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Economic burden of low physical activity and high sedentary behaviour in Finland

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ABSTRACT

Background Low physical activity and high sedentary behaviour are unquestionably relevant for public health while also increasing direct and indirect costs.
Methods The authors examined the direct and indirect costs attributable to low physical activity and high sedentary behaviour in Finland in 2017. Costs related to major non-communicable diseases drawn from Finnish registries covered direct costs (outpatient visits, days of inpatient care, medication and institutional eldercare) and indirect costs (sickness-related absences, disability pensions, unemployment benefits, all-cause mortality and losses of income tax revenue). Prevalences of low physical activity and high sedentary behaviour (≥8 hours per 16 waking hours) were based on self-reports among adolescents or accelerometer data among adults and the elderly from three Finnish population studies: FINFIT 2017, Health 2011 and the Cardiovascular Risk in Young Finns Study. Cost calculations used adjusted population attributable fractions (PAF) and regression models. Total annual costs were obtained by multiplying PAF by the total costs of the given disease.
Results The total costs of low physical activity in Finland in 2017 came to approximately €3.2 billion, of which direct costs accounted for €683 million and indirect ones for €2.5 billion. Costs attributable to high sedentary behaviour totalled roughly €1.5 billion.
Conclusion The findings suggest that low physical activity and high sedentary behaviour levels create substantial societal costs. Therefore, actions intended to increase physical activity and reduce excessive sedentary behaviour throughout life may yield not only better health but also considerable savings to society.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Worldwide, around a third of adults do not reach the recommended weekly level of aerobic physical activity.
⇒ While prior work attests to a link between physical activity and higher labour market returns, little is known about physical inactivity's impacts on tax revenue and unemployment benefits.
⇒ According to prior studies physical inactivity represents approximately 0.3%–4.6% of the nation's healthcare costs.

WHAT THIS STUDY ADDS

⇒ The study produced deeper insight related to costs arising from low physical activity and high sedentary behaviour.
⇒ The indirect costs were more than three times the direct ones.
⇒ Physical inactivity costs Finnish society several billion euros each year.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ Societal investments in actions that can raise the population's physical activity levels are likely to lead to substantial savings at the societal level.
⇒ An important topic for future studies would be to explore the indirect costs of low physical activity in more detail.

INTRODUCTION

Self-reported data indicate that, worldwide, around a third of adults do not reach the recommended weekly level of aerobic physical activity.[1] In Finland, estimates of the proportion of adults meeting the health-enhancing-aerobic-physical-activity recommendation range from accelerometer-measured 22.5%[2] to 31% from self-reporting.[3] Physical activity is unquestionably relevant for public health: there is an established relationship between a physically active lifestyle and a lower risk of many non-communicable diseases, all-cause mortality[4 5] and a higher quality of life.[6] Additionally, high sedentary behaviour, irrespective of meeting physical-activity recommendations, has been shown to pose an independent risk of deleterious health outcomes (eg, type 2 diabetes, cardiovascular diseases, all-cause mortality).[6 7] However, according to Ekelund *et al*,[8] high levels of moderate-intensity physical activity (about 60–75 min per day) seem to eliminate the increased risk of death associated with high sitting time.

Non-communicable diseases reduce individuals' health-related quality of life while also increasing direct and indirect costs.[9] In recent years, research has revealed various costs of low physical activity and high sedentary behaviour[4 7 9]; for example, Ding *et al*[9] estimated that, globally, physical inactivity created approximately international dollar (INT$)53.8 billion in direct healthcare costs and

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INT$13.7 billion in productivity losses in 2013. Moreover, direct healthcare costs from prolonged sedentariness (>6 hours/day) in England alone have been put at roughly £0.8 billion for 2016–2017,[7] which is so far the only cost-of-illness study on sedentary behaviour. Alongside the direct costs due to non-communicable diseases and all-cause mortality, research in this area pinpoints a connection between physical activity and labour market rewards such as higher earnings[10–13] and employment.[11 14–16] Inversely, physical inactivity may diminish individuals' work ability or attachment to the labour market, thereby leading to higher indirect costs.

