Occupational physical activity and longevity in working men and women in Norway: a prospective cohort study

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Summary

Background **Studies suggest that high occupational physical activity increases mortality risk. However, it is unclear whether this association is causal or can be explained by a complex network of socioeconomic and behavioural factors. We aimed to examine the association between occupational physical activity and longevity, taking a complex network of confounding variables into account.**

Methods **In this prospective cohort study, we linked data from Norwegian population-based health examination surveys, covering all parts of Norway with data from the National Population and Housing Censuses and the Norwegian Cause of Death Registry. 437 378 participants (aged 18–65 years; 48·7% men) self-reported occupational physical activity (mutually exclusive groups: sedentary, walking, walking and lifting, and heavy labour) and were followed up from study entry (between February, 1974, and November, 2002) to death or end of follow-up on Dec 31, 2018, whichever came first. We estimated differences in survival time (death from all causes, cardiovascular disease, and cancer) between occupational physical activity categories using flexible parametric survival models adjusted for confounding factors.**

Findings **During a median of 28 years (IQR 25–31) from study entry to the end of follow-up, 74 203 (17·0%) of the participants died (all-cause mortality), of which 20 111 (27·1%) of the deaths were due to cardiovascular disease and 29 886 (40·3%) were due to cancer. Crude modelling indicated shorter mean survival times among men in physically active occupations than in those with sedentary occupations. However, this finding was reversed following adjustment for confounding factors (birth cohort, education, income, ethnicity, prevalent cardiovascular disease, smoking, leisure-time physical activity, body-mass index), with estimates suggesting that men in occupations characterised by walking, walking and lifting, and heavy labour had life expectancies equivalent to 0·4 (95% CI –0·1 to 1·0), 0·8 (0·3 to 1·3), and 1·7 (1·2 to 2·3) years longer, respectively, than men in the sedentary referent category. Results for mortality from cardiovascular disease and cancer showed a similar pattern. No clear differences in survival times were observed between occupational physical activity groups in women.**

Interpretation **Our results suggest that moderate to high occupational physical activity contributes to longevity in men. However, occupational physical activity does not seem to affect longevity in women. These results might inform future physical activity guidelines for public health.**

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Introduction

Seminal work almost 70 years ago suggested lower risks of coronary heart disease and mortality in men with high occupational physical activity than in those with less physically demanding work tasks.[1] In the following decades, technological advances and mechanisation reduced the need for manual labour, and the contribution of energy expenditure from work to total energy expenditure decreased.[2] Subsequently, since the 1990s, research has emphasised examining the association between leisure-time physical activity (LTPA) and health outcomes. Results from large prospective studies done in men, women, ethnically diverse populations, and samples from countries at varying income levels, and adjusted for confounding factors, have consistently shown an inverse dose–response association between physical activity and risk of death.[3] Combined with results from randomised controlled intervention studies,[4] the effect of physical activity on morbidity and longevity is now widely recognised, and its importance is emphasised through national and international guidelines on physical activity, such as those recently revised in the USA (2018) and UK (2019), and by WHO (2020).[5]

However, several studies have challenged whether occupational physical activity actually conveys health benefits, and a meta-analysis suggested an 18% higher risk of all-cause mortality in men with high occupational physical activity than in those with low activity.[6] Although these results might be explained by heterogeneity in the classification of occupational physical activity and residual

Research in context

Evidence before this study

Compelling evidence from a combination of large, prospective cohort studies and randomised controlled trials showed that physical activity might reduce the risks of many non-communicable diseases and premature mortality. We searched PubMed and Google Scholar from database inception to Jan 31, 2020, for articles using the terms "physical activity", "occupation", "mortality", "cardiovascular disease", and "cancer", finding at least 25 studies published over the past decade that questioned whether occupational physical activity conveyed health benefits. A 2018 systematic review and meta-analysis observed that men with high occupational physical activity had an 18% higher risk of all-cause mortality than did men in sedentary occupations, supporting a so-called physical activity paradox. If causal, this finding would have large implications for future physical activity guidelines and work safety regulations. However, it is unclear whether the higher mortality risks observed are caused by high occupational physical activity per se or by a complex network of socioeconomic and behavioural factors associated with occupations involving a high level of physical activity.

Added value of this study

This study extends previous meta-analyses by use of nationally representative, harmonised data on occupational physical activity in 437 378 men and women by examining whether occupational physical activity affects longevity. The large number of cases; long duration of follow-up; linkage to detailed registry data on socioeconomic factors updated during follow-up; and adjustment for smoking by detailed data on smoking status, leisure-time physical activity, and measured anthropometric data allow more robust modelling of the associations between occupational physical activity and longevity.

Implications of all the available evidence

Our results contrast with a so-called physical activity paradox and suggest a positive dose–response relationship between occupational physical activity and longevity in men. This finding might have public health implications suggesting that all activity is beneficial, regardless of domain, and might inform future public health recommendations on physical activity. However, additional research is needed investigating why occupational physical activity appears to be differently associated with longevity between men and women.

confounding from socioeconomic factors (eg, education and income) and socially graded health behaviours (eg, smoking),[7] mechanisms have been hypothesised supporting detrimental associations between occupational physical activity and mortality from cardiovascular disease.[8] However, others argue that there is no compelling biological evidence that LTPA and occupational physical activity have opposite effects on mortality.[9] Therefore, it can be hypothesised that, if the association between physical activity and mortality is truly causal, associations between physical activity from different domains and mortality are similar when confounding is taken into account.[9] Nonetheless, if occupational physical activity per se does increase the risk of premature mortality, this would have implications for public health policy and work safety regulation.

To overcome some of the shortcomings of previous studies, we aimed to estimate the effect of occupational physical activity on longevity using data from a nationally representative sample comprising more than 430 000 Norwegian individuals. Among these individuals, occupational physical activity was assessed by the same instrument and with information on socioeconomic factors, such as education and income, LTPA, and other potentially confounding variables.

