Supplementary material

Contents

1.Methods

1.1. The population attributable fraction

The population attributable fraction (PAF) is the proportion of a non-communicable disease that could, in theory, be prevented if the recommended level of physical activity was reached (Rockhill et al. 1998, Zapata-Diomedi et al. 2016). The mathematical formula for PAF is:

$$PAF\ (\%) = \frac{\mathrm{P}\left(\mathrm{RR}_{adj} - 1\right)}{\mathrm{RR}_{adj}} * 100$$

where P denotes the proportion of physical inactivity among the population with a given non-communicable disease and RR denotes the adjusted relative risk for the non-communicable disease of interest when inactive people are compared with active ones (Rockhill et al. 1998, Zapata-Diomedi et al. 2016) (see Table 2 in the main article).

When the prevalence of physical inactivity among the population with the given disease was not available from Finnish population studies, the adjustment factor was derived from the data in earlier studies (Heron et al. 2019, Lee et al. 2012) and multiplied by the prevalence of physical inactivity.

1.2. Prevalence of low physical activity and high sedentary behaviour

Data on physical inactivity and sedentary behaviour among adults (20–69 years) were drawn from the FINFIT population study from the year 2017 (Husu et al. 2021), with *n*=2,358 and *n*=2,256, respectively. Corresponding data for older individuals (70–84 years) were obtained from the Health 2011 study (Husu et al. 2016), with *n*=206 for physical inactivity and *n*=248 for sedentary behaviour. In both studies, both physical inactivity and high sedentary behaviour were measured with a hip-worn triaxial accelerometer (FINFIT: UKK RM42; Health 2011: Hookie AM20) and analyzed with the same algorithms (Vähä-Ypyä et al. 2015a, Vähä-Ypyä et al. 2015b, Vähä-Ypyä et al. 2018). Participants carried the accelerometers on an elastic belt on their waist for seven consecutive days to achieve objective measurement of overall daily physical activity, apart from time in the shower, swimming, and other water-based activities. Individuals who kept the accelerometer in place at least for 10 hours per day during at least four days were included in the analysis. Both datasets were age-and sex-standardised.

Only a minority of Finnish adults attained the recommended weekly levels of aerobic physical activity. Accelerometer measurements of physical activity from the FINFIT 2017 population study and the Health 2011 study indicate 76.4% physical inactivity among working-age adults (20–69 years) and 85.6% physical inactivity among elderly persons (70–84 years). The prevalence of high sedentary behaviour (at least 50% during waking hours, i.e., at least 8 hours if the person wore the accelerometer 16 hours) for those aged 20–84 was 83%. Sedentary behaviour was defined as sitting, reclining, or lying down during the daily wear time. The meta-analysis by Chau et al. (2013) indicates that every additional hour of self-reported sitting time per day increased the risk of an adult's all-cause mortality by 2% when physical activity was controlled for; furthermore, after seven hours, the risk of all-cause mortality increased 5% for each extra hour of daily sitting. It is also known that self-reported sitting time is underestimated compared to objective measurements (Prince et al. 2020). Therefore, we reported the costs of sedentary behaviour based on at least 8 hours daily sedentary time.

The 67% prevalence of physical inactivity in adolescence was drawn from the Cardiovascular Risk in Young Finns Study (YFS) (Raitakari et al. 2008), in which leisure-time physical activity outside school hours was assessed with self-reports. At the age of 15, participants were asked about the intensity of their leisure-time physical activity, frequency of intense physical activity, number of weekly hours of the activity**,** the average duration of physical activity sessions, and any membership in a sports club (Telama et al. 2014). The response alternatives were coded 1, 2, or 3—except participation in a sports club, which was coded 1 or 2—and then summed to yield a physical-activity index (PAI) that provides scores from 5 (the lowest physical activity level) to 14 (the highest physical-activity level). The participants were divided into two groups by physical activity so that the person was categorised as physically inactive if PAI<10 and physically active otherwise.

1.3. Costs

Direct and indirect costs were derived for certain non-communicable diseases, for which physical inactivity and sedentary behaviour are confirmed risk factors (Ding et al. 2016, Heron et al. 2019, Lee et al. 2012). The ICD-10 diagnoses were coronary heart disease (I20–I25), type 2 diabetes (E11) (including long-term complications), breast cancer (C50), colon cancer (C18), ischaemic stroke (I63 and I69) including hemiplegia and quadriplegia(G81–G83), mild and moderate depression (F32.0, F32.1, F33.0, and F33.1), fractures of the proximal humerus, distal radius, or hip (S42.2, S52.5, S72.0, and S72.1), and back pain (M54).