We undertook this study to estimate direct and indirect costs attributable to low physical activity and high sedentary behaviour levels in Finland in 2017, thereby contributing to the discussion in three important ways. First, our study enriches understanding of costs arising from physical inactivity by considering not only direct costs related to healthcare but also indirect costs, including sickness-related absences, disability pension, losses in income taxes and unemployment benefits. While previous studies[17–19] attest to a connection between physical activity and higher labour market returns, little is known about the impact of physical inactivity on tax revenue (ie, returns not received by the government) and unemployment benefits (ie, costs paid by the government). Second, our study used multiple population-based data sets from Finland, with both self-reported and accelerometer-measured information on physical inactivity and sedentary behaviour, covering various stages of life, alongside national statutory registries of the use of healthcare services and indirect labour market costs. Lastly, our sedentary behaviour-related estimates cover both the healthcare and productivity costs.

METHODS

Data

Our estimates account for costs attributable to low physical activity defined as less than 150 min of moderate-intensity or 75 min of vigorous physical activity per week[6] and high sedentary behaviour (at least 8 hours of sitting/reclining/lying during 16 waking hours, ie, accelerometer wear time) (see online supplemental material, p. 2) as follows: (1) direct healthcare costs (outpatient visits, days of inpatient care, medication) and eldercare (institutional care or formal care in the client's own home) and (2) indirect costs including sickness-related absences, disability pensions, unemployment benefits, all-cause mortality and losses of income tax revenue. Table 1 summarises the main variables, the age ranges and the register-based data sets employed in the present study. Costs were evaluated from a societal perspective and were all converted to values in 2017,[20] the year of the FINFIT population-based study.[21]

Direct costs

Cost estimates for healthcare use arising from non-communicable diseases (see table 1) were based on statutory national registries from 2016: the National Institute for Health and Welfare's Care Register for Health Care (HILMO) and Register of Primary Health Care Visits (AvoHILMO). Exceptionally, costs from type 2 diabetes were derived from Finnish Diabetes Association data for 2011, because these were the most accurate data obtainable for the condition and also included the comorbidities.[22 23] Data for costs for the institutional eldercare[24] are described in online supplemental material 1 (p. 4).

Indirect costs

Indirect costs arising from non-communicable diseases were estimated for the same diseases as the direct costs and were derived from the year 2017 national statistic of Social Insurance

Table 1 Variables and register-based data sets employed in the cost estimations in different age groups

Variable	Data set and data-collection year	Age range (years)
Physical activity and sedentary behaviour rate		
Accelerometer-measured physical activity	FINFIT 2017 (Finnish population study) Health 2011 (Finnish population study)	20–69 70–84
Accelerometer-measured sedentary behaviour	FINFIT 2017 (Finnish population study) Health 2011 (Finnish population study)	20–69 70–84
Self-reported physical activity	Cardiovascular Risk in Young Finns Study (1980–1992)	15
Direct costs		
Non-communicable diseases*	Hospital-discharge register, 2016 Finnish Statistics on Medicines, 2016 Finnish Diabetes Association, 2011 Finnish Cancer Registry, 2016	All
Institutional eldercare†	Hospital-discharge register for social welfare, 2016	≥65
Indirect costs		
Sickness-related absences and disability pension‡	Social Insurance Institution of Finland, 2017 Finnish Diabetes Association, 2011 (type 2 diabetes) Finnish Centre for Pensions, 2017 (depression)	15–64
All-cause mortality	Causes of Death, 2016	15–64
Unemployment benefits	Finnish Longitudinal Employer–Employee Data (FLEED), 2005–2012	28–47
Income taxes	FLEED, 2005–2012	28–47

*Includes coronary heart disease, type 2 diabetes, breast cancer, colon cancer, stroke, depression (mild and moderate), fracture (proximal humerus, distal radius and hip) and back disorders (visits to a primary care physician).
†Includes Alzheimer's disease, hip fracture and stroke.
‡Includes coronary heart disease, type 2 diabetes, breast cancer, colon cancer, stroke, depression, fracture and back disorders.

Table 2 Adjusted relative risks (RR) for non-communicable diseases that is attributable to low physical activity and high sedentary behaviour reported in studies of physical inactivity, institutional eldercare and sedentary behaviour

