Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Association of Leisure-Time Physical Activity With Mortality From Diabetes Among Older Chinese Adults: A Multicity Prospective Cohort Analysis

Xuehua Hu
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Wenqing Ni
Department of Elderly Health Management, Shenzhen Center for Chronic Disease Control (Shenzhen Dermatology Hospital, Shenzhen Institute of Dermatology)

Lin Yang
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Yiding Zhuang
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Yanlong Li
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Lingling Yu
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Fanshu Yan
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Tianyong Wu
Luzhou Center for Disease Control and Prevention

Yicheng Zhang
Zaozhuang Center for Disease Control and Prevention

Lijun Wang
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Maigeng Zhou
National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Peng Yin

yinpengbjh@163.com

National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention

Jian Xu

Department of Elderly Health Management, Shenzhen Center for Chronic Disease Control (Shenzhen Dermatology Hospital, Shenzhen Institute of Dermatology)

Research Article

Keywords: Leisure-time physical activity, exercise frequency, mortality from diabetes, older adults, prospective cohort

Posted Date: November 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11212905/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Physical activity is associated with lower mortality, but whether the frequency of leisure-time physical activity (LTPA) is associated with mortality from diabetes among older adults has not been well characterized. Clarifying this association may inform the interpretation of routinely collected exercise information in community health management in China.

Methods

We conducted a prospective cohort analysis of 1,565,890 Chinese adults aged 65 years or older enrolled between 2017 and 2019 at three study sites (Luzhou, Shenzhen, and Zaozhuang) of the Multi-city Elderly Health Examination Cohort Study (MEHECS). LTPA frequency was categorized as no LTPA, occasional LTPA, LTPA at least once weekly but not daily, and daily LTPA. Participants were followed through December 31, 2024. Cause-specific Cox models estimated hazard ratios (HRs) and 95% confidence intervals (CIs) for mortality from diabetes, with deaths from other causes censored; all-cause mortality was secondary. Models adjusted for demographic, socioeconomic, lifestyle, anthropometric, chronic-disease, and city variables. Fine–Gray regression and restriction to participants with more than 2 years of follow-up were performed as sensitivity analyses; models for mortality from diabetes were additionally repeated after excluding participants with baseline diabetes.

Results

During a median follow-up of 5.06 years (interquartile range, 3.30–6.73 years), 5,584 deaths from diabetes and 185,815 all-cause deaths occurred. Compared with no LTPA, the fully adjusted HRs for mortality from diabetes were 0.86 (95% CI, 0.74–1.01) for occasional LTPA, 0.83 (0.73–0.94) for LTPA at least once weekly but not daily, and 0.67 (0.62–0.72) for daily LTPA. Corresponding HRs for all-cause mortality were 0.85 (0.82–0.87), 0.81 (0.79–0.82), and 0.67 (0.66–0.68). Among participants reporting LTPA, longer session duration and more years of regular LTPA were associated with lower risks of mortality from diabetes and all-cause mortality after adjustment for LTPA frequency. The overall pattern was broadly similar in competing-risk and early-follow-up analyses; daily LTPA remained inversely associated with mortality from diabetes in all sensitivity analyses.

Conclusions

LTPA frequency derived from routinely collected community health-examination data was prospectively associated with lower mortality from diabetes among older Chinese adults, with the most consistent

association observed for daily LTPA. More detailed and repeated activity assessment is needed to clarify the independent contributions of frequency, duration, intensity, and total activity volume.

Background

Diabetes remains a major public health challenge worldwide, with a substantial burden among older adults. In 2024, an estimated 158.3 million adults aged 65–99 years were living with diabetes worldwide, including 47.9 million in China[1]. As populations continue to age, identifying modifiable behaviors associated with mortality among older adults is important for prevention and long-term health management.

Physical activity is an established modifiable behavior associated with lower mortality risk. An umbrella review of older adults and a meta-analysis of individuals with diabetes have reported inverse associations between higher physical activity and all-cause mortality[2][3]. More specifically, a large prospective US cohort reported an inverse association between moderate-to-vigorous physical activity and mortality from diabetes among adults with type 2 diabetes[4]. Research has also moved beyond total activity volume to examine exercise frequency[5][6], weekly activity patterns [7][8], and session duration within such patterns[8], while objective studies have examined daily walking duration in relation to mortality among older adults [9]. In NHANES III, an LTPA score incorporating self-reported frequency and intensity was associated with diabetes-related mortality among US adults [10]. Collectively, these studies suggest that mortality associations may relate not only to the amount of activity performed but also to how activity is accumulated. However, they do not directly address whether broad self-reported LTPA-frequency categories are associated with mortality from diabetes in a general population of older adults.

