Revisiting the ‘physical activity paradox’ in a Chinese context: Occupational physical activity and mortality in 142,302 urban working adults from the China Kadoorie Biobank study

Mengyun Luo,a,b,c Nidhi Gupta,d Andreas Holtermann,d Emmanuel Stamatakis,b,e and Ding Ding a,b*

aSchool of Public Health, Faculty of Medicine and Health, The University of Sydney, Camperdown, NSW, Australia
bCharles Perkins Centre, The University of Sydney, Camperdown, NSW, Australia
cSchool of Public Health, School of Medicine, Shanghai Jiao Tong University, Shanghai, People’s Republic of China
dDepartment of Musculoskeletal Disorders and Physical Workload, The National Research Centre for the Working Environment, Copenhagen, Denmark
eSchool of Health Sciences, Faculty of Medicine and Health, The University of Sydney, Camperdown, NSW, Australia

Summary
Background Previous research suggests that while leisure-time physical activity (LTPA) is beneficial, occupational physical activity (OPA) may be detrimental to health, known as the ‘physical activity paradox’. However, the current evidence is primarily based on data from Western countries. We examined the association of OPA with all-cause and cardiovascular disease mortality in working adults in urban China.

Methods This prospective longitudinal study was based on a sample of 142,302 urban working adults aged 30−79 years from the China Kadoorie Biobank study. Self-reported OPA (mainly sedentary, standing occupation, and manual work) was collected at baseline (year 2004−2008) and linked to death registries until 31st December 2016. Multivariable Cox proportional hazards models were used to examine the relationship between OPA and mortality outcomes, with further tests for effect modification by sex, educational attainment and LTPA.

Findings During a median follow-up of 10.2 years, 4,077 deaths occurred, of which cardiovascular disease was the primary cause for 727 deaths. Crude modelling showed that compared with the sedentary workers, manual work was associated with increased risk of all-cause mortality. However, after adjusting for socio-demographic and lifestyle variables, the association was attenuated to null (HR=1.00, 95%CI: 0.93−1.08). In subgroup analysis, higher OPA was associated with lower risk of all-cause mortality in the least educated group (HR=0.84, 95%CI: 0.75−0.95 for manual work, and HR=0.86, 95%CI: 0.75−0.99 for standing occupation), but harmful in the most educated group (HR=1.17, 95%CI: 1.01−1.36) and in those who reported regular LTPA (HR=1.20, 95%CI: 1.01−1.43).

Interpretation OPA was not associated with mortality risk in the overall sample. However, findings support the ‘physical activity paradox’ within better educated Chinese workers.

Funding None.

Copyright © 2022 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Keywords: Physical activity; Mortality; Epidemiology; China; Low and middle income countries; LMIC

DOI of original article: http://dx.doi.org/10.1016/j.lanwpc.2022.100437

Abbreviations: OPA, Occupational physical activity; LTPA, Leisure-time physical activity; LMICs, Low-to-middle income countries; SG-PALS, Saltin-Grimby Physical Activity Level Scale; BMI, Body mass index; ICD, International Statistical Classification of Diseases; DSP, Disease Surveillance Points; UK, United Kingdom; CVD, Cardiovascular disease; USD, United States Dollars; CNY, Chinese Yuan; IQR, Interquartile range; HR, Hazard ratio; CI, Confidence interval

*Corresponding author at: School of Public Health, Faculty of Medicine and Health, The University of Sydney, Camperdown, NSW, Australia.
E-mail address: melody.ding@sydney.edu.au (D. Ding).
Research in context

Evidence before this study

While the evidence for the protective effects of overall physical activity and leisure-time physical activity on health and longevity is well established, evidence on occupational physical activity (OPA) is inconclusive. Several studies found OPA to be harmful, which has been widely considered as the ‘physical activity paradox’. We reviewed the literature to identify prospective cohort studies that aimed at exploring the association between OPA and mortality risk by using the following terms in PubMed on 30th September 2021: “occupational physical activity”, “mortality”, and “cardiovascular disease”, finding more than 30 studies with conflicting findings. The most recent and comprehensive systematic review and meta-analysis published in 2018 concluded that high levels of OPA were associated with higher risk of all-cause mortality among male workers, but not females. Since then, two more large cohort studies were published but had inconsistent findings. To date, the evidence on OPA and mortality almost all came from high-income countries. Considering the different socioeconomic structures and occupational environment in low- to middle-income countries (LMICs), it is unclear whether the evidence generated from Western samples can be generalized to non-Western LMICs, such as China.

Added value of this study

Our study extends the previous evidence on ‘physical activity paradox’ to a non-Western LMICs setting, by following a population representative sample from urban China for more than 10 years. Our findings suggest that within a LMICs setting, whether OPA is harmful may depend on educational attainment, where high OPA appears harmful in those with higher education and protective in those with lower education. Such novel findings may be partially explained by China’s rapid economic growth and structural shift in the labor market. As one of the first studies on OPA and mortality from a LMICs setting, our study adds unique contribution to the current literature which is dominated by studies from high-income Western countries.