	Study/reference	RR (95% CI)	Adjustment factor*
Physical inactivity			
Coronary heart disease	Lee *et al*[4]	1.16 (1.04 to 1.30)	1.20
Type 2 diabetes	Lee *et al*[4]	1.20 (1.10 to 1.33)	1.23
Breast cancer	Lee *et al*[4]	1.33 (1.26 to 1.42)	1.05
Colon cancer	Lee *et al*[4]	1.32 (1.23 to 1.39)	1.22
Stroke	Ding *et al*[9]	1.18 (NA)	1.40†
Depression	Schuch *et al*[40]	1.19 (1.13 to 1.26)‡	NA
Back pain	Shiri and Falah-Hasani[41]	1.12 (1.03 to 1.22)	NA
Fracture	Qu *et al*[42]	1.41 (1.25 to 1.59)	NA
All-cause mortality	Lee *et al*[4]	1.28 (1.21 to 1.36)	1.22
Institutional eldercare			
Alzheimer's disease	Beckett *et al*[43]	1.64 (1.37 to 1.92)	NA
Fracture	Qu *et al*[42]	1.41 (1.25 to 1.59)	NA
Stroke	Ding *et al*[9]	1.18 (NA)	1.40
Sedentary behaviour			
Coronary heart disease	Petersen *et al*[44]	1.12 (0.95 to 1.28)§	1.23
Type 2 diabetes	Heron *et al*[7]	1.88 (1.62 to 2.17)	1.12
All-cause mortality	Heron *et al*[7]	1.25 (1.16 to 1.34)	1.87
Colon cancer	Heron *et al*[7]	1.30 (1.12 to 1.49)	1.22
Breast cancer	Shen *et al*[45]	1.17 (1.03 to 1.33)	NA
Depression	Zhai *et al*[46]	1.14 (1.06 to 1.21)	NA

*Adjustment factor was used to explore differences in physical activity and sedentary behaviour between cases with non-communicable disease of interest and healthy participants: If not reported for the cases, physical acitivity was derived from the entire study population.[7]
†From Finnish (FINRISK) cohort study.
‡OR.
§Pooled HR.
NA, not available.

Institution of Finland and Finnish Centre for Pensions. All-cause mortality figures were based on national statistics[25] (see online supplemental material, p. 5). Sickness-related absences and disability-pension figures about type 2 diabetes were calculated from Finnish Diabetes Association data from 2011.[26] For the second category of indirect costs, labour market costs, we estimated the additional costs connected with average yearly income tax and unemployment benefits in 2005–2012 from the Cardiovascular Risk in Young Finns Study data linked to the Finnish Longitudinal Employer–Employee Data and Longitudinal Population Census Data of Statistics Finland (see online supplemental material, pp. 5–6).

Population attributable fraction

Direct costs, productivity losses from sickness-related absences, disability pension and all-cause mortality, and costs of institutional eldercare arising from low physical activity and high sedentary behaviour were calculated as per the approaches by Ding *et al*[9] and Lee *et al*,[4] using adjusted population attributable fraction (PAF)[27] (see online supplemental material, page 1, first paragraph).

Relative risks (RRs) for each non-communicable disease were mainly based on values reported in meta-analyses and were age-adjusted. However, most RRs were adjusted for several factors, such as physical activity, age, body mass index, smoking habits and education (see table 2). Total annual costs were obtained by multiplying the PAF by the total costs of the non-communicable disease of interest (see tables 1 and 2 and online supplemental table 1).

Ordinary least squares (OLS) models were employed for detecting longitudinal associations between physical inactivity in adolescence and indirect labour market costs in adulthood (see online supplemental material, 1.3.2.2, for details on variables). Self-reported physical activity was assessed at the age of 15. On average, 67% of the adolescents were physically inactive while the proportion of physically active adolescents was 33% (see online supplemental table 4). To account for variables that could confound the association between physical inactivity and indirect labour market costs in adulthood, we adjusted the models for several individual-background and family-background factors (see online supplemental table 5). The individual factors comprised sex, birth cohort, birth month, the individual's chronic diseases, body fat, education level in adulthood and employment status, whereas the family factors comprised parental education, parents' physical activity, family income and family size.

Sensitivity analysis

To evaluate uncertainty of the findings, we performed five sensitivity analyses. First, we assumed that instead of 77% physically inactive adults found with accelerometry, 85% of adults were physically inactive, because those willing to participate in scientific studies may well be physically more active than non-participants. This selection bias may lead to underestimating the costs. Second, the cost calculations applied a friction-cost approach,[28] not a human-capital one: costs related to premature mortality were estimated for a 3–6 month period during which the employer can replace a deceased employee. Third, we based the analysis on the change in prevalence of the non-communicable

Table 3 Mean direct and indirect costs associated with low physical activity (of 77% of adults) and high sedentary behaviour (83%), in millions of euros, except unemployment benefits and income tax or earnings-tax contributions (cited as per-individual costs in euros and were converted to values in 2017)