In China, adults aged 65 years or older are offered annual health management through the National Basic Public Health Service Programme [11]. The standardized elderly health examination form used in the programme includes brief items on physical exercise frequency, duration per session, years of regular exercise, and the main exercise type [11]. These routinely collected data provide an opportunity to examine whether simple indicators of LTPA frequency are associated with subsequent mortality in older adults. Previous health-screening cohorts have shown that simple exercise-frequency measures can distinguish groups with different subsequent risks of all-cause mortality [5][6]. Whether such information is associated with mortality from diabetes among older Chinese adults, however, has not been well characterized.

Therefore, this study examined the prospective association of LTPA frequency, operationalized from routinely collected exercise information, with mortality from diabetes among Chinese adults aged 65 years or older, with all-cause mortality examined as a secondary outcome. Among participants reporting LTPA, duration per exercise session and years of regular exercise were evaluated as secondary exposure characteristics.

Methods

2.1 Study design and participants

The current study used data from Multi-city Elderly Health Examination Cohort Study (MEHECS) which is an ongoing multicenter prospective cohort study in China with yearly data available between 2012 and 2023, aiming to provide a reliable source of Chinese elderly health data and detailed multidimensional information. The present study was a prospective cohort analysis using routinely collected, anonymized data from MEHECS. Details of the study design and methods have been reported previously[12].

The study population included 1,816,029 participants aged ≥ 65 years at enrollment who were enrolled in MEHECS between 2017 and 2023 across three geographically distinct cities in China: Luzhou (Sichuan), Shenzhen (Guangdong), and Zaozhuang (Shandong). These sites span southwestern, southern, and eastern China, providing a multi-city sample from geographically diverse settings. Participants were followed until death or December 31, 2024, whichever occurred first. From this study, we excluded (N = 92,916) participants with missing LTPA data and a further (N = 198,193) participants with incomplete covariate information, yielding a final analytic sample of (N = 1,565,890) eligible participants. The detailed study profile and participant selection process are illustrated in Supplementary Figure.1, whereas the baseline profiles for both included and excluded individuals are summarized in Supplemental Table 1. This study was approved by the Ethics Committee of National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention (No. 202328-02).

2.2 Assessment of leisure-time physical activity

Baseline physical-exercise information was collected during routine health examinations using the physical-exercise items contained in the Health Examination Form specified in the National Basic Public Health Service Standards (Third Edition) [11]. This nationally specified form is routinely used in community health management for older adults and was not developed specifically for the present study. In the present analysis, the recorded physical-exercise items were operationalized as leisure-time physical activity (LTPA).

In the original guidance, physical exercise is defined as voluntary activity undertaken consciously for physical fitness and health, excluding activities required for work or other necessities, such as cycling for commuting or heavy physical work. Examples of exercise types specified in the related health examination materials include walking, brisk walking, jogging, dancing, swimming, tai chi, and table tennis. On the basis of this definition, the recorded physical-exercise information was considered to represent LTPA in the present study.

The Health Examination Form records exercise frequency, duration per exercise session, years of regular exercise, and the main type of exercise. LTPA frequency was the primary exposure and was categorized

according to the original response categories as no LTPA, occasional LTPA (< 1 time/week), LTPA at least once a week but not daily, and daily LTPA, with no LTPA as the reference category.

Duration per exercise session was recorded in minutes, and years of LTPA were recorded as the reported number of years for which participants had maintained regular exercise. Because these exercise items have not been independently validated against objective measures of physical activity and do not assess exercise intensity, the exact number of exercise sessions per week, or total weekly exercise duration, they were treated as routine form-based indicators of self-reported LTPA behaviour rather than quantitative measures of physical activity dose. Accordingly, they were not converted into metabolic equivalent (MET) values or used to determine whether participants met current physical activity guideline recommendations.