1.3.1. Direct costs

Healthcare costs were judged from the number of appointments with a physician, number of emergency visits, number of inpatient-care days, and rehabilitation days. Type 2 diabetes was an exception: for this condition, costs were derived from Finnish Diabetes Association data from 2011 and included comorbidities of type 2 diabetes also (Koski et al. 2018). Since precise information on the prevalence of cardiovascular diseases among patients with type 2 diabetes in Finland was lacking, we used the 30% prevalence found for Europe (Einarson et al. 2018) and, accordingly, subtracted 30% from the direct costs of type 2 diabetes to avoid double-counting. We obtained medication costs from national data, classified by the main diagnosis group (Finnish Medicines Agency, Social Insurance Institution of Finland, 2017). The cost calculations followed the approach proposed by Ding et al.(Ding et al. 2016).

The direct costs did not include visits to private healthcare facilities or occupational healthcare, because information on these visits was not accessible to the public in 2016, except for occupational healthcare organised as a part of public healthcare and outsourcing of healthcare by private-sector providers to public healthcare.

Also, direct costs of severe depression were not included in the calculations, since patients with acute severe depression vary greatly in terms of the required medical treatments, where physical activity is not a first-line option. For back pain, visits to a primary care physician are factored in, but medication is not, because we had no data on specific medication for back pain. Cost estimates were based on average national unit costs for healthcare, with the unit costs of outpatient and inpatient care including salary and administrative costs (apart from laboratory expenses) and the charges of inpatient and outpatient clinics. (Kapiainen et al. 2014)

Medication costs were estimated from Finland's 2016 statistics on medicines except for type 2 diabetes. In cases of missing data, the number of outpatient individuals was multiplied by average annual medication costs for the ICD-10 medicine group. (Finnish Medicines Agency & Social Insurance Institution of Finland 2017)

For elderly persons aged more than 65 years of age in institutional care, costs were evaluated for f Alzheimer's disease, fractures, and stroke. These diseases are prevalent within the institutional setting and linked to physical inactivity (Agüero-Torres et al. 2001, Finne-Soveri 2012) (see Table 1 in the main article). Dementia is the most prevalent diagnosis among elderly people in institutional care in Finland (Finne-Soveri 2012), 70–80% of the dementia diagnoses being of Alzheimer's disease (Juva 2018). Consequently, in the estimation of costs of Alzheimer's disease, we removed 25% of dementia-related costs.

Institutional care encompasses regular home care, standard assisted living, sheltered housing with 24-hour assistance, and living in old people's homes (Arajärvi & Kurunen 2017). All these options were considered in the present calculations. Regular assisted living necessitated an exception in the calculations: we assumed an average of 300 inpatient days per year per resident. Elderly people's long-term inpatient stays in primary healthcare were not included, because these were already covered under the costs of primary care. Home care and institutional care costs were estimated from the average national unit cost (Kapiainen et al. 2014).

1.3.2. Indirect costs

1.3.2.1. Costs related to non-communicable diseases

Indirect costs comprised five variables: 1) short (1–10 working days) and long (>10 working days) sick leave, 2) disability pension, 3) all-cause mortality, 4) paid unemployment benefits, and 5) loss of taxable income. In contrast to direct costs, indirect costs of depression included all types of depression, not just mild and moderate, because the information source did not allow us to distinguish between types of depression. Likewise, indirect costs of fractures covered all fractures, not only those of the wrist, humerus, and hip.

Costs of longer sickness-related absences were derived from national-registry figures (Social Insurance Institution of Finland 2017). For the short-term absences, however, the number of days of sick leave was unavailable, because in Finland, this information cannot be collected from public registers. Hence, our figures for shorter absences come from only the first 10 days of longer sick leave. We were able to evaluate the sickness-related absence costs connected with colon cancer from the data of the Finnish Cancer Registry (2016). The salary costs related to short sickness-related absences were calculated from the median national monthly salary scales (Statistics Finland 2020a), with multiplication by 1.3 to encompass related expenses (Kapiainen et al. 2014).

Disability-pension costs were drawn from *Statistical Yearbook* data (Social Insurance Institution of Finland 2017), type 2 diabetes again being an exception: these disability-related costs came from the Finnish Diabetes Association and were based on the use of several national registers. The average amount of the pension was multiplied by the number of disability-pension days associated with non-communicable-disease diagnoses (Finnish Centre for Pensions 2017). Because of missing information, the disability-pension costs did not include costs attributable to breast cancer, colon cancer, or fractures.