	Cost (in millions of euros) of low physical activity (95% CI)*	Cost (in millions of euros) of ≥8 hours of sedentary behaviour per 16 waking hours (95% CI)
Direct costs†		
Use of healthcare services	214.1 (137.4 to 292.9)	346.3 (253.3 to 421.8)
Medications	49.1 (28.2 to 71.5)	122.9 (97.9 to 143.7)
Institutional eldercare	419.4 (306.2 to 504.3)	–
Total direct costs‡	682.6 (471.8 to 868.7)	469.2 (351.2 to 565.4)
Indirect costs		
Short sickness-related absence (≤10 days)†	11.3 (6.5 to 15.8)	2.3 (0.5 to 3.8)
Long sickness-related absence (>10 days)†	44.4 (29.3 to 59.3)	42.6 (27.4 to 54.9)
Disability pension†	324.9 (187.5 to 469.9)	691.3 (542.2 to 813.0)
All-cause mortality†	300.1 (238.1 to 363.1)	298.1 (205.6 to 378.1)
Income taxes§	1843.7 (639.0 to 3005.8)	–
Unemployment benefits §	21.2 (4.3 to 38.1)	–
Total indirect costs‡	2545.5 (1104.7 to 3952.0)	1034.3 (775.7 to 1249.8)
Total costs	3228.1 (1576.5 to 4820.7)	1503.5 (1126.9 to 1815.2)

*CIs are based on the lower and upper relative risk level, excluding unemployment benefits and income tax.
†Costs related to non-communicable diseases.
‡Total costs (excluding income taxes and unemployment benefits)= $\sum i = \text{disease } \mathrm{PAF}_i \text{x overall costs of healthcare}_i$, that is, total annual costs were obtained by multiplying the population attributable fraction by the total costs of the relevant disease.
§The results are based on ordinary least squares regression (see online supplemental material 1) in which the reference category is being physically active. Models include controls for gender, birth cohort, birth month, an individual's chronic diseases, body fat, education level, employment status, parents' education, parents' physical activity, family income and family size.

diseases from 2016 to 2019 and all-cause mortality from 2016 to 2018 (2019 data were unavailable), and estimates used the patient numbers reported by primary care physicians.[29] Fourth, we conducted a sensitivity analysis using the 6 hours cut-off of sedentary behaviour besides using the 8 hours cut-off. Finally, we followed Lechner[10] and Lechner and Downward[15] in using propensity score matching (PSM) for estimating indirect labour market costs. This identification strategy enables addressing any selection bias and unobserved heterogeneity when determining the association between physical inactivity and indirect labour market costs.

RESULTS

Direct costs

The annual direct costs of physical inactivity totalled approximately €683 million (see table 3), or 22% of the estimated direct costs of non-communicable diseases (see online supplemental material, tables 1–2). Costs from institutional eldercare represented 61% of the direct costs of physical inactivity (see table 3). The costliest non-communicable disease concerning the working-age population was type 2 diabetes, constituting the highest economic burden from physical inactivity, roughly €153 million/year (see online supplemental table 2).

In contrast, the largest component of direct costs due to high sedentary behaviour was the use of healthcare services, accounting for 74% of the €469 million total sum (see table 3). As in the case of physical inactivity, type 2 diabetes constituted a considerable economic burden, representing approximately 91% of the total direct costs attributable to high sedentary behaviour (see online supplemental table 3).

Indirect costs

Annual indirect costs due to physical inactivity totalled approximately €2546 million (see table 3) with €1844 million in income tax losses representing 72% of the costs (see table 3 and online supplemental table 5). Indirect costs of non-communicable diseases (sickness-related absences, disability pension and all-cause mortality) totalled approximately €681 million, with nearly half of these costs (48%) being attributable to disability pension (see table 3). All-cause mortality accounted for 44% of indirect costs of these diseases. The indirect costs due to high sedentary behaviour totalled €1034 million (see table 3), of which disability-pension payments accounted for 67%.

Total costs

With direct and indirect costs taken together, total costs of physical inactivity in 2017 were approximately €3.2 billion (see table 3). The greatest economic burden related to physical inactivity was from lost income tax (€1.8 billion), followed by institutional eldercare (€419 million) and disability-pension payments related to non-communicable diseases (€325 million) (see table 3). When the economic burden due to physical inactivity was broken down by disease, type 2 diabetes was the largest component (total costs: €391 million), depression the second-largest (€89 million) and stroke the third-largest (€46 million) (see online supplemental table 2). The costs of high sedentary behaviour totalled roughly €1.5 billion (see table 3).