Methods

Study design and participants

See Online for appendix

We used data from the Norwegian population-based health examination surveys done between February, 1974, and November, 2002, by the National Health Screening Service (later the Norwegian Institute of Public Health). The surveys covered all parts of Norway and were done with a similar methodological framework,[10–12] which facilitated harmonisation and pooling of data. Data from the health examination surveys were linked to the National Population and Housing Censuses and the Norwegian Cause of Death Registry by use of the participants' unique personal identification number. Permission to be absolved from professional secrecy and linking of the data was granted by the Regional Ethics Committee South-East (2009/605/REK [updated Feb 7, 2019]). The study complies with the Declaration of Helsinki.

We used surveys from The Norwegian Counties Study,[10] with an overall participation rate of 87·7%; the Age 40 programme,[11] with a rate of 73·5%; and the CONOR study,[12] with a rate 58·3% (figure 1). Participants were excluded if they were aged younger than 18 years or older than 65 years at study entry, had missing data on occupational physical activity or confounding variables, participated more than once within or between surveys, or died within 1 month of study entry. For participants with multiple participations within or between surveys, the earliest participation with valid data on occupational physical activity was used.

Exposure assessment

Occupational physical activity was assessed at study entry by the Saltin-Grimby Physical Activity Level Scale with four mutually exclusive options (appendix p 1).[13] Briefly, participants indicated their level of occupational physical activity during the past year from the following: mostly

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sedentary work (eg, desk work or work including assembling of minor parts), work characterised by some walking (eg, light industrial work, non-sedentary office work, inspection, etc), work characterised by walking and lifting (eg, mail delivery and construction work), or work characterised by heavy manual labour (eg, digging and shovelling). All participants responding to the occupational physical activity question were considered to be part of the workforce, including full-time homemakers. For brevity throughout this Article, the four categories are referred to as sedentary, walking, walking and lifting, and heavy labour.

Covariates

Data on education level, income, and ethnicity were obtained from the National Population and Housing Censuses done in 1970, 1980, 1990, and 2001. Highest attained education level between study entry and the last census was categorised into one of five levels corresponding to the current Norwegian standard: (1) basic (≤10 years of education); (2) intermediate 1 (11–12 years of education); (3) intermediate 2 (13–14 years of education); (4) higher education or undergraduate (14–17 years of education); and (5) higher education, graduate, or postgraduate (≥18 years of education). Personal income was categorised into census-specific quintiles (men and women separately), with the highest recorded quintile during follow-up used in statistical modelling. Ethnic background was categorised into Nordic (ie, individuals from Norway, Sweden, Denmark, Finland, Iceland, or Faroe Islands) and non-Nordic (ie, first-generation immigrants without a Nordic background or individuals born in a Nordic country to non-Nordic parents).

Height was measured to the nearest 0·1 cm and weight to the nearest 0·1 kg by trained research nurses, and body-mass index (BMI) was calculated with the standard formula (kg/m²). Data on smoking status (ie, never, former, or current), number of cigarettes smoked daily (ie, currently or in the past), and years of smoking were categorised into smoking grade: (1) never smoked; (2) former smoker with less than 20 pack-years; (3) former smoker with 20 pack-years or more; (4) current daily smoker with less than 20 pack-years; and (5) current daily smoker with 20 pack-years or more.

Self-reported data on history of myocardial infarction, stroke, diabetes, angina pectoris, and use of antihypertensive medications were categorised into prevalent cardiovascular disease categories: no prevalent cardiovascular disease; angina pectoris or hypertension; or myocardial infarction, stroke, or diabetes.

Non-fasting blood samples were collected and analysed for serum cholesterol and triglycerides. In the earlier surveys (1974–85), blood pressure was measured twice with sphygmomanometers and the second recording was selected. From 1985 onwards, three automatic oscillometric measurements (Dinamap; Criticon, Tampa, FL, USA) were taken and the average of the last two available

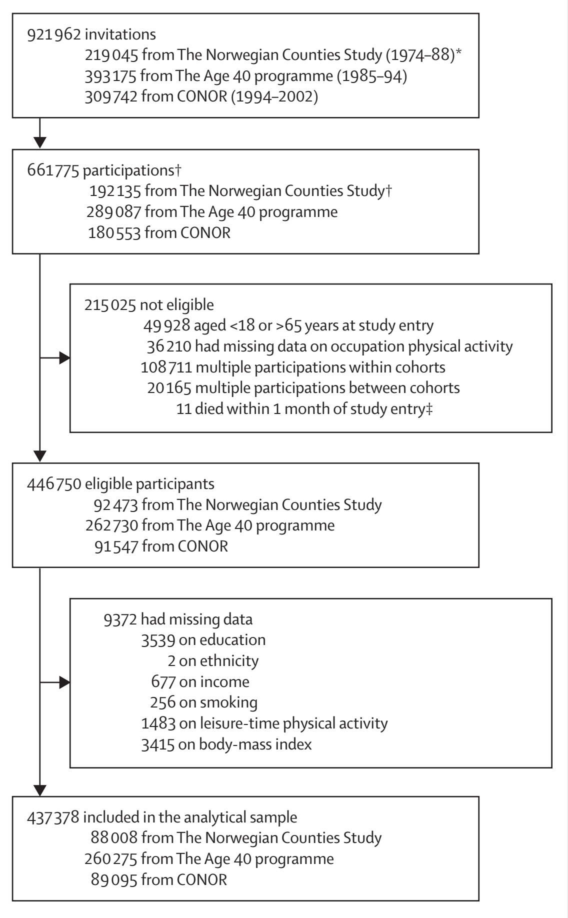


Figure 1: **Study profile**
*In The Norwegian Counties Study, the exact number of individuals invited is unknown; therefore, 921 962 and 219 045 refer to the number of invitations, not individuals invited. 94 034 individuals participated at least once in The Norwegian Counties Study, of which 88 008 met the inclusion criteria for this study. †661 775 and 192 135 refer to the number of participations, not the number of individuals who participated. ‡Due to risk minimisation in data protection, exact age in days at study entry was not available but calculated by subtracting year and month of birth from year and month at study entry (clinical examination). The 11 participants who died within the same month that they entered the study could, therefore, not be included in survival modelling.

measurements were selected. In individuals with automatic blood pressure assessment, resting heart rate was measured sitting down and used as a proxy for cardiorespiratory fitness in sensitivity analyses.

