The economic burden of physical inactivity: a systematic review and critical appraisal

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ABSTRACT

Objective To summarise the literature on the economic burden of physical inactivity in populations, with emphases on appraising the methodologies and providing recommendations for future studies.

Design Systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PROSPERO registration number CRD42016047705).

Data sources Electronic databases for peer-reviewed and grey literature were systematically searched, followed by reference searching and consultation with experts.

Eligibility criteria Studies that examined the economic consequences of physical inactivity in a population/population-based sample, with clearly stated methodologies and at least an abstract/summary written in English.

Results Of the 40 eligible studies, 27 focused on direct healthcare costs only, 13 also estimated indirect costs and one study additionally estimated household costs. For direct costs, 23 studies used a population attributable fraction (PAF) approach with estimated healthcare costs attributable to physical inactivity ranging from 0.3% to 4.6% of national healthcare expenditure; 17 studies used an econometric approach, which tended to yield higher estimates than those using a PAF approach. For indirect costs, 10 studies used a human capital approach, two used a friction cost approach and one used a value of a statistical life approach. Overall, estimates varied substantially, even within the same country, depending on analytical approaches, time frame and other methodological considerations.

Conclusion Estimating the economic burden of physical inactivity is an area of increasing importance that requires further development. There is a marked lack of consistency in methodological approaches and transparency of reporting. Future studies could benefit from cross-disciplinary collaborations involving economists and physical activity experts, taking a societal perspective and following best practices in conducting and reporting analysis, including accounting for potential confounding, reverse causality and comorbidity, applying discounting and sensitivity analysis, and reporting assumptions, limitations and justifications for approaches taken. We have adapted the Consolidated Health Economic Evaluation Reporting Standards checklist as a guide for future estimates of the economic burden of physical inactivity and other risk factors.

INTRODUCTION

Physical inactivity is a global pandemic. Every year, physical inactivity causes more than 5 million deaths[1] and costs billions of dollars to societies around the world.[2] To date, many countries have developed national physical activity plans; however, few have been fully implemented.[3] The substantial gap between policy and implementation may be due to a lack of resources, cross-sectoral partnership and clear strategies. Public health responses to address the pandemic of physical inactivity remain inadequate, uncoordinated and underfunded.[3]

Economic analysis is essential to bridging the policy–implementation gap, increasing political engagement and motivating actions. Around the world, governments are addressing many competing priorities with finite resources. Making an economic case for physical activity may help galvanise public support, inform decision making and prioritise funding allocation to develop and implement interventions to reduce physical inactivity in the population.[4] Estimating the economic burden of physical inactivity is a critical first step because it can provide comprehensive information regarding the burden of the pandemic and the costs of not taking action.[2] Conducting economic evaluation of interventions designed to mitigate physical inactivity is the key to identify strategies that are the best value for money to fully inform resource prioritisation.

It is important that studies adopt robust, standardised and transparent methods when assessing the economic burden of risk factors, such as physical inactivity. Methodological consistency between studies enables valid comparisons regarding the absolute and relative burden of physical inactivity compared with other risk factors. This can be expected to increase the confidence of decision makers to commission and use such analyses in decision making. To date, a range of studies have been published on the economic burden of physical inactivity at local, state or national levels, mostly in developed countries. In 2016, as part of the *Lancet* Physical Activity Series, we published the first global estimate that included 142 countries.[2] However, prior estimates, even for the same country, vary substantially across studies. For example, Carlson *et al* estimated that physical inactivity accounted for 11.1% of the healthcare expenditure in the USA[5] while Colditz estimated the proportion to be 2.4%.[6] The difference between 11.1% and 2.4% is enormous. Understanding and perhaps resolving such divergent estimates is crucially important to enhance the overall credibility of economic burden estimates in decision making.

The purpose of this paper is to undertake a systematic review of the current literature on the economic burden of physical inactivity in populations or population-based samples, with emphases on a critical appraisal of the methodologies of each study and a discussion on how the conduct and interpretation of future studies may be improved.

METHODS

Data sources and searches

The protocol for this systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42016047705, available at http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016047705). This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[7]

We identified studies through searching electronic databases, including Medline (via OvidSP; 1946–present), Scopus and Global Health (via OvidSP; 1910–present) for peer-reviewed papers, and Web of Science conference proceedings (1900–present), ProQuest Dissertations and Theses Global, Google Scholar and Google for grey literature. The literature search was conducted from database inception to October 2016, using search terms outlined in supplementary file 1. Additional articles were identified through searching the references of eligible articles and consultation with experts in the field (authors of the global estimate paper by Ding *et al*[2] and experts listed in the Acknowledgements section of that paper).

Eligibility criteria

A study was considered eligible if it: (1) examined physical inactivity as a risk factor; (2) examined the economic burden of physical inactivity in any format, such as an estimated amount, a percentage (eg, of healthcare expenditure) or the differential costs between those who were physically inactive and those who were not; (3) provided estimates based on a population (eg, Canadian adults) or a population-based sample (eg, the Australian Longitudinal Study on Women's Health); (4) provided sufficient methodological details to allow for data extraction; and (5) included an English abstract or summary. No additional restrictions regarding the date of publication, language or peer-review status were imposed.

A study was excluded if it was based on a workplace sample only,[8] if it provided little information on methodologies or used a patented technique or tool[9] or if it included physical inactivity as a component of an overall lifestyle index or factor.[10] Finally, publications that did not include original analysis, such as reviews and commentaries, were also excluded.

Study selection

Eligibility of identified studies was assessed independently by two authors (DD and TLK-A) following a standard protocol that involved reading the title, abstract and full-text articles. Uncertainty was discussed after reading the full text, and any disagreement was resolved by consensus. A PRISMA flow diagram presents the summary of the study selection process (figure 1).

Data extraction

The outcomes of the studies included direct (ie, healthcare expenditure) and indirect costs (eg, productivity losses). Studies estimating the direct healthcare costs of physical inactivity generally used two approaches: (1) a PAF-based approach,

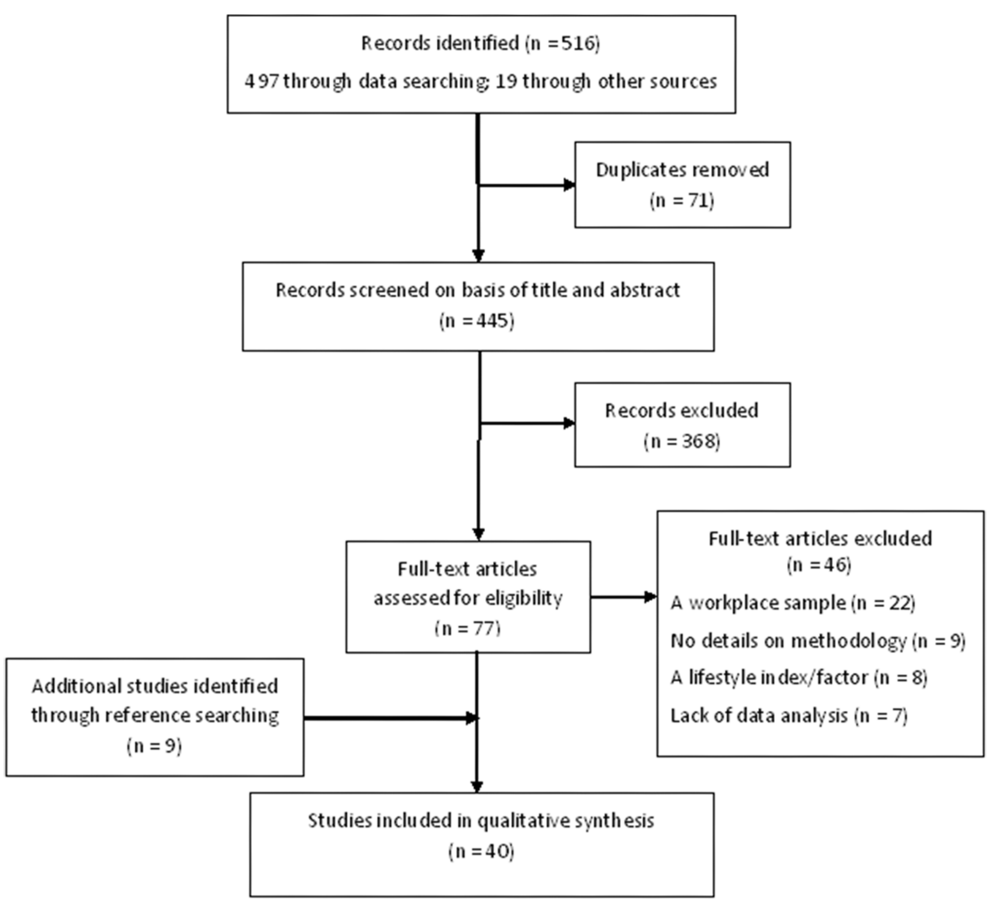

Figure 1 Selection of articles for systematic review.