Sensitivity analysis

The first sensitivity analysis, using 85% instead of 78% as the proportion for physically inactive adults, suggests direct and productivity-related costs (excluding unemployment benefits and lost income tax revenue) of €1469 million instead of the €1363 million we obtained (not shown in table). The second analysis involved a friction-cost approach to mortality costs: with a 3–6 month friction period, direct and productivity costs were €1139 million and €1214 million, respectively. With the third analysis, the total costs, assuming a higher prevalence of non-communicable diseases in 2019, rose to €1351 million. Thus, the results suggest that the costs from non-communicable diseases may lie in the €1214–€1469 million range. The fourth analysis based on the 6 hours cut-off of sedentary behaviour indicated costs of €1.7 billion (not shown in table). Lastly, if the aggregate indirect labour market costs were based on PSM instead of OLS estimates, the approximate costs would be €2.3 billion in income tax losses (95% CI: €850 million to €3.7 billion) and €41 million in unemployment benefits paid (95% CI: €22 million to €59 million) (see online supplemental table 6). These aggregate costs are €490 million higher (€470 million from tax losses plus €20 million from unemployment benefits) than those obtained via OLS estimates.

DISCUSSION

This study used several data sets and evaluated the direct and indirect costs of low physical activity and high sedentary behaviour from a societal perspective. The findings extend insights into costs arising from physical inactivity and sedentary behaviour, through encompassing not only direct healthcare costs but also indirect costs from sickness-related absences, disability payments, income tax losses and unemployment benefits.

The results attest to substantial costs of low physical activity (€3.2 billion) and high sedentary behaviour (€1.5 billion) in Finland in 2017, thereby showing that actions to increase physical activity levels and reduce excessive sedentary behaviour would be beneficial. For example, greater physical activity would produce higher income tax revenue and reduce healthcare expenditure—in 2017 alone, Finland's direct healthcare expenditure was €20.6 billion.[30] Our results indicate that roughly 1.3% of the latter expenditure (excluding costs of institutional eldercare) is attributable to physical inactivity (see online supplemental table 2). This proportion is consistent with previous findings that physical inactivity represents approximately 0.3%–4.6% of the nation's healthcare costs.[31] While Ding *et al*[9] estimated the corresponding direct healthcare costs to the Finnish public sector in 2013 at 86 million euros (international dollar values from 2013 were converted to 2017 euros, with inflation considered), our figures were considerably higher. We found the healthcare costs borne by the public sector to be €263 million. There are several reasons for these divergent results. First, the study by Ding and colleagues used a self-reported 27%–29% prevalence for physical inactivity, which is a considerably lower proportion than our accelerometer measurements revealed (77%). Second, that study obtained total healthcare costs per disease case by dividing the total healthcare costs for the disease by the case count, whereas we based the healthcare cost values on the actual use of healthcare services as per national registries. In addition, our estimations factored in also the costs of depression, fractures and back pain in addition to coronary heart disease, stroke, type 2 diabetes, breast cancer and colon cancer, which explains the higher costs in our study.

The costs related to high sedentary behaviour, in turn, were found considerably lower in UK than in Finland (£677 million vs €1.5 billion).[7] There are at least three reasons. First, the UK study considered fewer diseases. Also, the direct healthcare costs found for type 2 diabetes in UK were considerably lower than those found for Finland, and only 30% of adults in UK appeared to meet the criterion on high sedentariness for weekdays (≥6 hours/day), as per a questionnaire, while 83% of Finnish adults were sedentary more than 8 hours/day. Lastly, our sedentary behaviour-related estimates cover both the healthcare and productivity costs.

In calculations, physical inactivity and sedentary behaviour are treated as binary variables. However, in reality, there is a gradient between the volume of sedentary behaviour and the risk of non-communicable diseases: for example, 6 hours of daily sedentary behaviour increase risk to a certain extent, but 7 hours of sedentary behaviour increase more and 8 hours even more. Similarly, the risk of non-communicable diseases increases while the volume of weekly physical activity decreases.