Implications of all the available evidence

In contrast to ‘physical activity paradox’ that was repeatedly observed in Western cohorts, we found that in China, high levels of OPA were not associated with higher or lower mortality risk when socio-demographic and lifestyle confounders were adjusted for. However, our novel findings of effect modification by educational attainment and LTPA highlight the importance of context for OPA research. Considering that OPA accounts for the majority of physical activity in LMICs, and that many of these countries are experiencing mechanization and related transition in the labor structure, it is important to continue to investigate the health effects of OPA within a LMICs context. Such emerging evidence base could inform decision making to ensure the health, wellbeing and longevity of workers in LMICs.

Introduction

Physical activity prevents non-communicable diseases and premature death, and improves mental health, physical function and wellbeing. It is considered as today’s ‘best buy in public health’. However, most studies to date have been based on overall or leisure-time physical activity (LTPA). For most working adults, work constitutes the largest part of their awake hours, and for some workers, particularly those in low- to middle-income countries (LMICs), occupational physical activity (OPA) constitutes a much larger proportion of their total physical activity than LTPA.6,7 However, whether OPA benefits health similarly as LTPA remains inconclusive.7–9

The current evidence on the association between OPA and mortality is mixed. Earlier evidence, as synthesized in a 2011 meta-analysis of 82,412 participants from 6 cohort studies,10 suggested a protective effect of OPA. However, a 2018 meta-analysis of 193,696 participants from 17 cohort studies using similar searching terms concluded the opposite — that high levels of OPA were associated with higher risk of all-cause mortality among male workers.11 Such findings that OPA may be harmful to health in contrast to LTPA have been widely considered as the ‘physical activity paradox’.12 To date, the evidence on OPA and mortality is almost exclusively based on Western samples.11–13 For example, only two of the 33 studies included in the 2018 systematic review and meta-analysis were based on non-Western populations,11 namely from Iran and Taiwan.14,15 Both of the studies were based on small samples selected from specific regions, and they had conflicting findings. Furthermore, considering the different socioeconomic structures and occupational environment in LMICs and the context-specific nature of the existing evidence, whether the evidence generated from Western samples can be generalized to non-Western LMICs, such as China, remains unknown.

In the past few decades, China, the largest manufacturing economy of the world, has experienced rapid economic development and urbanization.16 Technological innovations, mechanization, and the booming e-commerce in China have led to significant shifts in the labor market. For example, the share of ‘routine manual workers’ (e.g., factory and construction workers) declined from 57% in 1990 to 32% in 2015.17 Such changes in employment structure, paired with rapidly increasing educational levels,18,19 have led to a ‘reshuffling’ of jobs, characterized by a more diverse composition of the labor market, where traditional manufacturing jobs coexist with emerging professional, managerial and technical jobs.20 This transition has also led to job loss and under employment, as it has become more challenging for Chinese workers to find jobs compatible with their educational levels.20 Considering this unique transitional situation of the Chinese labor market, which may apply to some other emerging...
economies, it is particularly important to test whether the ‘physical activity paradox’ holds true in China.

In this study, we examined the association between OPA and all-cause and cardiovascular disease (CVD) mortality in 142,302 working adults sampled from geographically diverse urban areas in China. Furthermore, we tested whether the association differed by sex and LTPA, as implied in previous studies, and by educational attainment, considering the impact of the economic transition on the Chinese labor market across socioeconomic spectrum. We hypothesize that, according to the ‘physical activity paradox’, OPA was positively associated with mortality risk in China, and that the association differed by sex, educational attainment and LTPA.

Methods

Study design and participants

Data are from the China Kadoorie Biobank, a large prospective cohort study of 512,891 Chinese adults. Detailed information about the study design and baseline characteristics of the participants has been reported previously. Briefly, between June 2004 and July 2008, adults aged 30–79 years old living in 10 geographically defined areas (5 urban and 5 rural) were invited to participate. The selected urban areas were Qingdao, Harbin, Liuzhou, Suzhou, and Haikou, and rural areas were Sichuan, Zhejiang, Huns, Gansu, and Henan. These areas were strictly selected via China’s nationally representative Disease Surveillance Points (DSP) system to cover a wide range of disease patterns and to maximize socioeconomic diversity rather than to represent the general population in China.

Trained health workers administered a laptop-based questionnaire on demographic, socioeconomic, and lifestyle risk factors (e.g., smoking, alcohol drinking, diet, and physical activity) and measured standing height (using a stadiometer) and body weight (using body mass index [BMI] composition analyzer (TBF-300GS)). Ethical approval was obtained from the China Center for Disease Control and Prevention (Beijing, China, approval number: 005/2004, 9.7.2004) and the Oxford Tropical Research Ethics Committee, University of Oxford (UK, approval number: 025–04, 3.2.2005), and all participants provided written informed consent before participation.

For the current study, we restricted analysis to urban residents because rural residents were asked different OPA questions, which were not comparable with those asked to the urban participants. We further excluded those who were retired or not currently working at baseline, and those with missing data on independent variables or covariates. To minimize the risk of reverse causation (i.e. severe health conditions precede lifestyle change), we further excluded those who reported having the following conditions at baseline: diagnosed coronary heart disease, stroke (including transient ischemic attack), rheumatic heart disease, cancer and continuous pain lasting for ≥3 months. We did not choose the less severe conditions, such as gallstone, arthritis and fracture, because they were less likely to lead to reverse causation. Final analysis included 142,302 urban participants (Figure 1).

