the sensitivity analysis is provided in Hafner *et al.*¹⁵

As reported in table 3, compared with the baseline (status quo) scenario, global GDP is estimated to be 0.15%–0.24% higher, on average, per year over the 30-year period. The productivity gain is assumed to fully manifest in the first year and remain constant

thereafter; further gains then accumulate over time through a comparatively larger labour force and the secondary and multiplicative effects in the economy. Therefore, the change (between adjacent time periods) in annual and cumulative benefits increases in later years. For example, table 3 shows that the annual economic gain rises from US\$138–203 billion in 2025 to US\$314–446 billion in 2050. Finally, the total cumulative difference in economic output over the 30-year period is US\$6.0–8.6 trillion or approximately US\$3060–4409 per adult who becomes more physically active.

Most of the gains are a result of an improvement in productivity (ie, lower absence and presenteeism rates) as shown in table 4.

DISCUSSION

There are numerous benefits of improving physical activity, from better mental and physical health, lower all-cause mortality rates and higher workplace productivity to improved life satisfaction. While the direct economic benefits associated with lower cost of healthcare have been thoroughly investigated in prior literature, the broader macroeconomic benefits presented in this study have been missing from the overall picture. The analysis suggests that improving physical activity in the population, for example, by making everyone adhere to the lower threshold of the 2020 WHO guidelines range¹⁴ could be associated with economic benefits, potentially adding trillions of dollars in added economic output over a 30-year period and providing a range of other benefits to the people affected.

Table 3 Estimated difference in annual global gross domestic product relative to baseline scenario with current physical activity levels

	Scenario	2025	2030	2035	2040	2045	2050
Aggregate							
Annual, %	Low	0.15	0.15	0.16	0.16	0.16	0.17
	High	0.22	0.22	0.23	0.23	0.23	0.24
Annual, US\$ billion	Low	137.5	167.1	198.1	231.9	270.3	313.5
	High	203.3	243.1	285.6	332.4	385.7	446.3
Cumulative, US\$ trillion	Low	0.4	1.2	2.1	3.2	4.5	6.0
	High	0.6	1.7	3.1	4.7	6.5	8.6
Per more active adult							
Cumulative, US\$	Low	246.0	652.1	1118.8	1684.0	2343.1	3059.8
	High	363.6	958.0	1632.6	2446.1	3388.3	4408.5

All US\$ values in 2019 prices.

Table 4 Average annual estimated global gross domestic product gain in US\$ billion 2019 prices, by mechanism (mortality, absence, presenteeism), over the assumed 30-year period

	Total	Mortality	Absence	Presenteeism
Scenario 1 (low)	219.7	33.2	28.7	157.8
Scenario 1 (high)	316.1	33.2	55.9	227.0

Critically, the threshold of 150min of moderate-intensity physical activity (or its equivalents) can be achieved, for example, by fast-pace walking for 10–20min after each lunch, cycling to work a couple times per week or by choosing to walk instead of using car or public transport more often. Indeed, the Global Action Plan for Physical Activity (GAPPA) 2018–2030 suggests integrating physical activity into settings in which people live, work and play as well as promoting sports and active recreation, which can in turn become key drivers of tourism, employment and infrastructure.¹³

The reality is that the process of achieving such a change at the population, let alone on a global scale will be slow and difficult. GAPPA adopted a target of 15% relative reduction in the global prevalence of physical inactivity in adults and in adolescents by 2030, an extension of an earlier commitment by the WHO Member States of 10% by 2025. Although the current GAPPA target is significantly below the level of change assumed in this study, the associated benefits would remain substantial: using the methodology discussed above, we estimate that by achieving the GAPPA target, US\$25.0–36.5 billion could be added to the global GPD annually by 2030.