LTPA was assessed by the Saltin-Grimby Physical Activity Level Scale in most participants (348 383 [80%]). Participants indicated their usual level of LTPA during the past year by choosing from the response categories: reading, watching television, or engaging in sedentary activities (ie, sedentary); walking, bicycling, or engaging in other types of physical activity at least 4 h a week (ie, light LTPA); exercising to keep fit and participating in recreational athletics at least 4 h a week (ie, moderate LTPA); or regular, vigorous training or participating in competitive sports several times a week (ie, high LTPA).

For the remaining 20% of participants (88 995), LTPA was assessed by the instrument used in the CONOR study.[14] For the purpose of this study, LTPA for these remaining participants was harmonised into the Saltin-Grimby Physical Activity Level Scale (appendix p 1).

Outcome assessment

Participants were followed up prospectively from study entry (between February, 1974, and November, 2002) until death or end of follow-up on Dec 31, 2018, whichever came first. Data were all-cause mortality, mortality from cardiovascular disease (International Classification of Diseases [ICD]-8 codes 390–444·1, 444·3–458, 782·4; ICD-9 codes 390–459; ICD-10 codes I00–I99), and mortality from cancer (ICD-8 codes 140–209; ICD-9 codes 140–208; ICD-10 codes C00–C97), which were obtained during follow-up from the Norwegian Cause of Death Registry.[15]

Statistical analysis

The significance of differences in background characteristics between participants in the four categories of occupational physical activity was assessed by pairwise comparisons, following simple linear (ie, continuous variables) and logistic (ie, categorical variables) regression analysis.

All associations of occupational physical activity with all-cause and cause-specific mortality were estimated with flexible parametric survival models (stpm2 package for Stata [version 15.0]).[16] Age (months) was used as the timescale and we adjusted all models for birth cohort (1920–29, 1930–39, 1940–49, 1950–59, 1960–69, ≥1970). Because the proportional hazards assumption was violated for several models and because shortcomings of the hazard ratio (HR) are being increasingly recognised,[17] we analysed associations between occupational physical activity and mortality using differences in restricted mean survival time (RMST) with 95% CIs as effect sizes.[18] Time-varying HRs are presented in the appendix (pp 8–10). Because several studies have indicated different associations between occupational physical activity and mortality in men and women,[6] we stratified all analyses by sex.

On the basis of a priori directed acyclic graphs (appendix p 5), analyses were done with several levels of adjustment. Model A (crude model) was adjusted for age (timescale), sex (stratification), and so-called calendar effects (10-year birth cohorts); model B used model A and adjusted for highest attained education and income level by 2002, ethnicity, prevalent cardiovascular disease, and smoking; and model C used model B and adjusted for BMI and LTPA. Both models B and C can be regarded as finally adjusted, depending on whether or not LTPA and BMI are viewed as mediators (ie, model B) or as part of the confounding structure (ie, model C). Total cholesterol, triglycerides, and blood pressure were considered to be mediators (appendix p 5); therefore, these data are presented as background characteristics but are not included in the multivariable-adjusted model. Because BMI and LTPA might be considered as part of the confounding structure for mortality associated with occupational physical activity or as intermediates,[19,20] we present unadjusted and adjusted results as forest plots, but summarise results from model C in the text.

Sensitivity analyses

First, because cardiorespiratory fitness can be considered a confounder (a prerequisite of occupational physical activity and associated with mortality risk[21]), we reanalysed model C with adjustment for resting heart rate as a marker of cardiorespiratory fitness in 412 054 participants (appendix pp 6–7). Second, we investigated potential bias from reverse causation (ie, that diagnosed or undiagnosed subclinical disease leads to changes in occupational physical activity) by restricting model C to participants without known cardiovascular disease (eg, angina pectoris, hypertension, myocardial infarction, stroke, or diabetes) at study entry who survived the first 5 years of follow-up (n=415 549; appendix pp 6–7). Third, younger (aged <30 years) and older participants (aged >50 years) were assumed more likely to change their level of occupational physical activity during follow-up (eg, by completing their education or retiring soon after study entry); therefore, we also restricted the supplementary model 2 (appendix pp 6–7) to include only the 372 832 participants (85·2%) aged 30–50 years at study entry.

Role of the funding source

The funders of the Norwegian population-based health examination surveys had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We included 213 079 men and 224 299 women, with a median age of 41·3 years (IQR 40·3–42·6) at health survey examination (table). 59 565 (13·6%) individuals entered the study between 1974 and 1979, 114 754 (26·2%) during the 1980s, 239 609 (54·8%) during the 1990s, and 23 450 (5·4%) between 2000 and 2002, with approximately equal proportions of men and women across study entry decades. Additional background characteristics by occupational physical activity category and sex can be found in the appendix (p 3).

During a median of 28 years (IQR 25–31) from study entry to the end of follow-up on Dec 31, 2018, 74 203 (17·0%) of the participants died (all-cause mortality); 20 111 (27·1%) of the deaths were due to cardiovascular disease and 29 886 (40·3%) were due to cancer. About two-thirds of all deaths were caused by cardiovascular disease or cancer across occupational physical activity categories in both sexes; however, the proportion of men and women dying from the two causes varied, as did the proportion of people across occupational physical categories.

In men, crude analysis (model A) suggested that higher occupational physical activity was associated with