Underestimation of costs

There are some issues that may lead to underestimation of total costs. One of these stems from missing information. Public registers did not provide all the essential diagnosis-linked information on medication and disability pension for fractures, breast cancer and colon cancer. Additionally, information on inpatient care for back pain is absent because this condition was only recently added to the register data. Moreover, private-sector healthcare and occupational health costs were not included since that information was inaccessible as well. Second, most short-duration sickness-related absences (<11 days) were excluded because of missing information. The third limitation is related to the use of RRs. They were all based on self-reports, not on accelerometer data, so they may under-represent the actual risks. Also, self-reported physical activity and sitting time are overestimated/underestimated compared with accelerometer-based data reveal.[32] In addition, not all RRs had the same number of adjustments. Fourth, not every disease had an adjustment factor (see table 2) that explores differences in physical activity and sedentary behaviour between the less active cases with non-communicable diseases and more active healthy participants. Therefore, low physical activity among the cases with depression, back pain, fractures, Alzheimer's disease and breast cancer may be underestimated. Consequently, physical inactivity among cases may be underestimated concerning depression, back pain, fractures, Alzheimer's disease and breast cancer. Though we used adjusted RRs, figures for the prevalence of physical inactivity in our PAF-based estimation were largely based on a healthy population, because inactivity data were not available from people with the non-communicable disease of interest. Lastly, while the costs related to type 2 diabetes were based on the year 2011, the prevalence of this disease has shown a steady increase in Finland over 2000–2017.[33] Therefore, we assume that the costs found would have been higher if the current costs from type 2 diabetes had been used instead.

Overestimation of costs

Overestimation of the total costs is also possible, and at least four potential concerns need to be discussed in interpreting the results. First, our evaluation of lost productivity applied the commonly used human-capital approach for calculating all-cause mortality.[28] This yields much higher costs compared with costs from the friction-cost method. One argument for our choice, however, is that all-cause mortality among working-age people is a substantial economic loss from the societal perspective, especially in countries such as Finland where society pays for all education. Second, our estimate for institutional eldercare may be high since only stroke could be considered as a comorbidity of dementia due to absent information[34] and because the proportions for diseases in the institutional eldercare were based on capital-area data, not nationwide data, which may reduce the representativeness of data. Third, we could not exclude fractures caused by accidents from fractures caused by falling. Fourth, the costs connected with income taxes and unemployment benefits were based on a relatively small sample, about 2000 persons, so one should interpret the results with caution. Furthermore, the associations between adolescent physical inactivity and labour market outcomes in adulthood are not direct evidence of causality. There are many potential mediators through which childhood physical inactivity may affect labour market outcomes: health, cognitive and non-cognitive skills, networking and positive discrimination.[4 9 10 16–18] The association may even be spurious, stemming from unobserved factors affecting both adolescence physical inactivity and adulthood labour market performance. Hence, the findings suggesting higher unemployment benefits and lower income taxes for adolescents classified as physically inactive might have emerged irrespective of childhood physical activity levels. Although we were able to control for many possible confounding factors, such as childhood health, education and family background (eg, parents' education and physical activity), a wide range of unobserved confounding factors may remain.

Limitations of the study

The major limitation of our study is that the healthcare costs obtained from the hospital-discharge register were from 2016 but the physical inactivity and sedentary behaviour data were from 2017. That said, physical inactivity has provably remained quite stable; for example, the proportion of age-standardised physical inactivity among 20–69 year-olds was 78.6% in the Health 2011 study and 77.5% in the FINFIT 2017 study.[2 35] Also register-based studies have certain limitations, for example, diagnoses can be misclassified or unavailable. Neither do the register data provide all relevant background information since the data have not collected for research purposes.

Moreover, the costs of sedentary behaviour were calculated assuming that there is no risk of diseases if the daily sedentary behaviour is below 8 hours during the 16 hours daily measurement period. However, further research is needed to explore the specific time thresholds which are associated with negative effects of sedentary behaviour. Therefore, we also conducted a sensitivity analysis using the 6 hours cut-off, which indicated costs of €1.7 billion, instead of €1.5 billion. In addition, missing RR for depression in physical activity was replaced by OR. The latter one is known to overestimate the RR when both estimates are over 1, and therefore the total annual cost of physical activity is estimated to be 1%–5% too high.[36]