Table 1 Characteristics of studies (n=40)

Study characteristic	No. of studies	References (first author and year of publication)
Country		
Australia	5	Brown 2008[43]; Cadilhac 2011[27]; Musich 2003[44]; Peeters 2014[36]; Stephenson 2000[30]
Brazil	2	Bielemann 2015[29]; Codogno 2015[48]
Canada	8	Colman 2004[16]; Janssen 2012[18]; Katzmarzyk 2000[33]; Katzmarzyk 2004[20]; Katzmarzyk 2011[19]; Krueger 2014[23]; Krueger 2015[22]; Krueger 2016[21]
China	2	Popkin 2006[57]; Zhang 2013[26]
Czech Republic	1	Maresova 2014[31]
Japan	2	Aoyagi 2011[42]; Yang 2011[37]
Korea	2	Cho 2011[39]; Min 2016[38]
New Zealand	1	Market Economics Limited 2013[24]
Switzerland	1	Martin 2001[25]
Taiwan	1	Lin 2008[45]
UK	3	Allender 2007[58]; Scarborough 2011[34]; Townsend 2016[32]
USA	10	Anderson 2005[59]; Andreyeva 2006[35]; Carlson 2014[5]; Chevan 2014[46]; Colditz 1999[6]; Garrett 2004[60]; Pratt 2000[40]; Pronk 1999[47]; Wang 2004a[41]; Wang 2004b[49]
Multiple countries	2	International Sports and Culture Association and Centre for Economics and Business Research 2015[17]; Ding 2016[2]
Study perspective		
Healthcare payer only	27	Allender 2007[58]; Anderson 2005[59]; Andreyeva 2006[35]; Aoyagi 2011[42]; Bielemann 2015[29]; Brown 2008[43]; Carlson 2014[5]; Chevan 2014[46]; Cho 2011[39]; Codogno 2015[48]; Colditz 1999[6]; Garrett 2004[60]; Katzmarzyk 2000[33]; Lin 2008[45]; Maresova 2014[31]; Min 2016[38]; Musich 2003[44]; Peeters 2014[36]; Popkin 2006[57]; Pratt 2000[40]; Pronk 1999[47]; Scarborough 2011[34]; Stephenson 2000[30]; Townsend 2016[32]; Wang 2004a[41]; Wang 2004b[49]; Yang 2011[37]
Healthcare payer and the economy	12	Colman 2004[16]; Ding 2016[2]; International Sports and Culture Association and Centre for Economics and Business Research 2015[17]; Janssen 2012[18]; Katzmarzyk 2004[20]; Katzmarzyk 2011[19]; Krueger 2014[23]; Krueger 2015[22]; Krueger 2016[21]; Market Economics Limited 2013[24]; Martin 2001[25]; Zhang 2013[26]
Societal*	1	Cadilhac 2011[27]
Methodology for estimating direct healthcare costs		
Population attributable fraction (PAF)-based approach	23	Allender 2007[58]; Bielemann 2015[29]; Cadilhac 2011[27]; Colditz 1999[6]; Colman 2004[16]; Ding 2016[2]; Garrett 2004[60]; International Sports and Culture Association and Centre for Economics and Business Research 2015[17]; Janssen 2012[18]; Katzmarzyk 2000[33]; Katzmarzyk 2004[20]; Katzmarzyk 2011[19]; Krueger 2014[23]; Krueger 2015[22]; Krueger 2016[21]; Maresova 2014[31]; Market Economics Limited 2013[24]; Martin 2001[25]; Popkin 2006[57]; Scarborough 2011[34]; Stephenson 2000[30]; Townsend 2016[32]; Zhang 2013[26]
Econometric approach	17	Anderson 2005[59]; Andreyeva 2006[35]; Aoyagi 2011[42]; Brown 2008[43]; Carlson 2014[5]; Chevan 2014[46]; Cho 2011[39]; Codogno 2015[48]; Lin 2008[45]; Min 2016[38]; Musich 2003[44]; Peeters 2014[36]; Pratt 2000[40]; Pronk 1999[47]; Wang 2004a[41]; Wang 2004b[49]; Yang 2011[37]
Indirect costs estimated		
Yes	13	Cadilhac 2011[27]; Colman 2004[16]; Ding 2016[2]; International Sports and Culture Association and Centre for Economics and Business Research 2015[17]; Janssen 2012[18]; Katzmarzyk 2004[20]; Katzmarzyk 2011[19]; Krueger 2014[23]; Krueger 2015[22]; Krueger 2016[21]; Market Economics Limited 2013[24]; Martin 2001[25]; Zhang 2013[26]
No	27	Allender 2007[58]; Anderson 2005[59]; Andreyeva 2006[35]; Aoyagi 2011[42]; Bielemann 2015[29]; Brown 2008[43]; Carlson 2014[5]; Chevan 2014[46]; Cho 2011[39]; Codogno 2015[48]; Colditz 1999[6]; Garrett 2004[60]; Katzmarzyk 2000[33]; Lin 2008[45]; Maresova 2014[31]; Min 2016[38]; Musich 2003[44]; Peeters 2014[36]; Popkin 2006[57]; Pratt 2000[40]; Pronk 1999[47]; Scarborough 2011[34]; Stephenson 2000[30]; Townsend 2016[32]; Wang 2004a[41]; Wang 2004b[49]; Yang 2011[37]
Type of publication		
Peer-reviewed scientific paper	35	Allender 2007[58]; Anderson 2005[59]; Andreyeva 2006[35]; Aoyagi 2011[42]; Bielemann 2015[29]; Brown 2008[43]; Cadilhac 2011[27]; Carlson 2014[5]; Chevan 2014[46]; Cho 2011[39]; Codogno 2015[48]; Colditz 1999[6]; Ding 2016[2]; Garrett 2004[60]; Janssen 2012[18]; Katzmarzyk 2000[33]; Katzmarzyk 2004[20]; Katzmarzyk 2011[19]; Krueger 2014[23]; Krueger 2015[22]; Krueger 2016[21]; Lin 2008[45]; Maresova 2014[31]; Martin 2001[25]; Min 2016[38]; Musich 2003[44]; Peeters 2014[36]; Popkin 2006[57]; Pratt 2000[40]; Pronk 1999[47]; Scarborough 2011[34]; Wang 2004a[41]; Wang 2004b[49]; Yang 2011[37]; Zhang 2013[26]
Grey literature	5	Colman 2004[16]; International Sports and Culture Association and Centre for Economics and Business Research 2015[17]; Market Economics Limited 2013[24]; Stephenson 2000[30]; Townsend 2016[32]

*Combined perspectives from the healthcare payer, the economy and the household.
References of all studies are included in online supplementary file 2.

which calculates healthcare costs attributable to physical inactivity by applying a PAF (interpreted as the proportion of disease that would not exist if physical inactivity was eliminated) to disease-specific costs; and (2) an econometric approach, which uses data linking physical inactivity and healthcare expenditure at the individual level. Data were extracted separately for direct and indirect costs and for studies that used a PAF-based and an econometric approach.

One author (DD) extracted data from studies, and two other authors (TLK-A, BN) each independently re-entered 30% of the extracted data for quality assurance. Any disagreement was resolved by consensus. Extracted data elements included country, data sources, physical activity measures (eg, minimal risk counterfactual or physical activity categories), time frame (eg, 1 year vs lifetime) and perspective of the analysis (eg, 'healthcare payer', 'household', 'economy' or 'societal').[11] Various other methodological considerations were extracted. Specifically, for studies that estimated direct healthcare costs using a PAF-based approach, we extracted data on the diseases or health conditions included in the cost estimates (eg, diabetes and stroke), whether the PAF was based on crude or adjusted relative risks (RRs) and whether comorbidity among diseases was accounted for. For studies using an econometric approach, we extracted data on the study design (eg, longitudinal and cross-sectional), sample, the types of costs included (eg, inpatient and outpatient) and adjustment for covariates. Finally, we also extracted information on the reported funding sources and conflict of interest.

For studies that estimated indirect costs, we extracted the type of costs included (eg, productivity losses from absenteeism, presentism and others) and the methodology used. Three main approaches were used. The friction cost approach (FCA) takes an 'employer perspective' to estimate productivity losses during the 'friction period', which is the time before an employer replaces the worker lost to death or disability.[12] The human capital approach (HCA) takes an 'employee perspective' and estimates the productivity losses over an expected working lifetime, irrespective of whether an individual dies from the risk factor and/or an employer can replace the worker.[13] Finally, a value of a statistical life (VSL) approach monetises an average or 'statistical' life lost.[14] The key difference of a VSL approach is that it seeks to value life lost as opposed to estimating the productivity costs incurred. Overall, the estimates produced differ across methods, increasing from FCA to HCA to VSL.

For studies that involved an estimate of the economic burden over time, we extracted information on whether discounting was applied. Discounting is a process where all present and future costs are converted to a single net present value (NPV). Discounting is an essential practice in robust economic analysis.[15]

Finally, we extracted information on any uncertainty analysis/sensitivity analysis regarding the estimates produced. We searched for whether studies investigated statistical uncertainty and/or structural uncertainty. Statistical uncertainty concerns input parameters to the model and corresponding estimates of the economic burden the model produced. Statistical uncertainty is typically represented by means and standard errors/confidence intervals, and statistical sensitivity analysis explores sampling from the distributions to understand how the economic burden varies. Possibilities include, for example, multiway sensitivity analysis and probability sensitivity analysis. Structural uncertainty concerns the nature of the model (eg, uncertainty in the econometric assumptions used) and/or parameters included (eg, using FCA, HCA or VSL when estimating indirect costs). Structural sensitivity analysis explicitly investigates such uncertainties if relevant, by varying the model as appropriate (eg, different parameters and functional forms) and reporting the corresponding change in the economic burden estimates produced.

In the case of lacking specific information (eg, types of cost included), we examined the references provided by the authors to obtain relevant information. If the information was not available, we coded it as 'not specified', and when the information provided was ambiguous, we coded it as 'unclear'.

Risk of bias assessment

Due to the lack of risk of bias assessment tools or established methodological guidance on how to conduct a high-quality analysis of the economic burden of physical inactivity (or other lifestyle risk factor), we did not perform a formal risk of bias assessment according to an existing instrument, nor did we exclude studies based on low quality. Instead, we extensively discussed methodological and presentation issues throughout the paper and developed a checklist that could be used for future original studies and quality assessment.