	Men (n=213 079*)				Women (n=224 299*)			
	Sedentary (n=81 536)	Walking (n=57 374)	Walking and lifting (n=45 629)	Heavy labour (n=28 540)	Sedentary (n=64 420)	Walking (n=113 130)	Walking and lifting (n=42 133)	Heavy labour (n=4616)
Age, years	41·8 (6·2)	41·8 (6·3)	40·8 (6·5)	41·4 (7·1)	41·4 (6·6)	41·4 (6·1)	41·0 (6·5)	42·3 (6·7)
Body-mass index, kg/m²	25·6 (3·2)	25·4 (3·2)	25·5 (3·2)	25·6 (3·2)	24·2 (3·9)	24·3 (4·0)	24·7 (4·1)	25·5 (4·3)
Systolic blood pressure, mm Hg	134·4 (14·3)	134·9 (14·5)	135·1 (14·1)	136·3 (14·9)	124·9 (15·0)	126·9 (15·9)	126·1 (15·4)	130·2 (16·7)
Diastolic blood pressure, mm Hg	81·5 (10·4)	81·4 (10·4)	80·8 (10·4)	81·1 (10·8)	75·8 (10·3)	77·2 (10·5)	76·3 (10·5)	78·5 (10·8)
Resting heart rate, beats per min	68·9 (12·9)	69·8 (12·8)	70·5 (12·6)	69·5 (12·6)	73·2 (12·3)	74·6 (12·7)	73·9 (12·1)	72·8 (12·1)
Cholesterol, mmol/L	5·87 (1·14)	5·88 (1·15)	5·92 (1·19)	6·02 (1·23)	5·51 (1·08)	5·65 (1·13)	5·64 (1·12)	5·90 (1·19)
Triglycerides, mmol/L	2·12 (1·38)	2·11 (1·39)	2·12 (1·40)	2·12 (1·44)	1·31 (0·80)	1·38 (0·84)	1·39 (0·85)	1·48 (0·85)
Current smokers†	29 426 (36·1%)	23 888 (41·6%)	22 760 (49·9%)	13 042 (45·7%)	23 616 (36·7%)	43 846 (38·8%)	18 502 (43·9%)	1602 (34·7%)
Prevalent cardiovascular disease‡	4534 (5·6%)	3156 (5·5%)	2000 (4·4%)	1203 (4·2%)	2442 (3·8%)	4372 (3·9%)	1516 (3·6%)	237 (5·1%)
Non-Nordic ethnicity§	1675 (2·1%)	1440 (2·5%)	932 (2·0%)	263 (0·9%)	1204 (1·9%)	2002 (1·8%)	754 (1·8%)	98 (2·1%)
Education level¶								
≤10 years of education	9339 (11·5%)	10 906 (19·0%)	13 680 (30·0%)	10 381 (36·4%)	7073 (11·0%)	31 376 (27·7%)	10 470 (24·9%)	1669 (36·2%)
11–12 years of education	20 035 (24·6%)	17 727 (30·9%)	16 059 (35·2%)	11 263 (39·5%)	28 384 (44·1%)	43 353 (38·3%)	19 175 (45·5%)	2227 (48·3%)
13–14 years of education	19 541 (24·0%)	14 325 (25·0%)	13 636 (29·9%)	5857 (20·5%)	11 757 (18·3%)	12 375 (10·9%)	5490 (13·0%)	421 (9·1%)
14–17 years of education	20 648 (25·3%)	11 260 (19·6%)	1933 (4·2%)	811 (2·8%)	13 552 (21·0%)	24 075 (21·3%)	6847 (16·3%)	277 (6·0%)
≥18 years of education	11 973 (14·7%)	3156 (5·5%)	321 (0·7%)	228 (0·8%)	3654 (5·7%)	1951 (1·7%)	151 (0·4%)	22 (0·5%)
Income‖								
Level 1	2610 (3·2%)	2261 (3·9%)	2088 (4·6%)	2781 (9·7%)	1851 (2·9%)	7840 (6·9%)	1047 (2·5%)	269 (5·8%)
Level 5	42 596 (52·2%)	18 169 (31·7%)	9534 (20·9%)	5488 (19·2%)	34 722 (53·9%)	35 382 (31·3%)	13 028 (30·9%)	869 (18·8%)
Leisure-time physical activity								
Sedentary	20 829 (25·6%)	10 238 (17·8%)	8924 (19·6%)	6277 (22·0%)	16 647 (25·8%)	22 932 (20·3%)	9126 (21·7%)	1054 (22·8%)
Low	37 368 (45·8%)	29 860 (52·0%)	22 143 (48·5%)	11 624 (40·7%)	37 858 (58·8%)	75 973 (67·2%)	25 122 (59·6%)	2225 (48·2%)
Moderate	19 304 (23·7%)	14 535 (25·3%)	12 407 (27·2%)	8798 (30·8%)	8566 (13·3%)	12 766 (11·3%)	6904 (16·4%)	1207 (26·2%)
High	4035 (5·0%)	2741 (4·8%)	2155 (4·7%)	1841 (6·5%)	1349 (2·1%)	1459 (1·3%)	981 (2·3%)	130 (2·8%)

Data are mean (SD) or n (%). For p values with each variable and activity category, see the appendix (p 2). *Due to missing values, the number of participants varied from 212 866 to 212 889 in men and from 224 086 to 224 245 in women for systolic blood pressure, diastolic blood pressure, cholesterol, and triglycerides, and was 199 754 in men and 212 300 in women for resting heart rate. †Daily smokers with less than 20 pack-years and daily smokers with at least 20 pack-years combined. ‡Angina pectoris, use of antihypertensive medication, diabetes, myocardial infarction, or stroke. §First-generation immigrant without Nordic background or individuals born in a Nordic country (ie, Norway, Sweden, Denmark, Finland, Iceland, or Faroe Islands) to non-Nordic parents. ¶Highest level attained between study entry and Dec 31, 2001. ‖Percentage of participants consistently among the quintile with the lowest income during follow-up (ie, level 1) and among the quintile with the highest income at some point during follow-up (ie, level 5).