To the best of our knowledge, only one study has assessed the macroeconomic benefits of getting people to be more physically active, looking specifically at the Canadian economy.³⁴ Considering reductions in premature mortality, sickness absence and disability, the study estimates that getting 10% 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. Our estimates for Canada are higher as they also consider the added benefits of lower presenteeism rates, which are estimated to contribute more than the reduction in mortality and sickness absence combined (see online supplemental table 6). A study by PJM Economics³⁵ estimates the potential benefit of improved productivity due to higher levels of physical activity to UK businesses at £6.6 billion per year, broadly in line with our findings for the UK.

Our analysis considers only the adult population, potentially underestimating the total effect if, for instance, children and adolescents benefit from better health and educational outcomes by becoming more physically active.^{36 37} It is also important to highlight that this study does not consider the direct healthcare cost associated with physical activity, estimated at an additional US\$53.8 billion annually.⁶ We also do not directly quantify the intangible effects from being more physically active, such as higher life satisfaction or happiness.

However, it is important to highlight that this analysis does not consider in detail the potential cost associated with getting people to be more active. Such costs could include the direct costs of interventions and the unobserved negative utility cost for people who dislike physical activity. Utility costs are difficult to measure and monetise but could in principle for some individuals be larger than the benefits of getting them to be more active.

LIMITATIONS

The presented statistical and economic analysis has several limitations related to the lack of more appropriate data and a number of simplifying assumptions that need to be considered.

First, the estimated associations between physical activity and productivity do not necessarily represent a causal relationship. While

each multivariable regression model adjusts for a large set of covariates, reverse causality or omitting a relevant variable may cause a bias in the presented estimates.

Second, the survey data used to examine the association between physical activity and productivity are self-reported. This may lead to over-reporting of certain lifestyle factors, such as physical activity, or under-reporting negative habits, such as smoking or alcohol consumption. Even though we only examine individuals within the same organisation and adjust for a variety of different individual factors that could determine the likelihood of employees within an organisation participating in the survey (eg, age, gender, health status), the data may also suffer from selection bias. Nevertheless, the employee-level data have been shown to be remarkably representative of the broader population across a number of characteristics including age, gender, ethnicity and broader health characteristics, as reported in Stepanek *et al.*³⁰

Third, the input parameters for the economic model have been based on the best available evidence, including some additional statistical analysis presented in this study regarding the association between physical activity and mortality risk or productivity. However, some of the underlying data were not available for every country or region; in such cases, generalised estimates based on a limited number of countries have been applied.

Fourth, the economic model relies on the simplifying assumption that all additional physical activity happens during leisure time, not work time, and has no indirect negative effects on the aggregate economic output or labour supply. While there may be such effects, the opposite holds true as well: in some occasions, more active individuals may require new exercise equipment and clothes, a bicycle, gym memberships or may start going out more often as an indirect long-term result of being more active. Unemployed workers may also enter the labour force. In reality, it is impossible to measure the extent to which such effects are offset. The model therefore does not consider such effects and assumes a fixed labour supply in each country.

Furthermore, the model only considers the benefits of physical activity through improved productivity and lower mortality risk but does not take into account the potential opportunity cost for the individual for getting more active. For instance, watching TV may

What are the findings?

- ▶ A novel study assessing the economic benefits of increased physical activity on a global scale.
- ▶ If the entire adult population was doing at least 150 min of moderate-intensity physical activity per week, there would be an increase in global gross domestic product in the order of US\$6.0–\$8.6 trillion cumulatively over the 2020–2050 period (in 2019 prices).
- ▶ The results vary by country, with the USA estimated to see the greatest economic benefits both per capita and in absolute terms.

How might it impact on clinical practice in the future?

- ▶ Our results should encourage organisations and policymakers to develop new programmes and promote physical activity at the population level, particularly in high-income countries.
- ▶ Such policies could contribute not only to better health and lower mortality but also to substantial economic benefits associated with increased productivity and prosperity.

increase individual's utility which would be lost if the individual were to do physical activity instead. As it is very difficult to assess such trade-offs, none of the associated implications is considered in this study. Arguably, as previously mentioned, the time-cost required to raise the minimum physical activity level is rather small and might simply be a matter of changing behaviour.