The calculations of healthcare costs were based on some assumptions as well. First, no register is error-free but contains some misclassifications, although the healthcare registers in Nordic countries are generally regarded fairly reliable.[37] Second, some non-communicable diseases (eg, type 2 diabetes) can increase the risk of another non-communicable disease (eg, coronary artery disease). Therefore, it is possible that some costs for healthcare visits were calculated twice. In the present study, we tried to reduce double-counting by subtracting 30% from the direct costs of type 2 diabetes.[22] Third, the RRs used to calculate the costs were based on several international meta-analyses, whereas the actual RRs for certain diseases in the Finnish population could be somewhat different. Similar approaches have been proposed elsewhere.[4 9] Another possibility could be the use of Finnish cohort studies, but the lack of statistical power would be the case in several non-communicable diseases of lower prevalence. That directed us to use the methods that has been widely used in this type of calculations.[4 9] Fourth, the prevalence of physical inactivity used to calculate the direct costs was based on accelerometer-measured data from a population sample of Finnish adults. Therefore, the prevalence of physical inactivity in our study differs from earlier estimates based on self-reports.[9] Self-reported physical activity likely underestimates the actual prevalence of physical inactivity, because the accelerometer measurements, diaries or questionnaires do not provide interchangeable results.[38] Further, physically inactive persons may take part in this type of studies less likely than physically active persons. Therefore, in the sensitivity analysis, we also employed a somewhat higher proportion (85%) of physically inactive adults, while the precise prevalence of physical inactivity in the Finnish population remains unknown.[35]

Strengths of the study

The core strength of the study lies in including several population-based data sets that enabled examining with both accelerometer-measured and self-reported information on low physical activity and high sedentariness. In addition, Finnish national registries provide reliable information on the use of healthcare services and indirect productivity and labour market costs. These factors increased the accuracy of our estimates of the direct and indirect costs of low physical activity and high sedentary behaviour, while our multidimensional approach can be considered a major advantage over prior studies, most of which relied only on healthcare costs. While our work supports understanding the phenomenon as a range of costs, one can clearly conclude that low physical activity and high sedentary behaviour together cost society several billion euros every year. The costs are expected to only increase, because of ageing population, coupled with increased prevalence of some non-communicable diseases, depression and type 2 diabetes among them.[29] Regarding the generalisability of these results, we are persuaded to believe that the findings can be generalised to other developed European countries. This is because physical activity behaviour and labour market participation are rather similar among Europeans, and Europeans also have similar labour market institutions.[39]

In conclusion, the cumulative direct and indirect costs attributable to low physical activity and high sedentary behaviour levels are substantial. The key finding from our novel approach was that the indirect costs were more than three times the direct costs. Hence, it is all the more likely that effective actions aimed at increasing population-wide levels of physical activity would yield considerable savings for society. For example, our results suggest that increasing the proportion of people in Finland who meet the physical activity recommendation from 23% to 50% would create annual savings of about €1 billion. While an activity increase of this magnitude has not yet been witnessed at the population level, in theory, this is not an overwhelming demand, since the recommended minimum of 150 min moderate-to-vigorous physical activity per week for adults is quite reasonable. It demands only 2% of one's waking hours, or about 20 minutes a day, with 8 hours still left for sleep. Furthermore, were the percentage of people who are sedentary for more than 8 waking hours a day to fall from 83% to 70%, the annual savings would be €235 million.

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Data availability statement Data are available upon reasonable request. Data may be obtained from a third party and are not publicly available. No data are available. YFS-FLEED-LPC data: The Cardiovascular Risk in Young Finns Study (YFS) data set comprises health related participant data and their use is therefore restricted under the regulations on professional secrecy (Act on the Openness of Government Activities, 612/1999) and on sensitive personal data (Personal Data Act, 523/1999, implementing the EU data protection directive 95/46/EC). Also, the informed consents for the original study must be taken into consideration. In addition, data have also been obtained from registry authorities with permission to use them for the original research only. After appraising the request, the Ethics committee concludes that under applicable law, the data from this study cannot be stored in public repositories or otherwise made publicly available. The data controller (=this means the YFS investigators) may permit access on case-by-case basis for scientific research, not however to individual participant level data, but aggregated statistical data, which cannot be traced back to the individual participants' data. The FINFIT 2017: In line with the requirements of the ethics committees that approved this research, requests for access to data should be made in writing to the corresponding author (paivi.kolu@ukkinstituutti.fi). De-identified participant data can be made available, along with a data dictionary, to researchers who obtain ethical approval for their proposed analysis and provide a signed data-sharing contract, which enables data storage and analysis for a time-limited period.

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