***Table:* Baseline characteristics of study participants by sex**

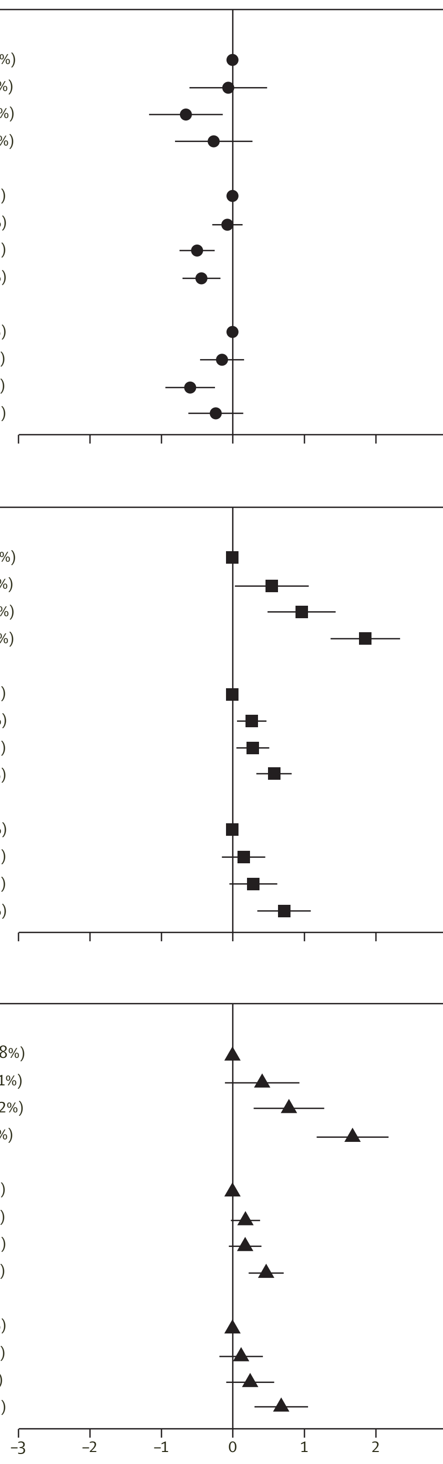
lower life expectancy, especially for mortality from cardiovascular disease. However, the results did not indicate a clear dose–response relationship, with the walking and lifting category having the shortest life expectancy (figure 2A). Results were reversed in models B and C and suggested a positive dose–response relationship; higher occupational physical activity was associated with higher life expectancy. In model C, men in the walking, walking and lifting, and heavy labour categories had life expectancies equivalent to 0·4 (95% CI –0·1 to 1·0), 0·8 (0·3 to 1·3), and 1·7 (1·2 to 2·3) years longer, respectively, than men in the sedentary referent category (figure 2C). Corresponding differences were smaller for cardiovascular disease-specific mortality (0·5 years [0·2 to 0·7]) and cancer-specific mortality (0·7 years [0·3 to 1·1]) when comparing the heavy labour category with the sedentary referent; however, the dose–response patterns were similar to those for all-cause mortality (figure 2C). Although slight attenuations and accentuations of associations from model C were observed in the sensitivity analyses (supplementary models 1–3; appendix pp 6–7), the overall patterns were not materially different.

In women, results from neither crude nor multivariable-adjusted models indicated any clear beneficial or detrimental association between occupational physical activity and mortality (figure 3). In model C, the only estimate with a 95% CI not including unity was found in the walking and lifting group when cardiovascular disease mortality was modelled as the outcome, indicating a shorter life expectancy compared with the sedentary reference group (figure 3C). However, this finding was not robust in sensitivity analyses (appendix p 7).

Time-varying HRs (model C) are shown for men and women in the appendix (pp 8–10).

Discussion

Men in occupations characterised by high physical activity had shorter life expectancies than did men in mainly sedentary occupations. However, after multivariable adjustment including comprehensive information on



A Model A

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	81 536	13 676 (16·8%)	0·0 (ref)
Walking	57 374	11 536 (20·1%)	–0·1 (–0·6 to 0·5)
Walking and lifting	45 629	10 144 (22·2%)	–0·7 (–1·2 to –0·1)
Heavy labour	28 540	7799 (27·3%)	–0·3 (–0·8 to 0·3)
Cardiovascular disease			
Sedentary	81 536	4037 (5·0%)	0·0 (ref)
Walking	57 374	3552 (6·2%)	–0·1 (–0·3 to 0·1)
Walking and lifting	45 629	3054 (6·7%)	–0·5 (–0·8 to –0·3)
Heavy labour	28 540	2617 (9·2%)	–0·5 (–0·7 to –0·2)
Cancer			
Sedentary	81 536	5148 (6·3%)	0·0 (ref)
Walking	57 374	4253 (7·4%)	–0·2 (–0·5 to 0·2)
Walking and lifting	45 629	3711 (8·1%)	–0·6 (–1·0 to –0·3)
Heavy labour	28 540	2625 (9·2%)	–0·2 (–0·6 to 0·2)