Exposure assessment

At baseline (year 2004–2008), an adapted OPA question of the Saltin-Grimby Physical Activity Level Scale (SGPALS) was asked “During the past 12 months, how active were you at work?”. Mutually exclusive response options were “Mainly sedentary (e.g. office worker)”, “Standing occupation (e.g. security guard, shop assistant)”, “Manual worker (e.g. plumber, carpenter)”, and “Heavy manual worker (e.g. miner, construction worker)”. This question has been widely used to measure OPA, and a comparison between this scale and accelerometer measures suggested high validity in ranking of physical activity levels based on SGPALS. Given the small percentage of participants selecting “heavy manual worker” (1.4%), we combined this category with “manual workers”.

Outcome assessment

Study outcomes included all-cause and CVD mortality. In all 10 study regions, the vital status of the participants was ascertained from the DSP death registries and health insurance systems, supplemented by information obtained from neighborhood committees or village administrators. Death data in all 10 study areas were updated annually from baseline until 31st December 2016. Causes of death were coded until 31st December 2016 and were classified using the International Statistical Classification of Diseases (ICD)-10 by trained staff. We used ICD-10 codes 100-199 for CVD death, similarly to previous investigation.

Covariates

We selected covariates from the baseline questionnaire based on an a-priori developed directed acyclic graph (Supplementary Figure 1). These covariates included socio-demographic characteristics, working hours and lifestyle risk factors.

Socio-demographic characteristics included sex (male, female), marital status (married, not married), educational level (primary school or below, middle school, high school or above), and household income (low: <20,000, middle: 20,000–34,999, high: ≥35,000 Chinese Yuan (CNY) per year; 1 CNY= $0.125 USD at the time of the survey). Participants were also asked to report the total number of hours they usually
worked in a typical week, and working hours was handled as a continuous variable.

Lifestyle risk factors included BMI, smoking, alcohol consumption, diet, and LTPA. BMI (kg/m²) was calculated from the objectively measured height and weight using the formula BMI=weight (kg)/height² (m²). We further categorized BMI into “underweight (<18.5)”, “normal (18.5−23.9)”, “overweight (24.0−27.9)”, and “obesity (≥28.0)”, using Chinese-specific cut-off points recommended by Cooperative Meta-analysis Group of China Obesity Task Force.25 Current smoking was defined as having smoked at least 100 cigarettes in one’s lifetime and being a current smoker. Alcohol consumption was measured by asking “During the past 12 months, how often did you drink any alcohol?”. Participants were categorized as currently drinking alcohol “at least weekly” vs “less than weekly”. Fruit intake was measured using the question “During the past 12 months, about how often did you eat fruit?” with response options of “never/rarely”, “monthly”, “1−3 days per week”, “4−6 days per week” and “daily”. Fruit consumption was dichotomized as “0−3 days per week” vs “4+ days per week”. We did not include vegetable intake as a dietary indicator because 97% of the participants chose the highest category of “daily”. LTPA was derived from a validated set of questions regarding different types of LTPA.6,26 Participants were asked about the frequency of performing any activities (examples include Taichi, walking for leisure, ball games, jogging/aerobic exercise, and swimming, and an “Other” option was also provided) in one’s spare time during the past 12 months, with answers including “never or almost never”, “1−3 times/month”, “12 times/week”, “3−5 times/week” and “daily or almost every day”. Considering the very low prevalence of LTPA among the Chinese adults, we dichotomized responses into “no regular LTPA” if a participant responded “never or almost never”, or “1−3 times/month”, and “regular LTPA” if otherwise.

**Statistical analysis**

We presented descriptive statistics of the participants at baseline by providing counts and percentages for categorical variables and median and interquartile range...
(IQR) for continuous variables. We calculated person-years at risk from the baseline to death, loss to follow-up or 31st December 2016, whichever occurred first. We used a multivariable Cox proportional hazards model to estimate the hazard ratio (HR) and 95% confidence interval (CI), with age as the underlying time scale and age at recruitment (ascertained from date of birth) as entry time. The proportional hazards assumption for the Cox model was checked based on the Schoenfeld residuals, and no violation was found (Supplementary Figure 2). Considering that missing data were minimal (n = 2), complete case analysis was used.

To delineate the influence of confounding, we sequentially built four models for each mortality outcome: Model 1 was univariate analysis and accounted for age as the underlying timescale; Model 2 adjusted for sex only; Model 3 additionally adjusted for socio-demographic variables (marital status, educational attainment and household income) and working hours; and Model 4 additionally adjusted for BMI categories, smoking, drinking, fruit consumption, and LTPA.

We tested sex, educational attainment and LTPA as potential effect modifiers graphically (using marginal plots), as well as adding multiplicative interaction terms in Model 4, followed by subgroup analysis. Finally, to reduce the risk of reverse causation, we conducted sensitivity analysis by excluding the first two years of follow-up data as a ‘wash-out’ period (Supplementary Figure 3). Further, we conducted a sensitivity analysis using the Fine-Gray model of competing risk to account for the marginal probability of the ‘sub-distribution’ (those who died from CVD versus from non-CVD causes). We conducted all analyses in R Studio (Version 1.2.5033).