Data synthesis

General characteristics of the selected studies, including country, perspective, methodology for estimating direct healthcare costs, whether indirect costs were estimated and type of publication, were summarised in a table. Additional specific information extracted from each study (see 'Data extraction') was synthesised separately by the type of costs (direct vs indirect costs) and the methodological approaches to estimating direct healthcare costs (PAF-based vs econometric).

To facilitate comparison of estimates across studies, we presented the percentage of overall healthcare expenditure attributable to physical inactivity. When the percentage was not reported by the study but the overall physical inactivity-related healthcare expenditure was available, we calculated the percentage based on the overall healthcare expenditure data for that year from the WHO website (http://apps.who.int/nha/database/Select/Indicators/en). Additionally, to facilitate comparison of national estimates from different years and in different currencies, we inflated the national estimates (point estimates only) in local currency units from the year of data to 2013, as the common year, using the annual consumer prices inflation indicators from the World Bank (http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG) and then converted to purchasing power parity (PPP) international dollars using conversion factors provided by the World Bank (http://data.worldbank.org/indicator/PA.NUS.PPP). This approach, similar to that used in our recent global estimates,[2] allows for comparison across countries using a common currency taking PPP into account. Finally, when the authors presented incorrect information (eg, using incorrect exchange rate and inappropriately calculated healthcare expenditure percentages), we attempted to present corrected information in summary tables and noted the correction in footnotes.

RESULTS

Selection of studies

As shown in figure 1, a total of 516 studies were identified, of which 445 were unique records. After excluding 368 records based on reading the title and abstract, full texts of the remaining 77 studies were examined. A total of 46 studies were excluded because they did not meet the inclusion criteria. In total, 40 studies were qualitatively synthesised and appraised (see online supplementary file 2).

Study characteristics

Table 1 demonstrates characteristics of the 40 studies. Nearly half of the identified studies were conducted in North America (10 in the US and eight in Canada), five studies were conducted in Australia, three in the UK, two were across multiple countries and the rest of the studies were conducted in Brazil, China, Czech Republic, Japan, Korea, Switzerland, New Zealand and Taiwan. Overall, 35 studies were peer-reviewed and five were grey literature reports.

Perspective

Two-thirds of the studies (n=27) took the sole perspective of the healthcare payer and estimated the direct healthcare expenditure only. Of the 13 studies that also estimated the indirect costs of physical inactivity, 12 combined the perspectives of the healthcare payer and the economy, by additionally estimating costs of productivity losses.[2 16–26] Only one study took a comprehensive societal perspective by estimating direct healthcare costs, indirect costs of productivity losses and those of home-based and leisure-based production.[27]

Estimates of direct costs

All studies included some estimates of the direct heathcare costs of physical inactivity. Of those, 23 studies used a PAF-based approach, while 17 used an econometric approach.

Converted national estimate: we inflated the national estimates in local currency units from the year of data to 2013 using the annual consumer prices inflation indicators from the World Bank (http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG) and then converted to PPP international dollars using conversion factors provided by the World Bank (http://data.worldbank.org/indicator/PA.NUS.PPP). However, the estimate was not converted for Martin *et al*[25] due to the lack of Swiss franc (SFr) to PPP international dollar conversion factor from the World Bank.

Studies using a PAF-based approach

As shown in table 2, although the 23 studies did not use a standardised minimal risk counterfactual for calculating the PAF, most used a definition that was equivalent to approximately 150 min of moderate-intensity physical activity per week as recommended by current physical activity guidelines.[28] Almost all studies included a broad range of healthcare expenditure, such as inpatient, outpatient, pharmaceutical and physician care costs. One study included inpatient costs only.[29] In estimating direct healthcare costs, studies included between four and eight health conditions, nearly all of which included ischaemic heart disease, diabetes, breast cancer and colon cancer. Some studies included additional conditions, such as stroke, hypertension and osteoporosis.

Regarding the PAF used for estimating direct healthcare costs, most studies did not specify whether the PAF was based on adjusted or unadjusted RR. After checking the cited references about the PAF, we could only confirm that nine studies used PAF based on adjusted RR.[2 18 19 21–23 26 29 30] All studies took an additive approach by summing costs attributable to physical inactivity across multiple diseases/conditions. This could potentially lead to double counting among those with multiple conditions, commonly known as comorbidity. Only two studies explicitly described efforts to address comorbidity. One study estimated the potential overlaps among ischaemic heart disease, stroke, and type 2 diabetes and subtracted the overlapped proportions from the sum.[2] The other study used data that could identify comorbidity through individual hospital records.[24]

All studies provided an overall amount for the healthcare costs of physical inactivity for a one-year time frame. Nineteen of the 23 studies provided a national level estimate, most of which was presented as or converted to a percentage of national healthcare expenditure. The percentages ranged from around 0.3% in the Czech Republic[31] and England[32] to 4.6% in New Zealand,[24] with the majority of the estimates ranging between 1% and 2.5% (Supplementary figure 1). Twelve studies provided some sensitivity analysis.[2 6 18 20–25 30 33 34] Of those, four included structural sensitivity analysis, by taking into account different physical activity prevalence and/or PAF.[2 25 30 34]

Studies using an econometric approach

Of the 17 studies that used an econometric approach, three applied a longitudinal design,[35–37] one used a retrospective cohort design,[38] and the remainder were cross-sectional studies (table 3). The sample size of studies ranged from 250 to 51 165. The measurement and categorisation of physical activity varied across studies and often included multiple levels. In most cases, healthcare cost data were measured objectively, based on health insurance claims or data from other healthcare systems. Only three studies used self-reported health expenditure data.[39–41] In most cases, health cost data included comprehensive types of expenditure, including both inpatient and outpatient care. However, two studies did not include inpatient services,[42 43] and one study primarily included inpatient services.[44] The types of expenditure included in each study depended on the data sources, such as public systems versus private health insurance companies.

Findings from these studies were presented in heterogeneous formats. For example, some studies presented excessive healthcare costs among those who were less active (or cost savings among those who were active), in terms of absolute or proportional difference,[5 38–40 43–45] some presented the magnitude of association between physical activity and healthcare expenditure[42 46 47] and a number of studies extrapolated findings from the sample to the population at the national level.[5 35 36 40 41 43 48 49] Overall, based on the converted national-level estimates of the proportion of healthcare expenditure associated with physical inactivity, studies that applied an econometric approach produced much higher estimates than those applying a PAF-based approach (Supplementary Figure 1). Only two econometric studies included structural sensitivity analyses by taking into account alternative model forms.[5 35]

Estimates of indirect costs

All of the 13 studies provided estimates of productivity losses in the workforce (table 4). Of those, the majority of the studies applied HCA and estimated cumulative productivity losses over a working lifetime of population affected (including current and future costs).[16–23 25 26] Two studies used FCA to estimate productivity losses during the replacement period.[2 27] In studies where both HCA and FCA were used, in the form of sensitivity analysis, FCA yielded much lower costs than HCA.[2 22 27] One study used a VSL approach and had much higher estimates of indirect costs than studies applying HCA and FCA.[24] Although at least 10 studies provided lifetime estimates by incorporating costs that will occur in the future, only four explicitly described discounting future costs,[18 20 24 27] another five were identified as applying discounting on checking their references or data sources.[16 19 21–23] Most studies included some form of statistical sensitivity analysis.[2 18 20–25 27] Five studies conducted structural sensitivity analysis by varying the model using alternative approaches/parameters.[2 22 24 25 27]

DISCUSSION

To our knowledge, the current systematic review is the first to comprehensively summarise findings and methodological considerations of studies estimating the economic burden of physical inactivity in populations. Although 40 studies were included in our review, the current estimates stem disproportionately from a small number of countries. Specifically, 38 single-country studies represented only 12 countries, of which 10 were high-income countries. At the global level, estimating the economic burden of physical inactivity remains an important yet underdeveloped area, particularly in low-income and middle-income countries.[4]

Based on the findings from the studies reviewed, it is evident that physical inactivity is a costly pandemic that is associated

Table 2 Characteristics of studies that applied a population attributable fraction (PAF) approach to estimating direct healthcare costs of physical inactivity (n=23)