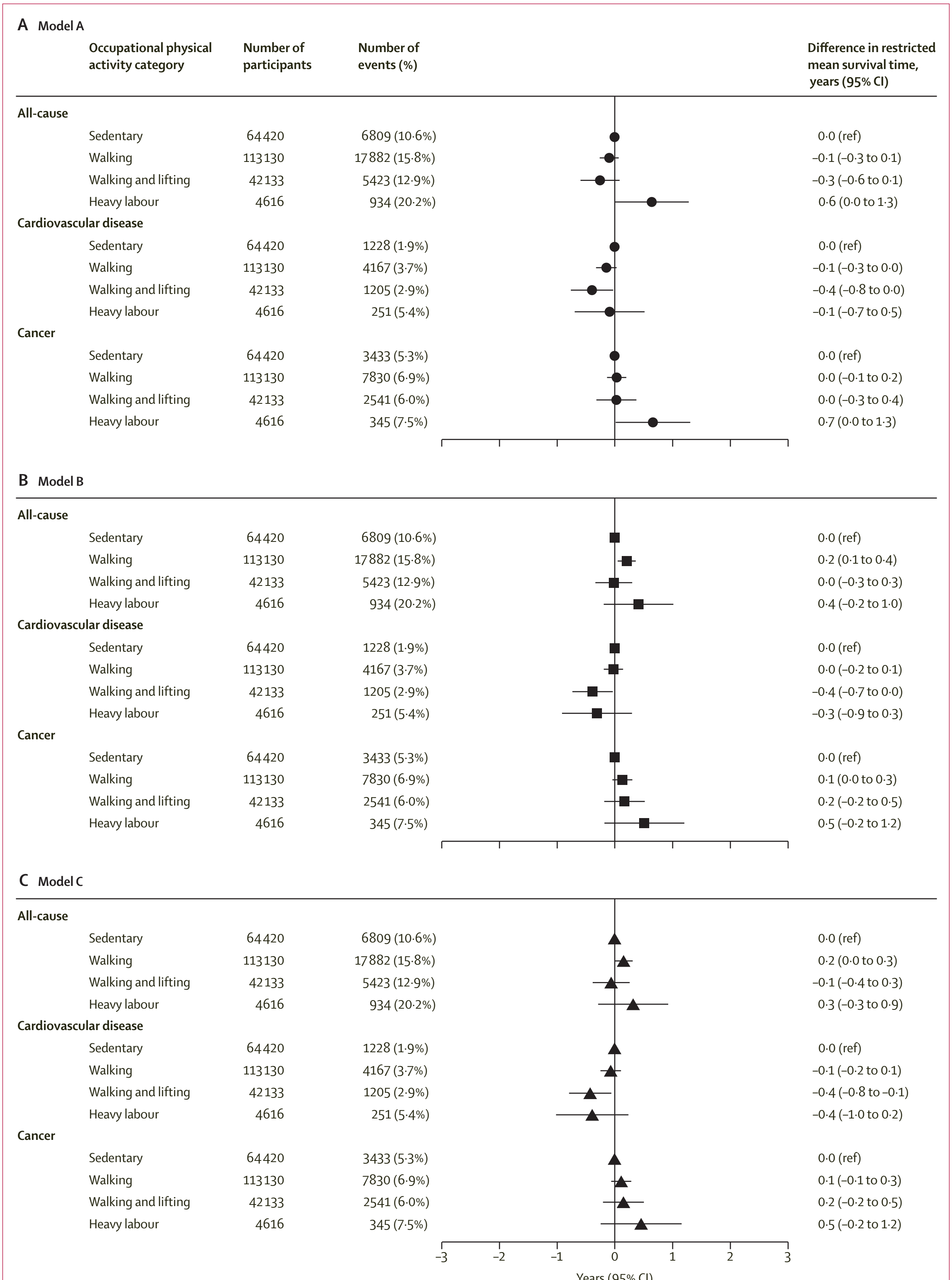
B Model B

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	81 536	13 676 (16·8%)	0·0 (ref)
Walking	57 374	11 536 (20·1%)	0·6 (0·0 to 1·1)
Walking and lifting	45 629	10 144 (22·2%)	1·0 (0·5 to 1·5)
Heavy labour	28 540	7799 (27·3%)	1·9 (1·4 to 2·4)
Cardiovascular disease			
Sedentary	81 536	4037 (5·0%)	0·0 (ref)
Walking	57 374	3552 (6·2%)	0·3 (0·1 to 0·5)
Walking and lifting	45 629	3054 (6·7%)	0·3 (0·1 to 0·5)
Heavy labour	28 540	2617 (9·2%)	0·6 (0·3 to 0·9)
Cancer			
Sedentary	81 536	5148 (6·3%)	0·0 (ref)
Walking	57 374	4253 (7·4%)	0·2 (–0·2 to 0·5)
Walking and lifting	45 629	3711 (8·1%)	0·3 (0·0 to 0·6)
Heavy labour	28 540	2625 (9·2%)	0·7 (0·4 to 1·1)

C Model C

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	81 536	13 676 (16·8%)	0·0 (ref)
Walking	57 374	11 536 (20·1%)	0·4 (–0·1 to 1·0)
Walking and lifting	45 629	10 144 (22·2%)	0·8 (0·3 to 1·3)
Heavy labour	28 540	7799 (27·3%)	1·7 (1·2 to 2·3)
Cardiovascular disease			
Sedentary	81 536	4037 (5·0%)	0·0 (ref)
Walking	57 374	3552 (6·2%)	0·2 (0·0 to 0·4)
Walking and lifting	45 629	3054 (6·7%)	0·2 (–0·1 to 0·4)
Heavy labour	28 540	2617 (9·2%)	0·5 (0·2 to 0·7)
Cancer			
Sedentary	81 536	5148 (6·3%)	0·0 (ref)
Walking	57 374	4253 (7·4%)	0·1 (–0·2 to 0·4)
Walking and lifting	45 629	3711 (8·1%)	0·3 (–0·1 to 0·6)
Heavy labour	28 540	2625 (9·2%)	0·7 (0·3 to 1·1)

***Figure 2:* Prospective associations between occupational physical activity and mortality from all causes, cardiovascular disease, and cancer in men**
(A) Model A was adjusted for age (timescale), sex (stratification), and so-called calendar effects (10-year birth cohorts). (B) Model B used model A and adjusted for highest education level attained between study entry and Dec 31, 2001 (five levels), ethnicity (either Nordic or first-generation immigrant without Nordic background or an individual born in a Nordic country [ie, Norway, Sweden, Denmark, Finland, Iceland, or Faroe Islands] to non-Nordic parents), prevalent cardiovascular disease (no prevalent disease; angina pectoris or hypertension; myocardial infarction, stroke, or diabetes), smoking ([1] never; [2] former and <20 pack-years; [3] former and ≥20 pack-years; [4] current daily and <20 pack-years; and [5] current daily and ≥20 pack-years), and income (highest attained sample quintile by 2002). (C) Model C used model B and adjusted for body-mass index (continuous) and leisure-time physical activity (four levels).



A Model A

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	64420	6809 (10·6%)	0·0 (ref)
Walking	113130	17882 (15·8%)	–0·1 (–0·3 to 0·1)
Walking and lifting	42133	5423 (12·9%)	–0·3 (–0·6 to 0·1)
Heavy labour	4616	934 (20·2%)	0·6 (0·0 to 1·3)
Cardiovascular disease			
Sedentary	64420	1228 (1·9%)	0·0 (ref)
Walking	113130	4167 (3·7%)	–0·1 (–0·3 to 0·0)
Walking and lifting	42133	1205 (2·9%)	–0·4 (–0·8 to 0·0)
Heavy labour	4616	251 (5·4%)	–0·1 (–0·7 to 0·5)
Cancer			
Sedentary	64420	3433 (5·3%)	0·0 (ref)
Walking	113130	7830 (6·9%)	0·0 (–0·1 to 0·2)
Walking and lifting	42133	2541 (6·0%)	0·0 (–0·3 to 0·4)
Heavy labour	4616	345 (7·5%)	0·7 (0·0 to 1·3)