2.3 Outcomes

Participants' vital status was ascertained through linkage to the China Population Death Information Registration System using unique resident identification numbers, with follow-up censored at December 31, 2024. The primary outcome was mortality from diabetes, defined as death with diabetes mellitus (International Statistical Classification of Diseases and Related Health Problems, 10th Revision [ICD-10] codes E10–E14) recorded as the underlying cause of death. Deaths from other causes were treated as censored observations in the primary cause-specific Cox analysis of diabetes mortality. All-cause mortality was examined as a secondary outcome and was defined as death from any cause during follow-up. Follow-up time was calculated from the baseline examination date to the date of death or the administrative end of follow-up. Person-years were calculated by dividing follow-up time in days by 365.25.

2.4 Covariates

Covariates were selected a priori based on their potential associations with exercise behavior and mortality and on their availability in the routine health examination data. These included age, sex, educational attainment, marital status, smoking status, alcohol consumption, body mass index (BMI), history or presence of cardiovascular disease, hypertension, diabetes, and study city. Age was categorized as 65–69, 70–74, 75–79, and ≥ 80 years. Educational attainment was classified as primary school or below and above primary school. Marital status was classified as married or other. Smoking status was categorized as never, former, or current smoking, and alcohol consumption as never, former, or current drinking. BMI was categorized as < 18.5, 18.5–23.9, 24.0–27.9, and ≥ 28.0 kg/m² and was included as a categorical covariate in the regression models. Baseline cardiovascular disease, hypertension, and diabetes were defined using the corresponding information available from self-reported medical history and routine examination or laboratory data according to the cohort protocol.

2.5 Statistical analysis

Baseline characteristics were summarized across the four exercise-frequency groups. Continuous variables were described using means and standard deviations or medians and interquartile ranges, as

appropriate, and categorical variables using numbers and percentages. Incidence rates were calculated as the number of deaths divided by accumulated person-years and expressed per 1,000 person-years. Cox proportional hazards regression was used as the primary analytical approach to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for the associations of exercise frequency with diabetes and all-cause mortality. No exercise was used as the reference category. For diabetes mortality, deaths from causes other than diabetes were censored at the date of death; therefore, the estimated HRs represent cause-specific hazard ratios. Four progressively adjusted models were fitted. Model 1 adjusted for age and sex. Model 2 additionally adjusted for educational attainment and marital status. Model 3 further adjusted for smoking status, alcohol consumption, BMI, baseline cardiovascular disease, hypertension, and diabetes. Model 4 additionally adjusted for study city. Estimates from Model 4 were considered the primary results. The proportional hazards assumption was assessed using Schoenfeld residuals. The primary Cox models were used to summarize the overall associations between LTPA frequency and mortality over follow-up.

Potential heterogeneity in the associations between LTPA frequency and mortality was examined according to age, sex, educational attainment, marital status, smoking status, alcohol consumption, BMI category, baseline cardiovascular disease, hypertension, diabetes, and study city. Within each subgroup, Cox models were fitted using the same covariate adjustment strategy as the fully adjusted model, except that the variable defining the subgroup was omitted from the adjustment set.

Overall effect modification was assessed by fitting models with and without the full interaction between LTPA frequency and each subgroup variable and comparing the models using a likelihood ratio test. The resulting global P value for interaction was used to assess whether the overall pattern of association between LTPA frequency and mortality differed across levels of the subgroup variable.

Frequency-specific interaction analyses were additionally performed for occasional LTPA, LTPA at least once a week but not daily, and daily LTPA, each compared with no LTPA. For binary subgroup variables, the corresponding interaction coefficient was tested directly. For subgroup variables with more than two categories, such as age, smoking status, alcohol consumption, and BMI, all interaction coefficients corresponding to a given LTPA-frequency comparison were jointly tested using Wald tests. Global interaction *P* values were considered the primary tests of heterogeneity, whereas frequency-specific interaction *P* values were reported as supplementary analyses.

Sensitivity analyses were conducted to assess the robustness of the primary findings. First, the primary Cox analyses were repeated after excluding participants with ≤ 2 years of follow-up to reduce the potential influence of reverse causation arising from pre-existing poor health or serious illness that may have limited LTPA and increased short-term mortality risk. In addition, Fine–Gray competing-risk regression was performed for mortality from diabetes, with deaths from causes other than diabetes treated as competing events. Subdistribution hazard ratios (*sHRs*) and 95% confidence intervals (*CIs*) were estimated. Because cause-specific Cox and Fine–Gray models characterize different aspects of the event process, HRs and *sHRs* were interpreted separately rather than treated as directly interchangeable

effect estimates. The competing-risk analysis was used to assess whether the direction and overall pattern of the association between LTPA and mortality from diabetes remained similar when competing deaths were taken into account.