First author and year of publication	Country	Data sources	Definition of PA minimal risk counterfactual	Types of costs	Conditions included	Adjusted PAF*	Comorbidity†	Findings‡: amount (% healthcare cost), uncertainty/sensitivity analysis	Time frame	Funding/COI
Peer-reviewed scientific paper										
Allender 2007[58]	UK	NHS 2002 total expenditure data, NHS 1992–1993 expenditure by disease code data	2.5 hours MPA or 1 hour VPA/week	Inpatient, outpatient, primary and community care, pharmaceutical	IHD, stroke, breast cancer, colon cancer, diabetes	No/unclear	No	£1.06 billion (1.5%) Converted national estimate: $2.0 billion INT	1 year (2002)	British Heart Foundation/no COI declared
Bielemann 2015[29]	Brazil	Brazilian Unified Health System data 2013, Brazil National Household Sample Survey 2008	Any leisure time PA	Inpatient costs only	IHD, stroke, hypertension, breast cancer, colon cancer, diabetes, osteoporosis	Yes	No	R$141.9 million, 15% of total inpatient costs of the seven major NCDs Converted national estimate: $86.2 million INT	1 year (2013)	No funding reported/ no COI declared
Cadilhac 2011[27]	Australia	National Health Survey 2004–2005, Australian Burden of Disease data 2003, Disease Costs and Impact Study 2000–2001	≥5×30 min MPA or ≥3×20 min VPA/week	Annual health sector cost	IHD, stroke, cancers, fractures, depression	No/unclear	No	$A672 million (1.3%) Converted national estimate: $522.7 million INT	1 year (2008)	VicHealth/no COI declared
Colditz 1999[6]	USA	Previously published cost estimates for each disease	Any leisure time PA	Hospital care, pharmaceutical, physician care, care in nursing home	IHD, hypertension, breast cancer, colon cancer, diabetes, osteoporotic fractures	No/unclear	No	US$24.3 billion (2.4%), statistical sensitivity analysis: US$37.2 billion (3.7%) Converted national estimate: $37.2 billion INT	1 year (1995)	Boston Obesity Nutrition Research Centre/COI statement missing
Ding 2016[2]	142 countries	WHO, World Bank and GBD Study data	≥150 min MVPA/week	Total health expenditure	IHD, stroke, breast cancer, colon cancer, T2DM	Yes	Yes	$53.8 billion INT worldwide (0.64%), structural and statistical sensitivity analysis: $14.9–147.6 billion INT when using unadjusted PAFs: $123.9 ($40.9–291.2) billion INT	1 year (2013)	No funding reported/ no COI declared
Garrett 2004[60]	USA	Blue Cross databases and Behavioral Risk Factor Surveillance System	≥5×30 min MPA or ≥3×20 min VPA/week	Inpatient and outpatient medical claim	IHD, stroke, hypertension, breast cancer, colon cancer, T2DM, osteoporotic fractures, depression, anxiety	No/unclear	No	US$83.6 million ($56/ member) among US Blue Cross members	1 year (2000)	No funding reported/ Blue Cross and Blue Shield employees involved as authors
Janssen 2012[18]	Canada	Canadian Health Measures Survey 2007–2009, EBIC 2000	7-day accelerometry ≥150 min/week	Hospital care, pharmaceutical, physician care, care in other institution and additional care expenditure	IHD, stroke, hypertension, breast cancer, colon cancer, T2DM, osteoporosis	Yes	No	$C2.4 billion (1.4%§), statistical sensitivity analysis: $C1.6–3.1 billion Converted national estimate: $2.1 billion INT	1 year (2009)	Public Health Agency of Canada/COI statement missing

Continued

Table 2 Continued

First author and year of publication	Country	Data sources	Definition of PA minimal risk counterfactual	Types of costs	Conditions included	Adjusted PAF*	Comorbidity†	Findings‡: amount (% healthcare cost), uncertainty/sensitivity analysis	Time frame	Funding/COI
Katzmarzyk 2000[33]	Canada	EBIC 1993, the PA Monitor Survey	Energy expenditure ≥12.6 kJ/kg/day	Hospital care, pharmaceutical, physician care and research	IHD, stroke, hypertension, breast cancer, colon cancer, T2DM, osteoporosis	No/unclear	No	$C2.1 billion (2.5%), statistical sensitivity analysis: $C1.4–3.1 billion Converted national estimate: $2.3 billion INT	1 year (1999)	Canadian Society for Exercise Physiology and Health Canada/ no COI declared
Katzmarzyk 2004[20]	Canada	CCHS 2000–2001, EBIC 1998/1993	Expenditure ≥6.3 kJ/kg/day	Hospital care, pharmaceutical, physician care, care in other institution and additional care expenditure	IHD, stroke, hypertension, breast cancer, colon cancer, T2DM, osteoporosis	No/unclear	No	$C1.6 billion (1.5%), statistical sensitivity analysis conducted for total costs Converted national estimate: $1.7 billion INT	1 year (2001)	Ontario Ministry of Tourism and Recreation/COI statement missing
Katzmarzyk 2011[19]	Canada	CCHS 2009, EBIC 1998	Expenditure ≥6.3 kJ/kg/day	Hospital care, pharmaceutical, physician care, care in other institution and additional care expenditure	Coronary artery disease, stroke, hypertension, colon cancer, breast cancer, T2DM, osteoporosis	Yes	No	$C1.02 billion in Ontario, Canada	1 year (2009)	Ontario Ministry of Health Promotion/ COI statement missing
Krueger 2014[23]	Canada	NHEX, CCHS 2009, EBIC 1998, Canadian Institute for Health Information Hospital Morbidity Database	Not defined as 'inactive' (did not specify)	Hospital care, pharmaceutical, physician care, other healthcare professionals (excluding dental), health research and other	IHD, stroke, hypertension, breast cancer, colon cancer, T2DM, osteoporosis	Yes	No	$C3 billion (1.4%), statistical sensitivity analysis conducted for combined risk factors Converted national estimate: $2.5 billion INT	1 year (2012)	No funding reported/ no COI declared
Krueger 2015[22]	Canada	NHEX, CCHS 2012, EBIC 2008	Leisure time energy expenditure ≥1.5 kcal/kg/day	Same as above	Same as above	Yes	No	$C3.27 billion (1.6%¶), quoted previous statistical sensitivity analysis ±17% Converted national estimate: $2.7 billion INT	1 year (2013)	No funding reported/ no COI declared
Krueger 2016[21]	Canada	NHEX, CCHS 2011–2012, EBIC 2008	Leisure time energy expenditure ≥1.5 kcal/kg/day	Same as above	Same as above	Yes	No	$C349.6 million for British Columbia, Canada, quoted previous statistical sensitivity analysis ±17%	1 year (2013)	Ministry of Health and Provincial Health Services Authority/ COI statement missing

Continued

Table 2 Continued

First author and year of publication	Country	Data sources	Definition of PA minimal risk counterfactual	Types of costs	Conditions included	Adjusted PAF*	Comorbidity†	Findings‡: amount (% healthcare cost), uncertainty/sensitivity analysis	Time frame	Funding/COI
Maresova 2014[31]	Czech Republic	Czech Republic European Health Interview Survey 2008, WHO GBD Study, data from health insurance companies that cover 75% of all healthcare expenditures	≥150 min/week MPA, ≥75 min/week VPA, or ≥180 min/week walking, or any combination resulting in 600 MET min over at least 3 days/week	Not specified	IHD, ischaemic stroke, breast cancer, colon cancer, T2DM	No/unclear	No	693 million CZK (0.35%) Converted national estimate: $58.8 million INT	1 year (2008)	University of Economics, Prague/ COI statement missing
Martin 2001[25]	Switzerland	Health-enhancing PA survey 1999, a published study on costs associated with each disease, accident statistics from the Swiss Council for Accident Prevention	≥5×30 min MPA or ≥3×20 min VPA	Not specified	CVD, hypertension, breast cancer, colon cancer, T2DM, osteoporosis, back pain, depression	No/unclear	No	2.7 billion SFr (structural sensitivity analysis conducted)	Not specified	No funding reported/ COI statement missing
Popkin 2006[57]	China	China Health and Nutrition Survey 2000, National Health Services Survey 1998	Not specified	Total costs: inpatient, outpatient, pharmaceutical, and other	IHD, stroke hypertension, breast cancer, colon cancer, endometrial cancer, T2DM (also included costs of NCDs indirectly through overweight/obesity)	No/unclear	No	US$1.35 billion (2.4%¶) Converted national estimate: $4.3 billion INT	1 year (2000; projected 2025 cost provided)	No funding reported/ no COI declared
Scarborough 2011[34]	UK	NHS Programme Budgeting estimates, WHO GBD Project	Achieving some PA at work, home, for transport or during discretionary time	All spending in primary and secondary care services	IHD, stroke, breast cancer, colon cancer, diabetes	No/unclear	No	£0.9 billion (0.75%¶), structural sensitivity analysis: £0.9–1.0 billion Converted national estimate: $1.6 billion INT	1 year (2006–07)	British Heart Foundation/COI statement missing
Zhang 2013[26]	China	Chinese Behavioral Risk Factors Surveillance 2007, National Health Services Survey 2003	≥5×30 min MPA or ≥3×20 min VPA/week	Hospital care, pharmaceutical, physician care and additional health expenditures	IHD, stroke, hypertension, cancer, T2DM (also included costs of NCDs indirectly through overweight/obesity)	Yes	No	US$3.5 billion (2.4%¶) Converted national estimate: $9.1 billion INT	1 year (2007)	Nike Inc./no COI declared
Grey literature										
Colman 2004[16]	Canada	CCHS 2000–2001, EBIC 1998	Expenditure ≥1.5 kcal/ kg/day	Hospital care, pharmaceutical, physician care, other institutions (including research), additional drug expenditure, private spending on medical care	CVD, cancer, endocrine and related diseases, musculoskeletal diseases	No/unclear	No	$C210.8 million for British Columbia, Canada	1 year (2001)	B.C. Ministry of Health Planning/COI statement missing

Continued

Ding D, *et al*. *Br J Sports Med* 2017;**51**:1392–1409. doi:10.1136/bjsports-2016-097385