B Model B

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	64420	6809 (10·6%)	0·0 (ref)
Walking	113130	17882 (15·8%)	0·2 (0·1 to 0·4)
Walking and lifting	42133	5423 (12·9%)	0·0 (–0·3 to 0·3)
Heavy labour	4616	934 (20·2%)	0·4 (–0·2 to 1·0)
Cardiovascular disease			
Sedentary	64420	1228 (1·9%)	0·0 (ref)
Walking	113130	4167 (3·7%)	0·0 (–0·2 to 0·1)
Walking and lifting	42133	1205 (2·9%)	–0·4 (–0·7 to 0·0)
Heavy labour	4616	251 (5·4%)	–0·3 (–0·9 to 0·3)
Cancer			
Sedentary	64420	3433 (5·3%)	0·0 (ref)
Walking	113130	7830 (6·9%)	0·1 (0·0 to 0·3)
Walking and lifting	42133	2541 (6·0%)	0·2 (–0·2 to 0·5)
Heavy labour	4616	345 (7·5%)	0·5 (–0·2 to 1·2)

C Model C

Occupational physical activity category	Number of participants	Number of events (%)	Difference in restricted mean survival time, years (95% CI)
All-cause			
Sedentary	64420	6809 (10·6%)	0·0 (ref)
Walking	113130	17882 (15·8%)	0·2 (0·0 to 0·3)
Walking and lifting	42133	5423 (12·9%)	–0·1 (–0·4 to 0·3)
Heavy labour	4616	934 (20·2%)	0·3 (–0·3 to 0·9)
Cardiovascular disease			
Sedentary	64420	1228 (1·9%)	0·0 (ref)
Walking	113130	4167 (3·7%)	–0·1 (–0·2 to 0·1)
Walking and lifting	42133	1205 (2·9%)	–0·4 (–0·8 to –0·1)
Heavy labour	4616	251 (5·4%)	–0·4 (–1·0 to 0·2)
Cancer			
Sedentary	64420	3433 (5·3%)	0·0 (ref)
Walking	113130	7830 (6·9%)	0·1 (–0·1 to 0·3)
Walking and lifting	42133	2541 (6·0%)	0·2 (–0·2 to 0·5)
Heavy labour	4616	345 (7·5%)	0·5 (–0·2 to 1·2)

Figure 3: **Prospective associations between occupational physical activity and mortality from all causes, cardiovascular disease, and cancer in women**
(A) Model A was adjusted for age (timescale), sex (stratification), and so-called calendar effects (10-year birth cohorts). (B) Model B used model A and adjusted for highest education level attained between study entry and Dec 31, 2001 (five levels), ethnicity (either Nordic or first-generation immigrant without Nordic background or an individual born in a Nordic country [ie, Norway, Sweden, Denmark, Finland, Iceland, or Faroe Islands] to non-Nordic parents), prevalent cardiovascular disease (no prevalent disease; angina pectoris or hypertension; myocardial infarction, stroke, or diabetes), smoking ([1] never; [2] former and <20 pack-years; [3] former and ≥20 pack-years; [4] current daily and <20 pack-years; and [5] current daily and ≥20 pack-years), and income (highest attained sample quintile by 2002). (C) Model C used model B and adjusted for body-mass index (continuous) and leisure-time physical activity (four levels).

markers of socioeconomic status and other confounding factors, we found no evidence that high occupational physical activity per se leads to a shorter life expectancy. Instead, our results suggest there might be a positive dose–response relationship between occupational physical activity and longevity in men. This finding was supported in analyses of cause-specific mortality and in sensitivity analyses exploring robustness to reverse causation. By contrast, neither crude nor multivariable-adjusted results indicated an association between occupational physical activity and mortality in women.

In men, our results contrast with a recently indicated so-called physical activity paradox, suggesting detrimental effects of high occupational physical activity on mortality.[6,8] When confounding variables were taken into account, our results indicate that occupational physical activity, like overall physical activity and LTPA, might increase longevity.[3] Therefore, we suggest residual confounding from the complex network of socioeconomic and behavioural factors associated with occupational physical activity as a more plausible explanation for the previously observed higher mortality rate with physical activity during work in men. A meta-analysis examining the association between occupational physical activity and mortality suggested an 18% higher risk of all-cause mortality with high occupational physical activity than with low activity. However, five of the included studies suggested lower mortality, five suggested higher mortality, and six observed no association with higher occupational physical activity.[6] Studies published after this meta-analysis have been equally inconsistent, and an umbrella review prepared for the 2020 WHO Physical Activity Guideline Development Group suggested inverse associations between occupational physical activity and incidence of some cancers, coronary heart disease, and type 2 diabetes, all of which are major contributors to premature mortality.[22] Nevertheless, individuals with high occupational physical activity had higher risk of all-cause mortality than did those with low activity. Additionally, several important limitations of studies investigating the association between occupational physical activity and mortality have been highlighted.[7] Our results add further nuances, extend previous work, and suggest that there is little evidence to support a detrimental effect of occupational physical activity on longevity in men.

Although corroborating previous observations,[6] we can only speculate about the observed differences between men and women in associations between occupational physical activity and longevity. Although less likely, one possible explanation is that doing the same amount of (occupational) physical activity might yield different effects on longevity in men and women.[23] However, it is also possible that men and women perceive the intensity of occupational physical activity differently, and that men and women self-selected into the same occupational physical activity categories were exposed to different physiological effort.[6] Factors associated with occupational physical activity, such as frequency of shift work, might also be involved and warrants further investigation. For example, many Norwegian women are employed in the health sector, usually characterised by walking, lifting, and shift work, which could increase mortality risk.[24] Future studies with device-based assessment of occupational physical activity (possibly located at both upper and lower extremities) and data on type of work and working hours are needed to clarify this theory. Furthermore, sex differences in health-related behaviours after retirement might also contribute to the observed differences and should ideally be adjusted for in future studies. If substantiated, differential effects of occupational physical activity on longevity in men and women might be incorporated into future guidelines. However, because current guidelines are based on all domains of physical activity and total physical activity is strongly associated with longevity with no sex difference,[5] sex-specific guidelines for one domain might be questionable.