Role of the funding source
No funding sources to report.

Results
Participants in the final analysis were on average 45.9 ± 7.6 years old at baseline. Of the 142,302 participants, 51.8% were men; 94.4% were married; 72.7% had completed at least middle school education. 40.0% were doing sedentary work, 24.3% had a standing occupation, and 35.6% were doing manual work. However, among those with the lowest educational attainment (i.e. primary school or below), both standing occupation and manual work were inversely associated with all-cause mortality (HR: 0.86; 95%CI: 0.75–0.99; HR: 0.84; 95%CI: 0.75–0.93), while the direction of association was the opposite for those with higher educational attainment, where manual work appeared harmful compared with sedentary workers with high school education or above (HR: 1.17; 95%CI: 1.01–1.36). Among those who regularly participated in LTPA, manual workers had higher risks of all-cause mortality (HR: 1.20; 95%CI: 1.01–1.43) than sedentary workers.

Occupational physical activity and mortality risk
During a median follow-up of 10.2 years (1.44 million person-years), 4,077 deaths occurred by 31st December 2016. Of the 3,688 with cause of death coded by 31st December 2014, CVD was the primary/underlying cause for 727 deaths. Table 2 shows the hazard ratios and 95% confidence intervals for the relationship between OPA and all-cause and CVD mortality after adjusting for different covariates sequentially. Compared with sedentary workers, manual workers had a higher risk of all-cause mortality in the crude model (Model 1). However, the association was attenuated once sex was adjusted for (Model 2), and further attenuated to null after other socio-demographic (Model 3) and lifestyle variables (Model 4) were introduced into the model. The association between OPA and CVD mortality was of similar magnitude but not statistically significant in any model as a result of wider confidence intervals.

In model 4, we found significant effect modification by educational attainment ($p = 0.007$ for all-cause mortality and $p = 0.029$ for CVD mortality). Both statistical tests and graphical exploration of interactions involving sex ($p = 0.102$ for all-cause mortality and $p = 0.785$ for CVD mortality), and by LTPA ($p = 0.111$ for all-cause mortality and $p = 0.346$ for CVD mortality) were not significant at 0.05 (Supplementary Figures 4–9). However, considering that the power for detecting significant interactions was generally much lower than that for main effects, we considered meaningful effect modification based on data plots, subgroup analysis and confidence intervals in addition to $p$ values for the interaction terms.

Subgroup analysis
Figures 2 and 3 shows the associations between OPA and mortality outcomes by sex, educational attainment and LTPA based on the covariates adjusted for in Model 4. In most cases, estimates were similar across strata. However, among those with the lowest educational attainment (i.e. primary school or below), both standing occupation and manual work were inversely associated with all-cause mortality (HR: 0.86; 95%CI: 0.75–0.99; HR: 0.84; 95%CI: 0.75–0.93), while the direction of association was the opposite for those with higher educational attainment, where manual work appeared harmful compared with sedentary workers with high school education or above (HR: 1.17; 95%CI: 1.01–1.36). Among those who regularly participated in LTPA, manual workers had higher risks of all-cause mortality (HR: 1.20; 95%CI: 1.01–1.43) than sedentary workers.

Sensitivity analysis
Excluding the first 2 years of follow-up (analytical sample n=141,865); Supplementary Table 1) did not appreciably change the associations between OPA and the two
mortality outcomes (Supplementary Table 2). The results of the subgroup analysis were similar to the main analysis, except that standing occupation was found to be protective against all-cause mortality among females (HR: 0.85; 95% CI: 0.72–1.00), but not among males (Supplementary Figure 10 and Supplementary Figure 11). Furthermore, the magnitude of several previously significant associations in subgroups (i.e., standing occupation and all-cause mortality in those with the lowest education and manual work and all-cause mortality in those with the highest education and those who reported regular LTPA) remained similar but the confidence intervals widened to include 1. There was little difference observed between a conventional Cox proportional hazards model and a Fine-Gray competing risk model (Supplementary Figure 12).

**Discussion**

Based on data from 142,302 urban Chinese workers with a median follow-up of more than 10 years, we found no evidence for OPA being harmful or beneficial in the overall sample. However, the association between OPA and mortality seems to differ by educational attainment and LTPA. High OPA was found to be protective in the least educated group, but harmful in the group with the highest educational levels. In addition, high OPA and mortality outcomes (Supplementary Table 2). The results of the subgroup analysis were similar to the main analysis, except that standing occupation was found to be protective against all-cause mortality among females (HR: 0.85; 95% CI: 0.72–1.00), but not among males (Supplementary Figure 10 and Supplementary Figure 11). Furthermore, the magnitude of several previously significant associations in subgroups (i.e., standing occupation and all-cause mortality in those with the lowest education and manual work and all-cause mortality in those with the highest education and those who reported regular LTPA) remained similar but the confidence intervals widened to include 1. There was little difference observed between a conventional Cox proportional hazards model and a Fine-Gray competing risk model (Supplementary Figure 12).