Table 2 Continued

First author and year of publication	Country	Data sources	Definition of PA minimal risk counterfactual	Types of costs	Conditions included	Adjusted PAF*	Comorbidity†	Findings‡: amount (% healthcare cost), uncertainty/sensitivity analysis	Time frame	Funding/COI
International Sports and Culture Association and Centre for Economics and Business Research 2015[17]	EU-28	WHO, Organization for Economic Cooperation and Development, Eurostat, International Development Association, EUCAN and published studies	≥150 min MPA or ≥75 min VPA/week, or combinations	Direct costs: healthcare expenditure Indirect costs: DALYs	IHD, breast cancer, colorectal cancer, T2DM	No/unclear	No	UK: €1920 million (1.06%§); Germany: €1677 million (0.55%§); Italy: €1562 million (1.04%§); France: €1215 million (0.51%§); Spain: €992 million (1.03%§); Poland: €219 million (0.86%§). EU-28: €9.2 billion Converted national estimates: UK $2.4; Germany $2.2; Italy $2.1; France $1.5; Spain $1.5; Poland $0.5 billion INT	1 year (2012)	International Sport and Culture Association (contributors included various organisations and companies)/COI statement missing
Market Economics Limited 2013[24]	New Zealand	Various sources including the Ministry of Health, Statistics New Zealand, District Health Board reports, and others	≥30 min PA×5 days/week	Hospital care, pharmaceutical, outpatient, public health and other	IHD, stroke, hypertension, breast cancer, colorectal cancer, T2DM, osteoporosis, depression	No/unclear	Yes	$614 million NZD (4.6%), statistical sensitivity analysis conducted (+2%) Converted national estimate: $464.4 million INT	2010	Government commissioned/COI statement missing
Stephenson 2000[30]	Australia	Active Australia 1997 National PA Survey; RR from studies on PA and disease; Australian Institute of Health and Welfare's Disease Costs and Impact Study	Inactivity ≥150 min/week	Hospital care, pharmaceutical, medical services, allied health, research, public health and other	IHD, stroke, breast cancer, colon cancer, depression	Yes	No	$A377 million (1.1%#; structural sensitivity analysis conducted) Converted national estimate: $433.2 million INT	1 year (1993–1994)	Commonwealth Department of Health and Aged Care and Australian Sports Commission/COI statement missing
Public Health England 2016	UK	Programme budgeting data released by NHS England in 2010–2014	Not specified	Not specified	IHD, stroke, breast cancer, colon cancer, diabetes	No/unclear	No	£455 million for England, UK (0.3%#) Converted national estimate: $657.8 million INT	1 year (2013–2014)	Public Health England/COI statement missing

*Adjusted PAF: whether PAF used was based on relative risks adjusted for confounders. Yes=explicitly described adjustment in the paper; No/unclear=did not describe adjustment in the paper, we could not use a consistent methodology to determine whether the PAF was crude or adjusted but not stated.
†Comorbidity: whether the potential double counting among comorbidities was addressed (yes/no).
‡Findings: interpreted as the total amount of direct healthcare cost that was associated with physical inactivity (all findings referred to the general population with the exception of Garrett 2004,[60] which referred to all Blue Cross members ≥18 years). % interpreted as the percentage of overall healthcare cost that was spent on diseases that were attributable to physical inactivity. In most cases, the percentages were reported in the original studies; in some cases, the author (DD) calculated or recalculated the percentages based on national healthcare expenditure data from the WHO (available at http://apps.who.int/nha/database/ViewData/Indicators/en).
§Recalculated and corrected by the authors of the current review.
¶Calculated or recalculated percentages.
A, Australian dollars; C, Canadian dollars; CCHS, Canadian Community Health Survey; COI, conflict of interest; CVD, cardiovascular disease; CZK, Czech Koruna; DALYs, Disability Adjusted Life Years; EBIC, Economic Burden of Illness in Canada; EU-28, 28 member countries of the European Union; GBD: Global Burden of Disease; IHD, ischaemic heart disease; INT, international dollars; MET, metabolic equivalents; min, minutes; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; NCD, non-communicable disease; NHEX, National Health Expenditure Database for Canada; NHS, National Health Service; NZD, New Zealand dollars; min, minutes; PA, physical activity; PAF, population attributable fraction; £, pounds sterling; R, Brazil real; T2DM, type 2 diabetes mellitus; RR, relative risks; SFr, Swiss francs; VPA, vigorous physical activity.

Table 3 Characteristics of studies that applied an econometric approach to estimating the direct healthcare costs of physical inactivity (n=17)

First author and year of publication	Country	Data sources	Design	Sample	PA categories	Types of costs	Covariates adjusted	Major findings	Population-level amount* (%)†, sensitivity/uncertainty analysis	Time frame‡	Funding/COI
Anderson 2005[59]	USA	HeathPartners members survey (1995) linked with administrative healthcare claim data (1996–1999)	Cross-sectional	Members ≥40 years of age (n=4674)	≥4×30 min/week (yes vs no)	Professional and hospital claims	Age, sex, chronic disease, smoking, BMI	Physical inactivity, overweight and obesity were associated with 23% health plan charges and 27% of national healthcare charges	Statistical sensitivity analysis conducted	1 year (1997)	HealthPartners Center for Health Promotion/COI statement missing
Andreyeva 2006[35]	USA	Health and Retirement Study	Longitudinal	Adults aged 51–61 years and their spouses (n=7338)	Any VPA versus no VPA	Total healthcare cost	Baseline healthcare spending, socio-demographics, chronic health conditions, smoking, alcohol, BMI	PA was associated with a 7.3% reduction in healthcare cost over 2 years	Structural and statistical sensitivity analysis: 13.2% reduction when baseline health was not adjusted	1 year (2004)	No funding reported/COI statement missing
Aoyagi 2011[42]	Japan	Nakanojo Study	Cross-sectional	All willing community residents aged ≥65 years (not severely demented or bedridden; n=5200)	Quartiles based on accelerometer and pedometer Q1=2000 steps/day and 5–10 min/day of activity at >3 METs	Insurance payments for treatment by a doctor or outpatient service of a hospital (no inpatient treatment cost)	Not stated	Increase in PA of 5% of each group by a single ranking leads to 3.7% of total medical expense		1 year (2009)	Japan Society for the Promotion of Science/no COI declared
Brown 2008[43]	Australia	ALSWH 2001	Cross-sectional	Women participants aged 50–55 years (n=7004)	High: ≥1200 MET.min/week Moderate: 600–<1200 MET.min/week Low: 240–<600 MET.min/week Very low: 40–<240 MET.min/week None: <40 MET.min/week	Australian Medicare System (outpatient, general practitioner, specialist, and others)	Area of residence, education, smoking, alcohol	Costs were 26% higher in inactive than in moderately active women, and 43% higher in inactive and obese women than in healthy weight, moderately active women	Potential population-level savings: increasing from 'none' to 'low' without changing BMI: $A39.1 million, with change in BMI: $A47.1 million	1 year (2001)	Australian Government Department of Health and Ageing/COI statement missing
Carlson 2014[5]	USA	NHIS 2004–2010, MEPS 2006–2011	Cross-sectional	Adults aged ≥21 years (non-pregnant, did not respond unable to do PA; n=51 165)	Active: ≥150 min MVPA/week Insufficiently active: >0–<150 min MVPA/week Inactive: 0 MVPA	Expenditures for all services	Age, sex, race/ethnicity, marital status, census region, area, poverty level, health insurance, education, smoking, BMI	Mean annual difference in inactive adults (compared with active) was US$1437 (29.9%) and in insufficiently active US$713 (15.4%)	Physical inactivity accounted for US$131 (91–172) billion (12.5%), US$117 (76–158) billion (11.1%) after adjusting for BMI; multiple structural and statistical sensitivity analyses, eg, after excluding those with difficulty walking: US$90 (58–122) billion (9.9%); and further adjusted for BMI: $79 (46–112) billion (8.7%) Converted national estimate: $132.9 billion INT	1 year (2012)	No funding reported/no COI declared

Continued

Table 3 Continued

First author and year of publication	Country	Data sources	Design	Sample	PA categories	Types of costs	Covariates adjusted	Major findings	Population-level amount* (%)†, sensitivity/uncertainty analysis	Time frame‡	Funding/COI
Chevan 2014[46]	USA	NHIS 2006–2007, MEPS 2007–2009	Cross-sectional	Non-disabled adults (did not respond unable to do PA; n=8843)	(1) PA guidelines (strength and/or aerobic PA) (2) Aerobic PA (0; <75; 75–149, 150–299, >300 min/week)	Expenditures for all services	Age, sex, race, income, health status	No significant association between PA and expenditure when adjusted for covariates		1 year (2012)	No funding reported/No COI declared
Cho 2011[39]	Korea	A study of 250 adults	Cross-sectional	Adults aged ≥ 40 years, selected from community centres (n=250)	Inactive versus acceptable versus active based on questionnaire score	Self-reported healthcare visits and direct expenditure	None	The mean difference between active and inactive persons was US$14.12/month		1 year (2009)	Korean Government/COI statement missing
Codogno 2015[48]	Brazil	Local municipality health offices healthcare expenditure data	Cross-sectional	Adults randomly selected in five basic healthcare units in Bauru (≥50 years; n=963)	Habitual PA questionnaire score quartiles	Overall healthcare expenditure (all items registered in the medical records)	Age, sex, smoking, blood pressure, BMI	Inverse association between PA and expenditure	PA explained 1% of medicine and 0.7% overall expenditure (statistical sensitivity analysis conducted)	1 year (2010)	Brazilian Government and Brazilian Ministry of Science and Technology/no COI declared
Lin 2008[45]	Taiwan	NHIS 2001, National Health Insurance Research Database 2001	Cross-sectional	Adults selected from three major regions of Taiwan (n=15 670)	Exercised in the past 2 weeks (yes versus no)	Healthcare claim data (inpatient and outpatient)	Age, sex, ethnicity, marital status, employment status, income, education,	Those who exercised had lower inpatient expenses (2079 vs 3330 NT$) but higher outpatient expenses (9738 vs 9151 NT$)		1 year (2001)	Taiwan's National Science Council/COI statement missing
Min 2016[38]	Korea	Korean National Health Insurance Database	Retrospective cohort	40 to 69-year-old adults who had not changed PA levels during the study period (n=47 290)	Continuously reported exercise that 'worked up a sweat' for >1 time/week	Inpatient, outpatient and prescription costs	Age, sex, income, area of residence, smoking, alcohol, BMI (propensity score matching)	Those who were continuously inactive had 11.7% higher medical costs (8.7%–25.3% disease specific)		Multiple years (2005–2010)	National Research Foundation of Korea and Seoul National University Hospital/no COI declared
Musich 2003[44]	Australia	AHMG Insurance Claim Health Risk Appraisal data (1995–1999)	Cross-sectional	AHMG members (n=19 812)	≤60 min/week (at risk) versus >60 min/week	Claim charges, primarily including inpatient and some ancillary services	None	At risk versus not at risk: $460 versus $A423/year (not statistically significant)		2 years (1995–1999)	No funding reported/COI statement missing
Peeters 2014[36]	Australia	ALSWH and Medicare system (2001–2010)	Longitudinal	Middle-aged cohort (born 1946–1951) of Australian women (n=5535–6108)	(1) Active (≥40 MET-min/day)/low sitting (<8 hours/day) (2) Active/high sitting (3) Inactive/ low sitting (4) Inactive/high sitting	Total Medicare cost paid by the government and out of pocket	Survey year, marital status, area of residence, education, smoking, BMI, depressive symptoms	Physical inactivity, not prolonged sitting was associated with higher costs ($A94/year)	$A40 million at the national level	1 year (2010)	Australian Government Department of Health and Ageing and Australian National Health and Medical Research Council/no COI declared
Pratt 2000[40]	USA	NMES 1987	Cross-sectional	Non-pregnant participants aged ≥15 years, without physical limitations (n=20 041)	≥30 min of MVPA over ≥3 days versus the rest of the sample	Self-reported medical costs confirmed by a survey of medical providers	Age, sex, lifetime smoking status	Lower annual direct medical costs among those who are physically active: US$1019 versus US$1349	US$29.2 billion, statistical sensitivity analysis conducted Converted national estimate: $103.6 billion INT	1 year (1987)	No funding reported/COI statement missing