Occupational physical activity and LTPA differ quantitatively (eg, duration, frequency, intensity) and qualitatively (eg, mode and domain [context or reason]), even if both can contribute substantially to increase energy expenditure from physical activity. In men, our results might be considered in line with emerging evidence of the association between device-measured physical activity and mortality, indicating that total amount of physical activity, irrespective of intensity, is associated with a substantially reduced risk of premature mortality, at least in middle-aged and older individuals (aged 50–80 years).[25] There is also little evidence to suggest that very high amounts of physical activity are detrimental to health.[26] However, the striking difference between crude and multivariable-adjusted modelling in this study also adds important nuance, and indicates that high physical activity during work might not be enough to offset socioeconomic health inequalities in men, which are strongly correlated with occupational physical activity. Nevertheless, further work is needed to understand if and how the mechanisms through which different types of physical activity act on mortality risk actually differ.[27]

Strengths of our study include the sample covering all parts of Norway, the high participation rate, the large number of cases, and the long duration of follow-up. Thus, the data represent a vast array of different occupations within each occupational physical activity category, allowing for the inclusion of several potentially confounding variables in multivariable adjustment without risk of sparse data bias. The data also allow sensitivity analysis with sufficient power, and examination of dose–response. We adjusted our analyses for socioeconomic status using detailed registry data on education and income, which were updated during follow-up, and for smoking using detailed data on smoking status, number of cigarettes smoked daily (currently or in the past), and years of smoking. Other strengths include mortality data from

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the Norwegian Cause of Death Registry, which has a high degree of completeness (approximately 98% of all deaths in Norway) and validity;[15] validated questionnaires to discriminate levels of occupational physical activity;[28] measured rather than self-reported anthropometric data; and a similar general organisation and methodological framework between the three included health surveys.[10–12] Additionally, we investigated associations between occupational physical activity and mortality by RMST differences. Calculated at the end of follow-up, the RMST difference is easy to understand, has a clear causal interpretation, and is not affected by frailty selection bias.[16] It is increasingly recognised that HRs from Cox proportional hazards models represent a potential threat to causal inference, even in the absence of unmeasured confounding, measurement error, and model misspecification.[16] Accordingly, we urge future studies to complement results from Cox proportional hazards models using alternative outcome measures, such as RMST differences.

Nevertheless, we also highlight various important limitations. First, the results might not be generalisable to other populations. However, it is unlikely that the frequency, intensity, and duration of occupational physical activity differ substantially between Norway and most other high-income countries. Interestingly, similar to our observations in men, results from large cohort studies from low-income and middle-income countries indicate an inverse association between occupational physical activity and mortality.[6,22] The PURE study, which included low-income, middle-income, and high-income countries, also found a similar inverse dose–response association between non-recreational physical activity (eg, occupational, transportation, and housework) and mortality.[29] Second, even though the Saltin-Grimby Physical Activity Level Scale has been shown to rank individuals reasonably well when validated against device-measured physical activity,[28] the true validity of self-reported occupational physical activity is not known because device-measured physical activity is not a gold standard measure of free-living occupational physical activity.[30] Third, repeated assessments of occupational physical activity during follow-up were not available for most (>85%) participants in this study. Thus, we do not know how changing levels of activity during follow-up might have affected the findings. In a subsample of 36 478 people, for which occupational physical activity was assessed three times, 3966 (76%) of 5214 individuals reporting heavy labour at study entry reported either heavy labour (2581 individuals [55%]) or work characterised by a lot of walking and lifting (1115 individuals [21%]) 11 years later. Over the same time period, 479 people (9%) reported a change from heavy manual labour to a sedentary occupation (appendix p 4). Nonetheless, comparing levels of occupational physical activity might be subject to a reverse causation in which individuals with or developing poor health are selected away from physically active occupations over time.[31] Although results from the sensitivity analysis excluding individuals with prevalent cardiovascular disease and the first 5 years of follow-up suggested robust associations (appendix pp 6–7), we were not able to exclude individuals with other prevalent diseases (eg, cancer), and reverse causation might persist. Additionally, we cannot exclude the possibility of healthy worker bias given that, by nature of the study, participants needed to be part of the workforce at study entry to be included. Finally, although we controlled for important putative confounding factors, the study is observational in design and we cannot exclude the risk of residual or unmeasured confounding or other biases. For example, we were not able to consider detailed information on type of work and working conditions, diet quality, sedentary leisure-time behaviour, or alcohol consumption.

Our findings need replication and further elaboration in population-based studies with repeated measures of occupational physical activity using a combination of device-based methods and logs to facilitate more accurate estimates of intensity, duration, and frequency, as well as postures and physical activity breaks. Data showing substantial differences in BMI, cardiorespiratory fitness, and smoking between different working groups at a young age[32] underpin that future cohorts should also be established early, preferably before participants enter the workforce, and that relevant confounders should be measured repeatedly during follow-up. Additionally, other study designs (eg, controlled trials and natural experiments) are needed to increase understanding of the physiological responses and adaptations to different and changing levels of occupational physical activity. Furthermore, our study does not address whether different amounts, types, or both, of LTPA (eg, muscle-strengthening activities) in people with different levels of occupational physical activity could potentially contribute to offset differences in health and mortality outcomes. For example, high levels of occupational physical activity have previously been shown to increase the risk of detrimental musculoskeletal outcomes.[33] Whether these outcomes could be prevented through tailored subgroup-specific guidance is yet to be established. Nevertheless, our results might have important public health implications, suggesting that all activity could increase longevity regardless of domain in men, but not in women. This conclusion might inform future public health recommendations on physical activity. Our results indicate that factors other than the physical activity per se explain why men with high occupational physical activity have shorter life expectancies than men with low occupational physical activity, as observed in previous studies.[6]

In conclusion, our results suggest that moderate to high occupational physical activity contributes to longevity in men; however, occupational physical activity does not seem to affect longevity in women.

Contributors
KED, UE, and PC conceptualised and designed the study. RMS and KED verified, pooled, and linked the data. KED analysed the data with help from JT, RMS, IKHA, and WN. KED and UE wrote the first draft of the report. All other authors assisted in developing the statistical models, reviewed results, provided guidance on methods, and critically reviewed the manuscript. KED takes responsibility for integrity of the data and the data analysis. KED, UE, RMS, WN, and IKHA had full access to all the data and all authors had final responsibility for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Data sharing
The approval from the Ethics Committee does not include permission to make data materials available.

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