**Discussion**

Based on data from 142,302 urban Chinese workers with a median follow-up of more than 10 years, we found no evidence for OPA being harmful or beneficial in the overall sample. However, the association between OPA and mortality seems to differ by educational attainment and LTPA. High OPA was found to be protective in the least educated group, but harmful in the group with the highest educational levels. In addition, high OPA was associated with higher risk of all-cause mortality in those who reported regular LTPA.

As compared with LTPA, which has been the most studied physical activity domain with well-established health benefits, \(^1^\) OPA may be less health-enhancing due to its lower intensity, longer durations and insufficient recovery time, which could lead to prolonged

---

### Table 1: Baseline characteristics of the analytical sample by occupational physical activity (year 2004–2008, \(n = 142,302\)).

| Socio-demographic variables | Sedentary work \((n = 56,991)\) | Standing occupation \((n = 34,637)\) | Manual work \((n = 50,674)\) | \(p\)-value |
|----------------------------|-------------------------------|---------------------------------|-----------------|-----------|
| **Sex**                    |                               |                                 |                 |           |
| Male                       | 27,923 (49.0%)                | 15,922 (46.0%)                 | 29,987 (59.0%)  | \(<0.001\) |
| Age group (years)          |                               |                                 |                 |           |
| 30-39                      | 14,932 (26.2%)                | 9012 (26.0%)                   | 10,809 (21.3%)  | \(<0.001\) |
| 40-49                      | 27,316 (47.9%)                | 16,708 (48.2%)                 | 24,019 (47.4%)  | \(<0.001\) |
| 50-59                      | 12,154 (21.3%)                | 7366 (21.3%)                   | 13,258 (26.2%)  | \(<0.001\) |
| \(\geq 60\)                | 2589 (4.5%)                   | 1551 (4.5%)                    | 2588 (5.1%)     | \(<0.001\) |
| Marital status             |                               |                                 |                 |           |
| Married                    | 53,657 (94.1%)                | 32,737 (94.5%)                 | 47,820 (94.4%)  | 0.057     |
| Educational attainment     |                               |                                 |                 |           |
| Primary school or below    | 9180 (16.1%)                  | 9324 (26.9%)                   | 20,406 (40.3%)  | \(<0.001\) |
| Middle school              | 15,488 (27.2%)                | 12,398 (35.8%)                 | 18,729 (37.0%)  | \(<0.001\) |
| High school or above       | 32,323 (56.7%)                | 12,915 (37.3%)                 | 11,539 (22.8%)  | \(<0.001\) |
| Household income (CNY/year)|                               |                                 |                 |           |
| Low (<20,000)              | 14,152 (24.8%)                | 10,575 (30.5%)                 | 16,252 (32.1%)  | \(<0.001\) |
| Middle (20,000-34,999)     | 19,651 (34.5%)                | 12,980 (37.5%)                 | 19,498 (38.5%)  | \(<0.001\) |
| High (\(\geq 35,000\))    | 23,188 (40.7%)                | 11,082 (32.0%)                 | 14,924 (29.5%)  | \(<0.001\) |
| **Lifestyle risk factors** |                               |                                 |                 |           |
| Currently smoking          | 16,731 (29.4%)                | 9874 (28.5%)                   | 20,306 (40.1%)  | \(<0.001\) |
| Currently drinking alcohol at least weekly | 12,680 (22.2%) | 6730 (19.4%) | 13,080 (25.8%) | \(<0.001\) |
| Regular consumption of fruit (\(\geq 4\) days/week) | 28,064 (49.2%) | 14,572 (42.1%) | 15,018 (29.6%) | \(<0.001\) |
| Regular leisure-time physical activity (at least 1-2 times/week) | 15,170 (26.6%) | 6725 (19.4%) | 6361 (12.6%) | \(<0.001\) |
| **Body mass index categories \((\text{kg/m}^2)\)** | | | | |
| Underweight (<18.5)        | 1398 (2.5%)                   | 944 (2.7%)                     | 1401 (2.8%)     | \(<0.001\) |
| Normal (18.5-23.9)         | 27,119 (47.6%)                | 17,502 (50.5%)                 | 26,816 (52.9%)  | \(<0.001\) |
| Overweight (24.0-27.9)     | 21,681 (38.0%)                | 12,584 (36.3%)                 | 17,683 (34.9%)  | \(<0.001\) |
| Obesity (\(\geq 28.0\))   | 6793 (11.9%)                  | 3607 (10.4%)                   | 4774 (9.4%)     | \(<0.001\) |
| Working hours (hours/day)  | 8.0 (8.0–10.0)                | 9.6 (8.0–11.2)                 | 9.6 (8.0–11.2)  | \(<0.001\) |

CNY (Chinese Yuan): 1 CNY = US$1.25 USD at the time of the survey.