The impact of premature mortality due to physical inactivity and high sedentary behaviour was estimated via a human-capital approach, which calculates the economic costs of premature mortality until normal retirement age (Koopmanschap & Rutten 1996). Mortality figures were based on all-cause mortality totals for the year 2016 (Statistics Finland 2020b), and the cost of lost productivity was inclusive of related expenses up to the common retirement age of 64 years, considering the median national monthly salary discounted at a rate of 3% (Max et al. 2004). Calculations considered also the annual earnings of an employed person, with household-based production excluded, and the proportion of the labour force involved. The mathematical formula for the human-capital approach is:

$$HC_i = \sum_{t=i}^{64} w_t e_t b_t \prod_i^{t-1} \left(\frac{l_{t+1}}{l_t}\right) \frac{(1+rp)^{(t-i)}}{(1+d)^{(t-i)}},$$

where *i* is the age group (15-19, 20-24, …, 60-64), *w* is the median wage multiplied by a factor 1.2 which encompass related expenses of average national monthly salary, *e* is the proportion of labour force, *b* is an employment rate, l_t is the number of persons alive at age *t*, *rp* is the rate for productivity, and *d* is the discount rate.

1.3.2.2. Costs related to income taxes and unemployment benefits

1.3.2.2.1. Data

Tax and unemployment-benefit data were obtained from three Finnish datasets: the YFS's ongoing longitudinal work, Statistics Finland's Finnish Longitudinal Employer–Employee Data (FLEED), and the Longitudinal Population Census (LPC) of Statistics Finland. All YFS participants gave written informed consent before taking part in the study, and the study was approved by the ethics committees of the participating universities. The YFS–FLEED–LPC linking of datawas approved by Statistics Finland for research purposes (permission TK-53-673-13) under that institution's ethics guidelines, which comply with national standards.

The YFS project was launched in the late 1970s to study cardiovascular risk in childhood and adolescence. Its baseline study in 1980 included a total of 3,596 children in (age groups of 3, 6, 9, 12, 15, and 18 years. The oldest age cohort, 18 years at baseline, was not included in our study. The participants were boys (51%) and girls (49%) selected at random from five Finnish communities. Since then, eight follow-ups have been conducted, the latest in 2018–2020. Each follow-up has employed comprehensive methods of data collection, including questionnaires, physical measurements, and blood tests (Raitakari et al. 2008).

FLEED is an annual panel for the entire working-age population in Finland. It records detailed information on labour market outcomes, such as stretches of unemployment, income, and unemployment benefits. The data come directly from tax and other administrative registers and are maintained by Statistics Finland, meaning that the labour market reporting does not suffer under-reporting, over-reporting, or recall errors. Information on families' education from the year 1980, was obtained from the register-based LPC data. The YFS, FLEED, and LPC data were linked to each other via unique personal identifiers. This procedure entailed exact matching, without misreported identifiers, avoiding thus any problems created by errors in record linkage.

1.3.2.2.2. Indirect labour market costs

Indirect labour market costs were elucidated with two register-based variables: 1) average yearly income tax and 2) average yearly unemployment benefits. The former indicates the potential returns not received by the government and the latter the costs paid by the government. To mitigate the possible issue of idiosyncratic fluctuations related to short-term measurements, we calculated the indirect labour market costs as a yearly average over 2005–2012. This span covers the prime working-age of the YFS participants, as their mean age ranged then from 28 to 47 years. The costs were transformed to 2017 euros by means of Statistics Finland's value-of-money converter.

2.Results

2.1. Tables of total costs of physical inactivity

Supplementary table 1: The annual costs of non-communicable diseases

Non-communicable diseases	Direct costs, EUR	Indirect costs, EUR	Total costs, EUR
Working-age people			
Coronary heart disease (I20–I25)	138,498,965	40,808,030	179,306,995
Type 2 diabetes (E11)	980,075,492	1,519,444,256	2,499,519,748
Breast cancer (C50)	95,875,079	26,979,883	122,854,962
Colon cancer (C18)	34,127,393	8,993,294	43,120,687
Stroke (G81–G83)[1]	204,838,711	81,687,107	286,525,818
Depression	84,450,702[2]	641,606,181[4]	726,056,883
Fracture	91,716,214[3]	63,645,425[5]	155,361,639
Back pain (M54)	16,099,081	295,661,752	311,760,832
All-cause mortality			1,471,713,083
Total	**1,645,681,636**	**4,150,539,011**	**5,796,220,647**
Diseases connected with institutional eldercare			
Alzheimer's disease	1,016,408,382		
Fracture[5]	110,308,883		
Stroke	286,470,385		
Total	**1,413,187,650**		
All causes	**3,058,869,286**	**4,150,539,011**	**7,209,408,297**

[1] Including cerebral infarction (I63) and sequelae of cerebrovascular disease (I69).