Finally, this study only examined the potential economic benefits of getting people to be more physically active, but it did not take into account the corresponding cost to achieve this outcome. Although many physical activity options involve no costs, we would like to emphasise that our work is therefore not a cost-benefit analysis of getting people more physically active.

CONCLUSION

Increasing physical activity levels of the world's population to at least the lower threshold of the 2020 WHO guidelines¹⁴ range of 150 min of moderate-intensity physical activity per week (equivalent to 600 MET-minutes) is estimated to contribute up to US\$8.6 trillion to the global economy cumulatively by 2050 (in 2019 prices), suggesting a potential economic benefit of policies promoting physical activity, particularly in high-income countries with currently lower physical activity levels.

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Contributors MH and EY were co-chief investigators. MS contributed to the economic modelling and helped to rewrite the original report into a journal article. WP, JP, AD, MW, FM, SS and CvS contributed to various parts of the report and made revisions. All authors read and approved the final manuscript.

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Table 7: Authorship, publication date and number of estimates of the studies included in the meta-analysis data sample.

Full reference	Publication year	# 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. 'Mediterranean diet, physical activity and their combined effect on all-cause mortality: The Seguimiento Universidad de Navarra (SUN) cohort.' <i>Preventive Medicine</i> 106: 45-52. doi:10.1016/j.ypmed.2017.09.021	2017	6
Andersen, L. B., P. Schnohr, M. Schroll & H. O. Hein. 2000. 'All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work.' <i>Archives of Internal Medicine</i> 160(11): 1621-709.	2000	32
Arem, Hannah, Ruth M. Pfeiffer, Eric A. Engels, Catherine M. Alfano, Albert Hollenbeck, Yikyung Park & Charles E. Matthews. 2015. 'Pre- and postdiagnosis physical activity, television viewing, and mortality among patients with colorectal cancer in the National Institutes of Health-AARP Diet and Health Study.' <i>Journal of Clinical Oncology</i> 33(2): 180-88. doi:10.1200/JCO.2014.58.1355	2015	42
Autenrieth, Christine S., Jens Baumert, Sebastian E. Baumeister, Beate Fischer, Annette Peters, Angela Doring & Barbara Thorand. 2011. 'Association between domains of physical activity and all-cause, cardiovascular and cancer mortality.' <i>European Journal of Epidemiology</i> 26(2): 91-99. doi:10.1007/s10654-010-9517-6	2011	8
Barengo, Noël C., Gang Hu, Timo A. Lakka, Heikki Pekkarinen, Aulikki Nissinen & Jaakko Tuomilehto. 2004. 'Low physical activity as a predictor for total and cardiovascular disease mortality in middle-aged men and women in Finland.' <i>European Heart Journal</i> 25(24): 2204-11. doi:10.1016/j.ehj.2004.10.009	2004	6
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Bellocco, Rino, Chongqi Jia, Weimin Ye & Ylva T. Lagerros. 2010. 'Effects of physical activity, body mass index, waist-to-hip ratio and waist circumference on total mortality risk in the Swedish National March Cohort.' <i>European Journal of Epidemiology</i> 25(11): 777-88. doi:10.1007/s10654-010-9497-6	2010	8
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Besson, Hervé, Ulf Ekelund, Søren Brage, Robert Luben, Sheila Bingham, Kay-Tee Khaw & Nicholas J. Wareham. 2008. 'Relationship between	2008	4