IQR: interquartile range.
### Table 2: Associations between occupational physical activity and all-cause and cardiovascular disease mortality (n = 142,302).

| Occupational physical activity | Deaths/n | Model 1 HR (95%CI) | Model 2 HR (95%CI) | Model 3 HR (95%CI) | Model 4 HR (95%CI) |
|-------------------------------|----------|--------------------|--------------------|--------------------|--------------------|
| **All-cause mortality**       |          |                    |                    |                    |                    |
| Sedentary work                | 1,513/56,991 | 1.00 (ref)         | 1.00 (ref)         | 1.00 (ref)         | 1.00 (ref)         |
| Standing occupation           | 935/34,637   | 1.05 (0.96–1.14)   | 1.03 (0.95–1.12)   | 0.99 (0.91–1.07)   | 0.99 (0.91–1.07)   |
| Manual work                   | 1,629/50,674 | 1.15 (1.07–1.24)** | 1.08 (1.01–1.16)*  | 1.02 (0.94–1.10)   | 1.00 (0.93–1.08)   |
| **Cardiovascular disease mortality** |         |                    |                    |                    |                    |
| Sedentary work                | 269/56,991   | 1.00 (ref)         | 1.00 (ref)         | 1.00 (ref)         | 1.00 (ref)         |
| Standing occupation           | 175/34,638   | 1.12 (0.92–1.35)   | 1.08 (0.89–1.30)   | 1.07 (0.88–1.30)   | 1.09 (0.90–1.33)   |
| Manual work                   | 283/50,674   | 1.15 (0.97–1.35)   | 1.06 (0.88–1.22)   | 1.06 (0.89–1.27)   | 1.09 (0.91–1.30)   |

HR: hazard ratio; 95%CI: 95% confidence interval.

Model 1: unadjusted model accounting for age as the underlying timescale;
Model 2: Model 1 + sex;
Model 3: Model 2 + marital status, educational attainment, household income and working hours;
Model 4: Model 3 + lifestyle risk factors: body mass index categories, smoking, drinking, fruit consumption, and leisure-time physical activity.

* \( p < 0.05, ** \( p < 0.01, *** \( p < 0.001.

---

**Figure 2.** Multivariable-adjusted* associations between occupational physical activity and all-cause mortality stratified by sex, educational level and leisure-time physical activity (n = 142,302).

* All the subgroup analysis were based on the fully adjusted models: accounted for age as the underlying timescale and adjusted for sex (except for in sex-stratified analysis), working hours, marital status, educational level (except for in education-stratified analysis), household income, body mass index categories, smoking, drinking, fruit consumption, and leisure-time physical activity (LTPA, except for in LTPA-stratified analysis). The x-axis is plotted on a log scale.
elevated heart rate and increased levels of inflammation.\textsuperscript{7} It is also less volitional, not done for enjoyment or recreation, and potentially placing higher physical demands than LTPA. Several Western studies as well as a study based on a small Taiwanese cohort have found a harmful effect of high OPA on mortality,\textsuperscript{8,14,21,30} hence supporting the ‘physical activity paradox’.\textsuperscript{12} To our knowledge, the current study is one of the first studies to test this paradox in a LMICs setting and our findings support the paradox in some subpopulation but not in the overall sample.

Previous reviews suggested that insufficient adjustment of potential confounders may have contributed to the repeatedly observed ‘physical activity paradox’.\textsuperscript{12} We specifically addressed confounding by entering covariates sequentially in each model. In our study, the positive association between OPA and mortality in the overall sample seemed to attenuate to null by accounting for socioeconomic status and working hours, as manual workers in our sample reported the longest working hours, the lowest socioeconomic status (both in terms of income and education), and the worst lifestyle profile. Our findings highlight the importance of accounting for confounders in exploration of the health effects of OPA. Previous studies repeatedly suggested that the association between OPA and mortality could be sex-specific,\textsuperscript{8,9,13} where OPA appeared to be more harmful in men than women. Findings from our study provided preliminary evidence that in China, standing occupation may be protective against all-cause mortality in female workers when compared with sedentary workers, based on findings from sensitivity analysis. In the early 2000s, many female sedentary workers worked in garment factories, infamous for their long working hours, poor conditions, low wages, and repetitive sedentary work without a break.\textsuperscript{31} In contrast, female workers in standing occupation tended to work in sales and services, which often involved better working conditions and substantial opportunities for incidental physical activity. We speculate that the potential differential mortality risk between those in standing and sedentary jobs may be a result of both physical activity and working conditions. Unfortunately, confirming this potential explanation would require additional data about the participants’ jobs, such as industry, working conditions, and activities performed at work, none of which was collected by the China Kadoorie Biobank study.