[2] Costs derived from mild and moderate depression (F32.0, F32.1, F33.0, and F33.1).

[3] Costs derived from fractures of the proximal humerus (S42.2), distal radius (S52.5), and hip (S72.0 and S72.1).

[4] Costs include all types of depression (mild, moderate, and severe).

[5] Costs include all types of fractures.

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Supplementary table able 2: The annual costs of physical inactivity

Non-communicable diseases	PAF	Direct costs, EUR	Indirect costs, EUR	Total costs, EUR[6]
Working-age people				
Coronary heart disease (I20–I25)	12.6%	17,513,910	5,160,386	22,674,297
Type 2 diabetes (E11)	15.7%	153,499,424	237,975,359	391,474,783
Breast cancer (C50)	19.9%	19,083,178	5,370,133	24,453,310
Colon cancer (C18)	22.6%	7,711,384	2,032,114	9,743,498
Stroke (G81–G83)[1]	16.3%	32,400,014	13,328,013	45,728,027
Depression	12.2%	10,301,566[2]	78,265,171[4]	88,566,737
Fracture	22.2%	20,375,310[3]	14,139,215[5]	34,514,525
Back pain (M54)	8.2%	1,317,825	24,202,026	25,519,851
All-cause mortality	20.4%			300,071,260
Total		**263,223,942**	**680,543,677**	**943,767,619**
Diseases connected with institutional eldercare				
Alzheimer's disease	33.4%	339,529,981		339,529,981
Fracture[5]	24.9%	27,456,741		27,456,741
Stroke	18.3%	52,368,729		52,368,729
Total		**419,355,451**		**419,355,451**
All causes		**682,223,942**	**680,543,677**	**1,363,123,070**

[1] Including cerebral infarction (I63) and sequelae of cerebrovascular disease (I69).

[2] Costs derived from mild and moderate depression (F32.0, F32.1, F33.0, and F33.1).

[3] Costs derived from fractures to the proximal humerus (S42.2), distal radius (S52.5), and hip (S72.0 and S72.1).

[4] Costs include all types of depression (mild, moderate, and severe).

[5] Costs include all types of fractures.

[6] Total costs = $\sum_{i=\text{disease}} \text{PAF}_i \; x$ overall costs of healthcare$_i$

2.2. Table of total costs of high sedentary behaviour

Supplementary table 3: The annual costs of high sedentary behaviour levels (≥8 hours per 16 waking hours)

Non-communicable diseases	PAF	Direct costs, EUR	Indirect costs, EUR	Total costs, EUR
Coronary heart disease (I20–I25)	10.5%	14,583,196	4,296,866	18,880,062
Type 2 diabetes (E11)	43.5%	426,462,125	661,158,689	1,087,620,814
Breast cancer (C50)	12.1%	11,562,371	3,253,728	14,816,098
Colon cancer (C18)	23.4%	7,974,784	2,101,525	10,076,310
Depression	10.2%	8,608,045[1]	65,398,806[2]	74,006,851
All-cause mortality	20.3%			298,051,334
Total		**469,190,521**	**1,034,260,947**	**1,503,451,468**

[1] Costs derived from mild and moderate depression (F32.0, F32.1, F33.0, and F33.1).

[2] The cost includes all types of depression (mild, moderate, and severe).

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2.3. The indirect labour market costs

The unadjusted differences in income taxes and unemployment benefits between physical-activity groups (physically active vs. physically inactive) are shown in Table 4. The results suggest that both differed significantly between the two groups: individuals categorised as physically inactive paid €2,100 less income taxes and drew €260 more unemployment benefits annually compared to their physically active counterparts.

Supplementary table 4: Income taxes and unemployment benefits in 2005–2012 by physical activity level at age 15 in year-2017 money, estimated with the Statistics Finland value-of-money converter (*n*=2,007)

	Share (%)	**Income taxes in 2017 (euros)**	**Unemployment benefits in 2017 (euros)**
Physically active at 15 years	33	8,335.23	613.02
Physically inactive at 15 years	67	6,198.10	873.99
Difference between groups		-2,137.13	260.97
p-value		$p<0.01$	$p<0.01$

Note: An individual was classed as physically inactive when PAI<10 and physically active otherwise. According to the value-of-money converter, there was a 1.03-fold change from 2012 to 2017.