All statistical analyses were performed using R software (version4.5.1; R Foundation for Statistical Computing, Vienna, Austria). Two-sided P values < 0.05 were considered statistically significant.

Results

Baseline characteristics according to LTPA frequency are presented in Table 1 and Supplementary Table 1. A total of 1,565,890 participants (mean age, 70.98 years; 53.22% women) were included, of whom 56.89% reported no LTPA and 33.83% reported daily LTPA. Compared with participants reporting no LTPA, those with more frequent LTPA were more likely to have higher educational attainment, be married, and be never smokers, and had a higher proportion with BMI ≥ 24 kg/m². Among participants reporting LTPA, both median session duration and years of LTPA tended to increase with LTPA frequency. Baseline profiles were generally comparable between included and excluded participants (Supplementary Table 1).

Table 1
Baseline characteristics of participants according to leisure-time physical activity frequency

Characteristics	Overall	No LTPA	Occasional LTPA (< 1 time/week)	LTPA ≥ 1 time/week, not daily	Daily LTPA
n	1,565,890	890,885 (56.89)	58,298 (3.72)	86,952 (5.55)	529,755 (33.83)
Age, years (mean (SD))	70.98 (6.11)	71.35 (6.54)	70.57 (5.88)	70.81 (5.68)	70.44 (5.34)
Age group (%)					
65–69 years	901,484 (57.57)	495,779 (55.65)	35,734 (61.3)	50,336 (57.89)	319,635 (60.34)
70–74 years	330,920 (21.13)	184,467 (20.71)	11,441 (19.63)	19,164 (22.04)	115,848 (21.87)
75–79 years	184,608 (11.79)	111,552 (12.52)	5,935 (10.18)	10,157 (11.68)	56,964 (10.75)
≥ 80 years	148,878 (9.51)	99,087 (11.12)	5,188 (8.9)	7,295 (8.39)	37,308 (7.04)
Sex (%)					
Female	833,444 (53.22)	469,492 (52.7)	33,986 (58.3)	48,080 (55.29)	281,886 (53.21)
Male	732,446 (46.78)	421,393 (47.3)	24,312 (41.7)	38,872 (44.71)	247,869 (46.79)
Education (%)					
Primary school or below	1,048,712 (66.97)	726,089 (81.5)	33,182 (56.92)	47,928 (55.12)	241,513 (45.59)
Above primary school	517,178 (33.03)	164,796 (18.5)	25,116 (43.08)	39,024 (44.88)	288,242 (54.41)
Marital status (%)					
Married	1,276,721 (81.53)	664,600 (74.6)	51,279 (87.96)	76,304 (87.75)	484,538 (91.46)
Unmarried	289,169 (18.47)	226,285 (25.4)	7,019 (12.04)	10,648 (12.25)	45,217 (8.54)
Smoking status (%)					

For duration per session and years of LTPA, overall values were calculated among participants reporting any LTPA only.

Characteristics	Overall	No LTPA	Occasional LTPA (< 1 time/week)	LTPA ≥ 1 time/week, not daily	Daily LTPA
Never	1,184,721 (75.66)	653,808 (73.39)	45,452 (77.96)	69,523 (79.96)	415,938 (78.52)
Current	285,947 (18.26)	200,019 (22.45)	8,713 (14.95)	11,483 (13.21)	65,732 (12.41)
Former	95,222 (6.08)	37,058 (4.16)	4,133 (7.09)	5,946 (6.84)	48,085 (9.08)
Alcohol drinking status (%)					
Never	1,242,427 (79.34)	703,367 (78.95)	45,947 (78.81)	71,702 (82.46)	421,411 (79.55)
Current	269,907 (17.24)	160,665 (18.03)	9,969 (17.1)	12,432 (14.3)	86,841 (16.39)
Former	53,556 (3.42)	26,853 (3.01)	2,382 (4.09)	2,818 (3.24)	21,503 (4.06)
BMI group, kg/m2 (%)					
< 18.5	73,494 (4.69)	51,289 (5.76)	2,215 (3.8)	2,975 (3.42)	17,015 (3.21)
18.5–24	823,053 (52.56)	499,832 (56.11)	27,706 (47.52)	42,772 (49.19)	252,743 (47.71)
24–28	517,708 (33.06)	260,020 (29.19)	21,387 (36.69)	32,208 (37.04)	204,093 (38.53)
28+	151,635 (9.68)	79,744 (8.95)	6,990 (11.99)	8,997 (10.35)	55,904 (10.55)
Cardiovascular disease history (%)					
No	1,482,565 (94.68)	844,378 (94.78)	54,664 (93.77)	82,084 (94.4)	501,439 (94.65)
Yes	83,325 (5.32)	46,507 (5.22)	3,634 (6.23)	4,868 (5.6)	28,316 (5.35)
Hypertension (%)					
No	862,330 (55.07)	471,191 (52.89)	32,817 (56.29)	50,444 (58.01)	307,878 (58.12)