Continued

Table 3 Continued

First author and year of publication	Country	Data sources	Design	Sample	PA categories	Types of costs	Covariates adjusted	Major findings	Population-level amount* (%)†, sensitivity/uncertainty analysis	Time frame‡	Funding/COI
Pronk 1999[47]	USA	HeathPartners members survey (1995) linked with administrative healthcare claim data (1995–1996)	Cross-sectional data	Members ≥40 years of age (n=5689)	Number of active days in the prior week	HealthPartners medical claims	Age, sex, race, chronic disease, smoking, BMI	An additional day of PA led to a 4.7% decrease in median medical charges		1.5 years (1995–1996)	HealthPartners/COI statement missing
Wang 2004[41]	USA	NMES 1987	Cross-sectional	Non-pregnant adults who reported being downhearted and blue at least a little of the time (n=12 250)	≥30 min of MVPA over ≥3 days versus the rest of the sample	Medical costs including hospitalisations, physician visits, medication, home care	Age, sex, race, socioeconomic status, area of residence, physical limitations, smoking, body weight	Among those downhearted and blue, physical inactivity was associated with 6.1% of the expenditure (US$133 in 1987 and US$429 in 2003)	Physical inactivity accounted for US$11.8 billioConverted national estimate: $37.2 billion INTn in 1987 (US$38 billion in 2003) among those who were downhearted and blue	1 year (1987/2003)	No funding reported/COI statement missing
Wang 2004[49]	USA	NHIS 1995, MEPS 1996	Cross-sectional	Non-pregnant adults without physical limitations (n=2472)	≥5×30 min MPA/week or ≥3×20 min VPA versus the rest of the sample	Self-reported medical costs confirmed by a survey of medical providers	Covariates were not specified, stratified by age groups, sex, smoking status and weight	Active adults and lower prevalence of CVD and lower cost per case of CVD	Physical inactivity accounted for 13.1% of medical expenditure of people with CVD	1 year (1996)	No funding reported/COI statement missing
Yang 2011[37]	Japan	A cohort of the National Health Insurance beneficiaries	Longitudinal	Seniors aged ≥70 years capable of PA, without CVD, cancer, arthritis, and cognitive dysfunction (n=483)	Low: no sports+ no brisk walking + low walking Moderate: no sports + no brisk walking + any walking High: any sports + any brisk walking + any walking	Inpatient and outpatient costs	Age, sex, hypertension, hyperlipidaemia, diabetes, liver or renal disease, smoking, drinking, BMI, physical performance, depressive symptoms, cognitive status	Per capita medical costs: low versus moderate versus high: US$875 versus US$751 versus US$723/month; when adjusted for physical performance: US$827 versus US$711 versus US$702/month (difference driven by inpatient costs)	Statistical sensitivity analysis conducted	5.5 years (2002–2008)	Japanese Society for Promotion of Science, Japan Atherosclerosis Prevention Fund, Ministry of Health, Labour and Welfare of Japan/COI statement missing

*Converted national estimate: we inflated the national estimates in local currency units from the year of data to 2013 using the annual consumer prices inflation indicators from the World Bank (http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG) and then converted to purchasing power parity (PPP) international dollars using conversion factors provided by the World Bank (http://data.worldbank.org/indicator/PA.NUS.PPP).
†Interpreted as the total amount of direct healthcare cost that was associated with physical inactivity. % interpreted as the percentage of overall healthcare cost that was spent on diseases that were attributable to physical inactivity.
‡The cost estimate may be based on data from multiple years; however, the time frame here refers to the year for which the estimate is presented. For example, Anderson 2005[59] averaged annualised charges over a 4-year period (from 1996 to 1999) but presented the estimates in 1997 US$.
A, Australian dollars; AHMG, Australian Health Management Group; ALSWH, Australian Longitudinal Study on Women's Health; BMI, body mass index; COI, conflict of interest; CVD, cardiovascular disease; INT, International dollars; MEPS, Medical Expenditure Panel Survey; MET, metabolic equivalents; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; NHIS, National Health Interview Survey; NMES, National Medical Expenditure Survey; NT$, New Taiwan dollars; PA, physical activity; Q1, quartile 1; VPA, vigorous physical activity.

Table 4 Characteristics of studies that estimated the indirect costs of physical inactivity

First author and year of publication	Country	Data sources	Definition of PA (minimal risk counterfactual)	Types of indirect costs	Methodology	Findings* (sensitivity analysis)	Time frame	Discounting costs
Cadilhac 2011[27]	Australia	National Health Survey 2004–2005, Australian Burden of Disease data 2003, Time Use Survey 2006	≥5×30 min MPA or ≥3×20 min VPA/week	Work-forced, home-based and leisure-based production	Workforce production: Friction Cost Approach (Human Capital Approach as sensitivity analysis); household production: 'replacement cost'; leisure time production: 'opportunity cost method' approach	$A1135 million, structural and statistical sensitivity analysis conducted Converted national estimate: $882.8 million INT	Lifetime	Yes
Ding 2016[2]	142 countries	International Labour Organization employment statistics, Global Burden of Disease Study 2013, World Bank 2013 gross domestic product data	≥150 min/week of MVPA	Productivity losses due to premature mortality	Friction Cost Approach (Human Capital Approach as sensitivity analysis)	$13.7 billion INT worldwide, structural and statistical sensitivity analysis: $3.5–34.5 billion INT, when using unadjusted PAFs: $21.3 ($6.1–47.6) billion INT	1 year (2013)	N/A
Janssen 2012[18]	Canada	Canadian Health Measures Survey 2007–2009, EBIC 2000	7-day accelerometry ≥150 min/week	Productivity losses due to illness, injuries/disability and premature deaths	Human Capital Approach	$C4.3 billion, statistical sensitivity analysis: $C2.8–6.1 billion Converted national estimate: $3.8 billion INT	Lifetime	Yes
Katzmarzyk 2004[20]	Canada	CCHS 2000–2001, EBIC 1998/93	Energy expenditure ≥6.3 kJ/kg/day	Productivity losses due to illness, injuries/disability and premature deaths	Human Capital Approach	$C3.7 billion, statistical sensitivity analysis±20% Converted national estimate: $3.8 billion INT	Lifetime	Yes
Katzmarzyk 2011[19]	Canada	CCHS 2009, EBIC 1998	Energy expenditure ≥6.3 kJ/kg/day	Productivity losses due to illness, injuries/disability and premature deaths	Human Capital Approach	$C2.3 billion in Ontario, Canada	Lifetime	Yes (based on checking the reference)
Krueger 2014[23]	Canada	CCHS 2009, EBIC 1998	Not defined as 'inactive' (did not specify)	Productivity losses due to illness, injuries/disability and premature deaths	Human Capital Approach	$C7 billion, statistical sensitivity analysis conducted Converted national estimate: $5.8 billion INT	Lifetime	Yes (based on checking the reference)
Krueger 2015[22]	Canada	CCHS 2012, EBIC 1998/2008	Leisure-time energy expenditure ≥1.5 kcal/kg/day	Productivity losses due to illness, injuries/disability and premature deaths	Human Capital Approach (Friction Cost Approach as sensitivity analysis)	$C7.5 billion, structural sensitivity analysis conducted: much lower estimates based on Friction Cost Approach Converted national estimate: $6.2 billion INT	Lifetime	Yes (based on checking the reference)
Krueger 2016[21]	Canada	CCHS 2012, EBIC 1998/2008	Leisure-time energy expenditure ≥1.5 kcal/kg/day	Productivity losses due to illness, injuries/disability, and premature deaths	Human Capital Approach	$C673.5 million for British Columbia, Canada, quoted previous statistical sensitivity analysis±17%	Lifetime	Yes (based on checking the reference)
Martin 2001[25]	Switzerland	Health-enhancing PA survey 1999, a published study on costs associated with each disease, accident statistics from the Swiss Council for Accident Prevention	5×30 min MPA or 3×20 min VPA /week	Productivity losses for cardiovascular disease, type 2 diabetes and back pain only	Human Capital Approach	1.4 billion SFr, structural sensitivity analysis conducted Indirect cost of sports accidents: 2.3 billion SFr	Lifetime	N/A