To account for variables that could confound the associations between physical inactivity and indirect labour market costs, the models were adjusted for several individual- and family-background factors (Table 5). These results suggest that, compared with the physically active group, the physically inactive paid less income taxes and received more unemployment benefits in 2005–2012. Annually, physically inactive individuals paid €1,050 less income taxes and drew €160 more unemployment benefits than did their physically active counterparts.

Supplementary table 5: Ordinary least squares estimates for the relationship between physical-activity group and indirect labour market costs (*n*=2,007)

	Income tax in 2005–2012 (euros)	**Unemployment benefits in 2012 (euros)**
Physically inactive at 15 years	-1,056.40***	161.53**
	(349.81)	(65.65)
95% CI	-1,742.21; -370.37	32.78; 290.29
Adjusted R^2	0.18	0.19

Note: Heteroscedasticity-robust standard error is in brackets. Reference category: physically active. Models are controlled for individual background factors (sex, birth cohort, birth month, the individual's chronic conditions in childhood per summary, body-fat level in childhood, employment status in adulthood (via a binary variable: 1 for employment throughout the observation year, 0 for unemployed, retired, or otherwise outside the labour force), and education level in adulthood) and family factors (parent education, parent physical-activity level, family income, and family size in 1980).

*** and **: Statistically significant at least at the 1% or 5% level, respectively.

Since the aim of the study was to illustrate the costs as a whole, t individual-level costs presented in Table 5 were translated to the aggregate level. In November 2017, Finland had approximately 2.5 million employed and 190,000 unemployed individuals (Official Statistics of Finland 2020). If we assume that the results in Table 5 were valid also in the aggregate level and that roughly 67% of the employed and unemployed persons in 2017 were physically inactive at age 15, we conclude that roughly 1.68 million employed and 127,000 unemployed people can be classified as having been physically inactive at age 15. At the aggregate level, this entails approximately €1.82 billion (95% CI: €658 million to €3.1 billion) in lost income taxes and €21 billion (95% CI: €4.4 million to 39.2 million) in unemployment benefits paid. These indirect costs are amounts either not received by the government (income taxes) or paid by it (unemployment benefits).

2.4. Sensitivity analysis, with propensity-score-matching estimation

We used propensity-score-matching (PSM) estimator (the Stata/MP 16.0 command 'tteffects psmatch') to estimate the average effect of childhood physical inactivity. The estimators were based on estimating a probit model for the probability of belonging to a lower physical activity group (physically inactive) as opposed to a higher physical activity group (physically active), conditional to individual- and family related control variables: sex, birth cohort, birth month, childhood health, body fat, parent education, parent physical activity level, family income, and family size. Adolescents fell into the lower physical activity group if their PAI was above 10 and into the higher physical activity group otherwise (PAI ≥ 10).

In the PSM results, adolescents categorized as physically inactive created, on average €1,300 less income taxes and €300 more in unemployment-benefit costs per year compared with physically active counterparts (see Table 6). In general, these results suggest higher indirect labour market costs relative to the ordinary least squares (OLS) estimates shown in Table 5. Were these indirect costs calculated from the PSM estimation results rather than OLS results, the aggregate cost of income taxes and unemployment benefits in 2017 would be approximately €2.3 billion (95% CI: €850 million to €3.7 billion) and €41 million (95% CI: €22 million to €59 million), respectively. In total, the aggregate costs with PSM values are €490 million higher (€470 million in lost income tax plus €20 million in unemployment benefits) than the aggregate costs based on OLS results.

Supplementary table 6: Propensity-score-matching estimation results (*n*=2,007)

	Average treatment effect on the treated
	Physically inactive vs. physically active at age 15
Average income taxes	
2005–2012	-1,327.63***
	(425.97)
95% CI	-2,162.51; -492.75
Average unemployment benefits	
2005–2012	308.48***
	(86.99)
95% CI	165.40; 451.56

Note: Robust Abadie–Imbens standard errors are in parentheses. Adolescents were grouped into the lower physical activity group when PAI<10 and into the higher physical activity group otherwise.

*** Statistically significant at least at the 1% level.

There is at least one issue that must be considered while interpreting these PSM results. The physical activity variable (PAI) pertains to adolescents' overall physical activity during leisure time, not, for example, the proportion of children who reached the levels of physical activity recommended for good health, which could serve as a proper cut-off. In our case, however, the range of PAI was from 5 (physically least activite) to 14 (physically most active). The subsamples for each value (5–14) are too small for robust matching analysis, so the cut-off point of 10 was chosen as a rough demarcation of physical activity levels. This means that children with PAI<10 were categorized as physically inactive, and children with PAI ≥10 were categorized as physically active.

3.References

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