Full reference	Publication year	# estimates
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Brown, Helen Elizabeth, Gemma C. Ryde, Nicholas D. Gilson, Nicola W. Burton & Wendy J. Brown. 2013. ‘Objectively Measured Sedentary Behavior and Physical Activity in Office Employees Relationships with Presenteeism.’ <i>Journal of Occupational and Environmental Medicine</i> 55(8): 945–53.	2013	20
Bucksch, J. 2005. ‘Physical activity of moderate intensity in leisure time and the risk of all cause mortality.’ <i>British Journal of Sports Medicine</i> 39(9): 632–38.	2005	38
Cardenas-Fuentes, Gabriela, Isaac Subirana, Miguel A. Martinez-Gonzalez, Jordi Salas-Salvado, Dolores Corella, Ramon Estruch, Montserrat Fito, Carlos Munoz-Bravo, Miguel Fiol, José Lapetra, Fernando Aros, Luis Serra-Majem, Josep A. Tur, Xavier Pinto, Emilio Ros, Oscar Coltell, Andres Diaz-Lopez, Miguel Ruiz-Canela & Helmut Schroder. 2018. ‘Multiple approaches to associations of physical activity and adherence to the Mediterranean diet with all-cause mortality in older adults: the PREvencion con DIeta MEDiterranea study.’ <i>European Journal of Nutrition</i> 58: 1569–78.	2018	6
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Dohrn, Ing-Mari, Michael Sjöström, Lydia Kwak, Pekka Oja & Maria Hagströmer. 2018. ‘Accelerometer-measured sedentary time and physical activity. A 15 year follow-up of mortality in a Swedish population-based cohort.’ <i>Journal of Science and Medicine in Sport</i> 21(7): 702–07. doi:10.1016/j.jsams.2017.10.035	2018	10
Edwards, Meghan K., Nitin Shivappa, Joshua R. Mann, James R. Hebert, Michael D. Wirth & Paul D. Loprinzi. 2018. ‘The association between physical activity and dietary inflammatory index on mortality risk in US adults.’ <i>Physician and Sportsmedicine</i> 46(2): 249–54. doi:10.1080/00913847.2018.1443665	2018	9

Full reference	Publication year	# estimates
Esteban-Cornejo, Irene, Verónica Cabanas-Sánchez, Sara Higuera-Fresnillo, Francisco B. Ortega, Arthur F. Kramer, Fernando Rodriguez-Artalejo & David Martinez-Gomez. 2019. 'Cognitive Frailty and Mortality in a National Cohort of Older Adults: the Role of Physical Activity.' <i>Mayo Clin Proc.</i> doi:10.1016/j.mayocp.2018.10.027	2019	4
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Full reference	Publication year	# estimates
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Full reference	Publication year	# estimates
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Matthews, Charles E., Sarah S. Cohen, Jay H. Fowke, Xijing J. Han, Qian Xiao, Maciej S. Buchowski, Margaret K. Hargreaves, L.B. Signorello & William J. Blot. 2014. 'Physical Activity, Sedentary Behavior, and Cause-Specific Mortality in Black and White Adults in the Southern Community Cohort Study.' <i>American Journal of Epidemiology</i> 180(4): 394–405. doi:10.1093/aje/kwu142	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. 'Effect of total, domain-specific, and intensity-specific physical activity on all-cause and cardiovascular mortality among hypertensive adults in China.' <i>Journal of Hypertension</i> 36(4): 793–800. doi:10.1097/HJH.0000000000001601	2018	72
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Table 8: Descriptive statistics of the meta-analysis data sample.

Factor	Estimate description	% of estimates
Male	Relates to only male sample	41
Female	Relates to only female sample	21
Middle age	Relates to sample with cohort age between 45 and 65	25
Old age	Relates to sample with cohort age between above 65	31
Unadj	Is unadjusted	1
Socio	Adjusted for socio-demographic factors	71
Smoking	Adjusted for smoking	72
BMI	Adjusted for Body Mass Index	55
Drinking	Adjusted for alcohol consumption	46
Chronic	Adjusted for chronic conditions (e.g. diabetes, hypertension)	58
China	Relates to a population sample from China	12
Other Asia	Relates to a population sample from other Asian countries than China (Taiwan, Hong Kong, Japan)	7
USA	Relates to a population sample from the USA	34
Europe	Relates to a population sample from Europe (UK, Spain, Netherlands, Denmark, Finland, Norway, Sweden, Germany)	42

Table 5: Descriptive statistics of variables used in the regression models.