Continued

Table 4 Continued

First author and year of publication	Country	Data sources	Definition of PA (minimal risk counterfactual)	Types of indirect costs	Methodology	Findings* (sensitivity analysis)	Time frame	Discounting costs
Zhang 2013[26]	China	Chinese Behavioral Risk Factors Surveillance 2007, National Health Services Survey 2003	5×30 min MPA or 3×20 min VPA /week	Economic output lost because of illness, injury-related work disability or premature death before retirement	Human Capital Approach	US$3.3 billion Converted national estimate: $8.5 billion INT	Lifetime	Not stated
Grey literature								
Market Economics Limited 2013[24]	New Zealand	Various sources including the Ministry of Health, Statistics New Zealand, District Health Board reports, and others	≥30 min PA×5 days/week	Monetary values for loss of productivity, pain and suffering. Also included other costs, such as promoting PA	Value of a statistical life/life years approaches	$661 million NZD, structural sensitivity analysis: $295 million–7.5 billion NZD Converted national estimate: $499.9 million INT	Lifetime	Yes
Colman 2004[16]	Canada	CCHS, EBIC 1998	Expenditure ≥1.5 kcal/kg/day	Productivity losses due to premature death and disability	Human Capital Approach	$C362 million/year for British Columbia, Canada	Lifetime	Yes (based on checking the reference)
International Sports and Culture Association and Centre for Economics and Business Research 2015[17]	EU-28	WHO, Organisation for Economic Cooperation and Development, Eurostat, International Development Association, EUCAN and published studies	150 min MPA or 75 min VPA/week or combination	Value of human capital that is lost due to premature morbidity and mortality	Human Capital Approach	UK: €12.31 billion; Germany: €12.85 billion; Italy: €10.58 billion; France: €8.25 billion; Spain: €5.62 million; Poland €1.96 million; EU-28: €71.1 billion Converted national estimates: UK $15.5; Germany $16.8; Italy $14.4; France $10.2; Spain $8.5; Poland $4.7 billion INT	Lifetime	Not stated

*Converted national estimate: we inflated the national estimates in local currency units from the year of data to 2013 using the annual consumer prices inflation indicators from the World Bank (http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG) and then converted to purchasing power parity (PPP) international dollars using conversion factors provided by the World Bank (http://data.worldbank.org/indicator/PA.NUS.PPP). However, the estimate was not converted for Martin *et al*[25] due to the lack of SFr to PPP international dollar conversion factor from the World Bank.

A, Australian dollars; C, Canadian dollars; CCHS, Canadian Community Health Survey; EBIC, Economic Burden of Illness in Canada; EU-28, 28 member countries of the European Union; INT, international dollars; MPA, moderate physical activity; N/A, not applicable; NZD, New Zealand dollars; PA, physical activity; PAF, population attributable fraction; £, pounds sterling; SFr, Swiss francs; VPA, vigorous physical activity.

with a substantial disease burden in almost every country where estimates exist. However, because of large variation in methodologies, health systems and the prevalence of physical inactivity over time, it is problematic to compare estimates of the cost of physical inactivity across studies and countries. As demonstrated by the current review, there is important variation in the perspective taken (eg, healthcare payer only vs societal perspective), type of costs included, specific costing approaches, measurement of physical activity, adjustment for covariates/confounding, time frame (eg, 1 year vs lifetime) and whether sensitivity analysis was undertaken and in what form. These all contributed to the substantial variations in the estimates of economic burden.

Study perspective

The perspective refers to the viewpoint from which an economic analysis is conducted, which influences the types of information included.[50] Both the original and second Panels on Cost-Effectiveness in Health and Medicine recommended taking a societal perspective as the most comprehensive approach because it estimates the total impact on society, including the health sector, non-health sector and households.[50 51] Economic burden of disease studies should ideally be aligned with this guidance for consistency. Specifically, studies should collect information on costs to the healthcare sector (ie, direct costs to public/private healthcare providers and patient costs), non-health sectors (indirect costs or productivity losses) and household economy (eg, impact on usual activities and carers, where appropriate). Most existing studies on physical inactivity take a narrower healthcare sector perspective with the rationale that the key decision maker in addressing inactivity is the health sector. While studies on healthcare costs are necessary, we argue that it is not sufficient, and it is straightforward to estimate non-health sector productivity losses and the impact on the household economy. Taking such wider impacts into account can help make the economic case for additional healthcare resources. Furthermore, policies and interventions that impact on physical activity may reside outside of the healthcare sector (eg, transportation) and may involve cross-sectoral partnership.

It is important to note that this approach estimates the 'production costs' resulting from physical inactivity to society, regarding the increase in healthcare production and the reduction in economy and household production. As discussed previously, it is possible to build on this to 'value' the impact of inactivity on health, rather than only estimating cost. There are alternative methods to do so, such as willingness to pay and VSL; however, these methods can be expensive to undertake. Therefore, in an effort to proceed incrementally and pragmatically, and to attempt to bring some initial alignment of future economic burden of disease studies, we reiterate our recommendation to take a societal approach concentrated on production costs and to disaggregate results into healthcare sector (direct costs), the wider economy or productivity impacts (indirect costs) and the household economy.

PAF-based versus econometric approaches

Two main approaches were used for estimating the direct healthcare costs of physical inactivity: a PAF-based approach and an econometric approach. Usually, an econometric approach leads to higher estimates. The marked differences in estimates using the two approaches may be explained in part by the following. First, a PAF-based approach focuses on capturing costs averted if certain diseases were prevented. Econometric models could additionally take into account potentially higher treatment intensity and costs, and possibly other ancillary costs among those with a disease/condition.[52] Second, although the US Physical Activity Guidelines Advisory Committee Report[28] concluded that there is moderate to strong evidence for the effects of physical activity on more than 20 diseases/conditions, most studies using a PAF-based approach included only a small subset of these. For example, no study reviewed included more than eight conditions (table 2). Therefore, using a PAF-based approach may underestimate the real healthcare costs associated with physical inactivity. Third, econometric analyses may capture differences in healthcare expenditure resulting from the fundamental differences between physically active and inactive individuals, such as overall health-seeking behaviour and health status. For example, according to Carlson *et al*'s cross-sectional analysis, adjusting for body mass index and excluding those with difficulty walking led to a 40% reduction in the estimated healthcare costs of physical inactivity.[5] Fourth, while studies using a PAF-based approach were mainly based on overall adult populations, most studies using an econometric approach were based on samples of older participants, where physical inactivity-related diseases and conditions were more likely to occur. Furthermore, in the longitudinal analysis by Andreyeva and Sturm, adjusting for baseline health led to 45% lower healthcare cost estimates.[35] Although most econometric analyses adjusted for covariates, which should be standard practice, without longitudinal data and careful methodological considerations, it is likely that econometric models could overestimate the actual healthcare costs of physical inactivity because of residual confounding and reverse causality.

The choice of applying a PAF-based approach versus an econometric approach depends mainly on data availability. Econometric analyses require data on physical inactivity and healthcare expenditure linked at the individual level. Regression models are usually performed to estimate the excess healthcare expenditure among those who are physically inactive, which could then be extrapolated to a population. Econometric analyses also provide opportunities to estimate healthcare costs within a particular population subgroup, for example, those who were 'downhearted and blue'.[49] However, it is important to ensure the generalisability of a sample before extrapolating findings to an entire population.

Studies using a PAF-based approach require data on healthcare costs for each of the diseases/conditions associated with physical inactivity. By applying PAF, one can estimate the proportion of healthcare costs attributable to physical inactivity. Several methodological aspects should be considered. First, the calculation of PAF should be based on adjusted RR. Unfortunately, more than half of the studies tabulated in table 2 did not adjust for covariates for PAF calculation. In our previous international study, we conducted a sensitivity analysis by applying PAF based on unadjusted RR. We found that this nearly doubled the estimates from the main analysis that was based on adjusted PAF.[2] Second, ideally for calculating PAF, RR and the prevalence of physical activity should be based on the same population using the same definition of physical activity. However, this is challenging because the current epidemiological evidence of physical activity mostly stemmed from a small number of countries using heterogeneous definitions and measurement of physical activity. Third, summing physical inactivity-related costs of each disease/condition may result in double counting due to comorbidity. Current studies rarely address this issue, leaving comorbidity an ongoing challenge for future methodological advancement.

Although the decision for methodological approaches is practically driven by data availability, it is vital that for whatever approach chosen, care is taken to address the methodological issues raised above and to report all key assumptions, limitations and justifications for approaches taken.