A novel finding of our study is the significant effect modification by socioeconomic status. We found high OPA to be protective against all-cause mortality among...
those with the lowest level of educational attainment, while the association pointed in the opposite direction among those with higher educational attainment. One potential explanation is that the reference category (i.e., sedentary workers) may be different across socioeconomic strata. For example, the ‘sedentary workers’ group within the highest educational level primarily includes professional (29%) and managerial staff (26%; Supplementary Table 3) while the sedentary workers group within the lowest educational level is primarily comprised of factory workers (41%) and those who either selected ‘other’ or declined to report on occupation (25%; which may be an indication of a lack of stable jobs). Perhaps as a result, sedentary workers with low education had the highest crude death rate, more than twice as high as the sedentary workers with the highest educational category (Supplementary Table 4). In the last three decades, China has been transitioning out of a manufacture-focused economy towards a more diverse economy, where many of the blue-collar jobs have been replaced by white-collar jobs. While the educational levels of the population have dramatically improved, educational requirement for white-collar jobs has increased over time, forcing some of the former manual workers out of the labor market. This may have acerbated the ‘Healthy Worker Effect’ where those who were older, less fit and with lower educational levels were forced to leave full-time manual work. Conversely, higher educational levels used to guarantee a ‘good’ job, exemplified by the 1990 census statistics that 61% of university graduates occupied managerial and technical jobs, but the proportion declined to less than 30% in 2015. As a result, some university graduates had to move into manual jobs, for which they were over-qualified. In fact, the proportion of university-educated Chinese adults working in manual jobs increased from 9% in 1990 to 14% in 2015. Perhaps, particularly for those with higher educational levels, working in a manual job because of no better options could lead to status loss and poor quality of life, which, according to the literature, may result in ‘deaths of despair’. Our findings underline the importance of long-term monitoring of occupational health, so that we can examine the potential effects of economic, social, and labor market changes on workers’ health and wellbeing. Such evidence should be considered in decision making to avoid any unintended negative consequences of economic development and labor market transition.

Another interesting finding from this study is the interaction between OPA and LTPA. Based on this finding, we speculate that for manual workers who work long hours every day (nearly 10 hours daily for our sample), being active in leisure time may be harmful to health, as a result of continuous strains and no recovery. However, this counterintuitive finding may also be an artifact of different reference categories, as over 63% of the participants who reported regular LTPA had high school education or above, therefore, the reason for which high OPA is harmful in those who reported regular LTPA may be similar to that for the group with the highest education. To date, only a small number of studies examined this interaction between OPA and LTPA and the findings were mixed. For example, while a Danish study found no evidence of interaction, a recent Norwegian study found a significant interaction between OPA and LTPA, where the protective effects of LTPA were only observed in the two lowest OPA categories, but not in participants with the highest level of OPA. Findings from these studies suggest that there may be a risk of ‘doing too much’. While the evidence base is only emerging, future studies should aim to understand the ‘balance’ between strain and recovery within the context of daily physical activity.

This study provides new insights on the relationship between OPA and mortality in a non-Western LMICs context. Based on a large population-representative sample, we examined confounding and effect modification by socio-demographic and lifestyle risk factors and identified new findings, such as the effect modification by socioeconomic status and LTPA. However, results should be interpreted in light of limitations. First, physical activity and occupational characteristics were self-reported, and are therefore subject to reporting bias. Future studies should consider a combination of self-reported and devise-based measures to quantify both the intensity and duration of OPA. Second, measures of important occupational characteristics, such as work-related stress, strains, and other hazards were not measured. Third, OPA was only measured at one time-point, which prevented us from capturing the long-term dynamic patterns of OPA. Finally, findings may not be generalizable to contexts outside of urban China, and future studies should be undertaken to explore the health effects of OPA in rural population.

In a large sample of urban Chinese workers, high levels of OPA were not associated with mortality risk in an overall sample. However, high levels of OPA seemed protective among participants with the lowest levels of education, while harmful in those with the highest levels of education and those who participated in LTPA regularly. These findings seem to support the ‘physical activity paradox’ within the context of the better educated Chinese workers. Considering that OPA accounts for the majority of physical activity in LMICs, and that many of these countries, similar to China, are experiencing mechanization and related transitions in the labor structure, it is important to continue to investigate the health effects of OPA, independent of and interactive with other domains of physical activity. Such emerging evidence base should be considered in decision making to ensure the health, wellbeing and longevity of workers in LMICs.
Data sharing
The data used in this study are available from the China Kadoorie Biobank website with approved access.

Declaration of interests
We declare no competing interests.

Acknowledgments
The authors thank Joseph Van Buskirk for statistical advice during the revision.

Supplementary materials
Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lanwpc.2022.100457.