Variable	Mean	Std. dev.
Gender: female (yes/no)	0.55	0.50
Age (years)	37.0	10.6
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)	45.3	34.3
Financial concerns (yes/no)	0.15	0.35
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
Sleep disturbance score	10.6	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	0.40
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
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
Work impairment %: absence + presenteeism	0.10	0.20
Work impairment %: absence	0.02	0.08
Work impairment %: presenteeism	0.08	0.17

Table 6: Estimated GDP annual gain (in US\$ billion, 2019 prices), difference from the baseline scenario with current physical activity levels, by country.

	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
	Scenario 1 (Low)						Scenario 1 (High)					
Argentina	0.6	0.8	1.0	1.2	1.5	1.8	0.9	1.1	1.4	1.7	2.1	2.6
Australia	2.7	3.3	4.0	4.8	5.6	6.6	4.0	4.9	5.9	7.0	8.2	9.6
Austria	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3
Canada	2.9	3.2	3.5	3.8	4.1	4.5	4.3	4.7	5.1	5.6	6.0	6.5
China	9.0	13.0	18.2	24.3	31.7	41.4	13.3	19.0	26.4	35.1	45.7	59.3
Ecuador	0.1	0.2	0.2	0.3	0.3	0.4	0.2	0.2	0.3	0.4	0.4	0.5
France	3.9	4.3	4.6	4.9	5.2	5.5	5.8	6.3	6.8	7.2	7.6	8.1
Germany	7.9	8.7	9.3	9.7	10.2	10.9	11.8	12.8	13.5	14.1	14.9	15.8
Hong Kong	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6
Japan	6.9	7.3	7.6	7.8	7.7	7.7	10.4	10.8	11.2	11.4	11.2	11.2
Malaysia	0.5	0.5	0.6	0.7	0.7	0.8	0.7	0.8	0.9	1.0	1.0	1.1
Netherlands	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.5
New Zealand	0.4	0.5	0.6	0.7	0.9	1.0	0.6	0.8	0.9	1.1	1.3	1.5
Pakistan	0.6	0.8	1.0	1.2	1.5	1.8	0.9	1.1	1.4	1.7	2.1	2.6
Philippines	0.5	0.6	0.8	0.9	1.2	1.4	0.7	0.9	1.1	1.3	1.6	2.0
Singapore	0.3	0.3	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.6	0.6	0.7
South Africa	0.8	1.1	1.4	1.8	2.1	2.5	1.1	1.4	1.8	2.2	2.7	3.1
South Korea	2.3	2.6	2.8	3.1	3.3	3.5	3.4	3.8	4.1	4.5	4.8	5.1
Sri Lanka	0.1	0.2	0.2	0.3	0.4	0.5	0.2	0.3	0.3	0.4	0.5	0.6
Thailand	0.6	0.7	0.8	0.9	1.0	1.1	0.9	1.1	1.2	1.3	1.4	1.5
United Kingdom	5.6	6.6	7.6	8.5	9.5	10.6	8.4	9.7	11.1	12.4	13.9	15.4
United States	51.9	61.2	70.0	79.4	89.6	100.4	76.8	89.2	101.3	114.4	128.7	143.8
Vietnam	0.3	0.4	0.6	0.7	0.9	1.1	0.5	0.6	0.8	1.0	1.2	1.5
Rest of the world	37.8	48.6	60.6	74.1	89.6	107.0	55.4	69.8	86.1	104.4	125.7	149.6

Notes: Estimates are shown for both variants of reductions in sickness absence and presenteeism levels ('Low' and 'High').