Estimates of indirect costs

Only one-third of studies estimated the indirect costs in addition to direct costs. Studies varied depending on whether an FCA, HCA or VS approach was taken, which naturally results in different estimates produced. For example, according to the 1998 Economic Burden of Illness in Canada report, which applied an HCA, indirect costs of cardiovascular disease represented 171% of its direct costs.[53] However, the same ratio was merely 3.1% according to the 2008 report,[54] which applied an FCA.[22]

It is important to recognise that the existence of the FCA, HCA and VSL approach is not a weakness of economic analysis. Each approach involves different value judgements regarding what the analysis should consider, such as the cost of replacement (to employers), lifetime (to employees) or the value of life itself. These are ethical and contestable concepts. We recommend that a transparent economic analysis should explicitly state the value frame used and assumptions made and calibrate the analysis to the intended decision makers/end-users. As part of this process, we recommend structural sensitivity analyses that adopt different approaches, similar to the study by Cadilhac *et al*[27] to enable readers to fully understand the impact of adopting different value judgements. Equally, it is important that those who interpret the estimates understand the differences between methods to avoid erroneous comparisons between studies and to avoid needless confusion. It is important that economists are part of research teams to guide the analysis undertaken and help communicate the methods and results.

Time frame

The economic burden of physical inactivity could occur at present and in the future. For example, deaths and disability due to illnesses could incur future costs in terms of losses of income and other production. Almost all studies reviewed used a 1-year time frame for direct costs to capture healthcare expenditure occurring in the year of analysis. Studies that included indirect costs adopt a lifetime approach by default, by valuing productivity losses in the present period and also in the future (for the FCA this is conditional on the replacement period). It is important that studies explicitly describe the time frame of the analysis and apply discounting to estimate the NPV of all current and future estimates. The NPV is a single estimate designed to create a consistent comparison across studies that may use different time periods.[15 50] A number of studies estimated lifetime costs did not use or explicitly mention discounting. This is poor practice that can be easily avoided.

Sensitivity analysis

Estimating the economic burden of physical inactivity, or any other risk factor, involves both inevitable statistical uncertainty and making various choices regarding which modelling approaches/methods (eg, FCA vs HCA) are included in the study. Therefore, it is imperative to clearly state assumptions for the main analysis and conduct comprehensive sensitivity analyses.[11 50 51] Sensitivity analysis is an integral component of any robust and transparent economic analysis.[55] Based on the current review of the literature, sensitivity analysis was not included in all studies. Again, this should be standard practice.

Study presentation

Most studies presented the results with sufficient information regarding the source of data, sampling frame (if applicable), measures of physical activity, type of costs, diseases/conditions included and year and currency. However, presentation of other methodological details was insufficient and often ambiguous, such as how the PAF was derived (eg, whether based on adjusted RR), perspectives, approaches, time frame, discounting and sensitivity analysis. Several studies presented the proportion of total healthcare expenditure attributable to physical inactivity, which is meant to facilitate comparison across studies and countries/regions. However, some studies presented such information in a misleading way by summing direct and indirect costs as the numerator, which inflated the percentage by several fold.[17 18] Future studies should clearly and accurately present key information to improve transparency and integrity.

The need for economic evaluation of interventions to address physical inactivity

Estimating the economic burden is a vital first step in understanding the overall burden of physical inactivity and the consequences of inaction, which helps galvanise policy efforts. However, burden of disease studies should not be the sole consideration in the prioritisation process. For instance, large problems may be addressed relatively inexpensively and vice versa. Therefore, it is vital that economic evaluation is undertaken to assess both the costs and benefits of interventions to reduce the economic burden and to identify interventions that are the greatest value for money. In this way, resource-constrained decision makers can best prioritise societal resources to increase population health. There are guidelines that should be followed when conducting and reporting economic evaluations.[56]

Future directions

Overall, estimating the economic burden of physical inactivity is an area of increasing research and policy importance. We recommend that future cross-disciplinary collaborations involve economists to ensure that best practice is adopted, and physical activity experts to ensure that analyses are valid. Specifically, we recommend that a societal perspective is adopted to include direct, indirect and household costs, with the overall estimate reported and then disaggregated to these three levels. Furthermore, it is vital to carefully consider potential confounding, reverse causality and comorbidity. Discounting (when future impacts are included) and sensitivity analysis should be undertaken routinely. Overall, it is vital that studies are transparent in reporting the objectives, rationale and intended end-users/decision makers and that they align with assumptions made with the objectives. Finally, studies should transparently report any funding sources and conflict of interest.

There are currently no guidelines specifically for studies that estimate the economic burden of risk factors; therefore, we have summarised what we have discussed above in a new checklist (table 5), adapted from the Consolidated Health Economic Evaluation Reporting Standards.[56] It is important to acknowledge that it is impossible to completely standardise methodologies because economic analysis is often conducted to address the needs of specific stakeholders. Hence, our newly developed checklist should be used as a guide for improving methodological rigour and reporting quality for future economic analysis that is set up to appropriately address specific objectives.

Assessing the economic burden of physical inactivity is important; however, there is a need for general improvement in

Table 5 Checklist for reporting estimates of the economic costs/burden of risk factors*

Section/item	Item no.	Recommendation	Reported on page no./line no.
Title and abstract			
Title	1	Identify the study as an estimate of the economic burden of a risk factor (ie, physical activity) and identify the study sample	
Abstract	2	Provide a summary of objectives, perspective, setting, methods (including study design and inputs), results, including statistical uncertainty, and sensitivity analysis (changes in key structural assumptions) and conclusions	
Introduction			
Background and objectives	3	Provide an explicit statement of the study objective(s) and broader context for the study. Present the study question and its relevance for health policy or practice decisions. Describe whether previous estimates existed for the same risk factor among the same (or comparable) populations	
Methods			
Target population and subgroups	4	Describe characteristics of the study sample/population. If subsamples/populations are chosen, provide justification of why and how they are chosen	
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made. Define decision maker(s) that the study is intended to inform	
Study perspective	6	Describe the perspective of the study, ensure this is consistent with the study objective(s) and aligned with the categories of costs/burden being evaluated	
The risk factor(s)	7	Define the risk factor(s) (eg, physical inactivity), how the risk factor is measured (eg, questionnaire), the reliability and validity of the measurement instrument, the minimal risk counterfactual and the rationale for selecting the counterfactual or categories (eg, meeting physical activity recommendations)	
Choice of health outcomes	8	Define the health outcomes associated with the risk factor(s), the rationale for selecting the outcomes (eg, evidence on the risk factor–outcome associations), describe whether comorbidity is taken into account	
Costs/burden estimated	9	Define the costs/burden estimated (eg, healthcare expenditure, productivity losses) and the estimates included (eg, inpatient and outpatient care)	
Data sources	10	Describe the sources of data, the years the data cover and any major caveats/limitations related to the data, if any	
Time frame	11	State the time frame over which costs/burden are considered (eg, single year, patient lifetime) and explain why it is appropriate	
Discount rate(s)	12	Report the choice of the discount rate(s) used for costs/burden and explain why this choice is appropriate	
Year of reporting and common unit of measure for costs/burden	13	Report the year that the estimates refer to and the common unit of measure used to collate costs/burden (eg, for costs state the currency, and for burden state the health measure, such as disability adjusted life years. If relevant, describe methods for converting costs into a common currency and year of reporting (eg, inflation rates, purchasing power parity conversion factors)	
Analytic methods and assumptions made	14 14a 14b	Describe the overall analytical approach (eg, population attributable fraction (PAF) approach and econometric approach). Describe all assumptions, such as rationale for choice of model, statistical distribution and any other major assumptions (eg, missing data imputation) For study using a PAF approach, report where the PAF was derived, whether PAF was based on adjusted or crude relative risk For study using an econometric approach, report the study design (eg, prospective, cross-sectional), statistical models and covariates adjusted	
Results			
Costs/burden estimates	15	Report the values (eg, mean) and associated statistical distributions/ranges for all parameters. If secondary data is used, reference appropriately. A bespoke table transparently reporting all input values (from methods) and outputs (from results) is strongly recommended	
Characterising uncertainty	16	If applicable, describe the effects of sampling uncertainty (statistical sensitivity analysis) on results and structural uncertainty in changing methodological assumptions (eg, study perspective, model choice and discount rates)	
Characterising heterogeneity	17	If applicable, report differences in costs and/or other outcomes that can be explained by variations between subgroups with different baseline characteristics or other observed variability in effects that are not reducible by more information	
Other			
Source of funding	18	Describe how the study was funded and the role of the funder in the identification, design, conduct and reporting of the analysis Describe other non-monetary sources of support	
Conflict(s) of interest	19	Describe any potential for conflict of interest among study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors to comply with International Committee of Medical Journal Editors' recommendations	

*Checklist adapted from the Consolidated Health Economic Evaluation Reporting Standards (CHEERS).

What is currently known?

- The pandemic of physical inactivity causes diseases and deaths and costs billions of dollars to societies around the world.
- Economic analysis is essential to bridging the policy–implementation gap, increasing political engagement and motivating actions.
- A range of studies have been published on the economic burden of physical inactivity, mostly in developed countries. However, prior estimates, even for the same country, vary substantially across studies.
- There is no existing quality assessment tool or established methodological guidelines on how to conduct a high-quality analysis of the economic burden of physical inactivity or other lifestyle risk factor.

What are the new findings?

- Among the current economic burden estimates, there is important variation in the perspective taken, type of costs included, specific costing approaches, measurement of physical activity, adjustment for covariates/confounding, time frame and whether sensitivity analysis was undertaken and in what form. These all contributed to the substantial variations in the estimates of economic burden.
- Two main approaches were used for estimating the direct health care costs of physical inactivity: a population attributable fraction-based approach and an econometric approach. Usually, an econometric approach leads to higher estimates based on fundamental differences between the two approaches.
- Many prior studies did not follow best practice in economic analysis and did not present sufficient information in a transparent fashion.
- We developed a new checklist as a guide for improving methodological rigour and reporting quality for future economic burden analysis, adapted from the Consolidated Health Economic Evaluation Reporting Standards checklist.

the conduct, reporting and interpretation of studies to increase the credibility of findings and to promote their use by decision makers.

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