References
1 World Health Organization. Physical activity fact sheet 2020. https://www.who.int/news-room/fact-sheets/detail/physical-activity
2 Relar AL, Stanton R, Geard D, Short C, Duncan MJ, Vandelanotte V. Physical activity and subjective well-being in healthy individuals: a meta-analytic review. Health Psychol Rev. 2020;15:574–592.
3 Morris JN. Exercise in the prevention of coronary heart disease: today's best buy in public health. Med Sci Sports Exerc. 1994;26:807–814.
4 Luo M, Phongsavan P, Basman A, Negin J, Zhang Z, Ding D. Correlates of domain-specific physical activity among older adults in six low- to middle-income countries: analysis of nationally representative samples from study of global aging and adult health (SAGE) [Wave 1]. J Aging Phys Act. 2020;28:473–493.
5 Du H, Li L, Whitlock G, et al: Patterns and socio-demographic correlates of domain-specific physical activities and their associations with adiposity in the China Kadoorie Biobank study. BMC Public Health. 2014;14:846.
6 Holtermann A. Krause NV, van der Beek AJ, Straker L. The physical activity paradox: six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does. Br J Sports Med. 2018;52:149–150.
7 Holtermann A, Schnohr P, Andersen BA, Marott JL. The physical activity paradox in cardiovascular disease and all-cause mortality: the contemporary Copenhagen General Population Study with 198,046 adults. Eur J Heart J. 2021;42:1499–1511.
8 Dalene KE, Tarp J, Selmer RM, et al: Occupational physical activity and longevity in working men and women in Norway: a prospective cohort study. Lancet Public Health. 2021;6:e86–e91.
9 Samitz G, Egger M, Zwahlen M. Domains of physical activity and all-cause mortality: systematic review and dose-response meta-analysis of cohort studies. Int J Epidemiol. 2011;40:1382–1400.
10 Coen P, Huysmans MA, Holtermann A, et al. Do highly physically active workers die early? A systematic review with meta-analysis of data from 193,696 participants. Br J Sports Med. 2018;52:149–150.
11 Holtermann A, Hansen JV, Burr H, Søgaard K, Søgaard G. The health paradox of occupational and leisure-time physical activity. Br J Sports Med. 2012;46:209–216.
12 Cillekens B, Lang M, van Mechelen W, et al. How does occupational physical activity influence health? An umbrella review of 23 health outcomes across 135 observational studies. Br J Sports Med. 2020;54:1474–1481.
13 Hu GC, Chien KL, Hsieh SF, Chen CY, Tsai WH, Su TC. Occupational versus leisure-time physical activity in reducing cardiovascular risks and mortality among ethnic Chinese adults in Taiwan. Asia Pac J Public Health. 2014;26:604–615.
14 Etemadi A, Almen CC, Kamangar F, et al. Impact of body size and physical activity during adolescence and adult life on overall and cause-specific mortality in a large cohort study from Iran. Eur J Epidemiol. 2014;29:95–109.
15 Song C, Liu Q, Gu S, Wang Q. The impact of China's urbanization on economic growth and pollutant emissions: an empirical study based on input-output analysis. J Clean Prod. 2018;189:1289–1310.
16 Ge P, Sun W, Zhao Z. Employment structure in China from 1990 to 2015. J Econ Behav Organ. 2021;185:168–190.
17 National Bureau of Statistics. China Labour Statistical Yearbook 2002. China Statistics Press; 2002.
18 National Bureau of Statistics. China Labour Statistical Yearbook 2016. China Statistics Press; 2016.
19 Chen Z, Lee L, Chen J, et al. Cohort profile: the Kadoorie study of chronic disease in China (KSCDC). Int J Epidemiol. 2005;34:243–2449.
20 Holtermann A, Marott JL, Jentjes G, et al. Occupational and leisure time physical activity: risk of all-cause mortality and myocardial infarction in the Copenhagen City Heart Study. A prospective cohort study. BMJ Open. 2012;2:e000566.
21 Sagely EH, Hopstock LA, Johannson J, et al. Criterion validity of two physical activity and one sedentary time questionnaire against accelerometry in a large cohort of adults and older adults. BMJ Open Sport Exerc Med. 2020;6:e000661.
22 Grimby G, Börjeson M, Jonssdotter HH, Schnohr P, Thelie DS, Saltin B. The “Saltin-Grimby physical activity level scale” and its application to health research. Scand J Med Sci Sports. 2015;25:119–125.
23 Meng R, Yu C, Liu N, et al. Association of depression with all-cause and cardiovascular disease mortality among adults in China. JAMA Netw Open. 2020;3:e2019243.
24 Gao M, Wei YX, Jia X, et al. [The cut-off points of body mass index and waist circumference for predicting metabolic risk factors in Chinese adults]. Zhonghua Liu Xing Bing Xue Za Zhi. 2010;31:1533–1540.
25 Pang Y, lv J, Kartsouksis C, et al. Association of physical activity with risk of hepatobiliary diseases in China: a prospective cohort study of 0.5 million people. Br J Sports Med. 2021;55:1024–1031.
26 Austin PC, Few LJ, Practical recommendations for reporting Fitten−Gray model analyses for competing risk data. Stat Med. 2017;36:4391–4400.
27 Marshall SW. Power for tests of interaction: effect of raising the type I error rate. Epidemiol Perspect Innov. 2007;4:4.
28 Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54:1439–1462.
29 Holtermann A, Burr H, Hansen JV, Krause NV, Søgaard K, Mortensen OS. Occupational physical activity and mortality among Danish workers. Int Arch Occup Environ Health. 2012;85:305–310.
30 Robertson RD, Di H, Brown D, Dheria R. Working conditions, work outcomes, and policy in Asian developing countries. SSRN Electron J. 2016. https://doi.org/10.2139/ssrn.2582692.
31 Li CY, Sung PC. A review of the healthy worker effect in occupational epidemiology. Occup Med. 1999;49:225–229.
32 Gutin I, Hummer RA. Occupation, employment status, and “despair”-associated mortality risk among working-aged U.S. adults, 1997–2015. Prev Med. 2020;137:106129.
33 Hermansen R, Jacobsen BK, Løchen ML, Mortensen B. Leisure time and occupational physical activity, resting heart rate and mortality in the Arctic region of Norway: the Finnmark Study. Eur J Prev Cardiol. 2019;26:1636–1644.
34 Holtermann A, Bortzmann CI, Hallman DM, Ding D, Damdud D, Gupta N. 24 hour physical behavior balance for better health for all: “the sweet-spot hypothesis. Sports Med Open. 2021;7:18.