For duration per session and years of LTPA, overall values were calculated among participants reporting any LTPA only.

Characteristics	Overall	No LTPA	Occasional LTPA (< 1 time/week)	LTPA ≥ 1 time/week, not daily	Daily LTPA
Yes	703,560 (44.93)	419,694 (47.11)	25,481 (43.71)	36,508 (41.99)	221,877 (41.88)
Diabetes mellitus (%)					
No	1,324,693 (84.6)	760,511 (85.37)	48,488 (83.17)	72,175 (83.01)	443,519 (83.72)
Yes	241,197 (15.4)	130,374 (14.63)	9,810 (16.83)	14,777 (16.99)	86,236 (16.28)
Duration per session, min, median (IQR)	40.00 (30.00)	Not applicable	30.00 (0.00)	30.00 (10.00]	60 (30.00)
Years of LTPA, median (IQR)	3.00 (8.00)	Not applicable	2.00 (4.00)	3.00 (4.00)	4 (9.00)
City (%)					
Luzhou	642,579 (41.04)	509,492 (57.19)	16,487 (28.28)	23,065 (26.53)	93,535 (17.66)
Shenzhen	609,149 (38.9)	118,058 (13.25)	36,533 (62.67)	56,232 (64.67)	398,326 (75.19)
Zaozhuang	314,162 (20.06)	263,335 (29.56)	5,278 (9.05)	7,655 (8.8)	37,894 (7.15)
For duration per session and years of LTPA, overall values were calculated among participants reporting any LTPA only.					

3.1. Association Between LTPA and Mortality

During a median follow-up of 5.06 [IQR: 3.30, 6.73] years[IQR: 3.30, 6.73], 185,815 all-cause deaths and 5,584 deaths from diabetes were identified. Compared with no LTPA, occasional, ≥ 1 time/week but not daily, and daily LTPA were associated with lower all-cause mortality in the fully adjusted model, with *HRs* of 0.85 (95%*CI*, 0.82–0.87), 0.81 (95%*CI*, 0.79–0.82), and 0.67 (95%*CI*, 0.66–0.68), respectively. For mortality from diabetes, the corresponding *HRs* were 0.86 (95%*CI*, 0.74–1.01), 0.83 (95%*CI*, 0.73–0.94), and 0.67 (95%*CI*, 0.62–0.72), respectively. (Table 2).

Table 2
Associations of leisure-time physical activity frequency with all-cause mortality and mortality from diabetes

Outcome	Events / Mean follow up (years)	Mortality rate/ 1,000 person-years	Model 1 HR (95% CI)	Model 2 HR (95% CI)	Model 3 HR (95% CI)	Model 4 HR (95% CI)
All-cause mortality						
No LTPA	140,485 / 5.27	29.95	1.00	1.00	1.00	1.00
Occasional LTPA (< 1 time/week)	4,988 / 4.57	18.71	0.73 (0.71–0.75)	0.82 (0.80–0.84)	0.83 (0.81–0.86)	0.85 (0.82–0.87)
LTPA ≥ 1 time/week, not daily	7,874 / 4.75	19.05	0.72 (0.70–0.73)	0.79 (0.78–0.81)	0.80 (0.79–0.82)	0.81 (0.79–0.82)
Daily LTPA	32,468 / 4.48	13.69	0.55 (0.54–0.55)	0.64 (0.63–0.65)	0.65 (0.64–0.66)	0.67 (0.66–0.68)
Mortality from diabetes						
No LTPA	4,045 / 5.27	0.86	1.00	1.00	1.00	1.00
Occasional LTPA (< 1 time/week)	169 / 4.57	0.63	0.82 (0.71–0.96)	0.90 (0.77–1.05)	0.82 (0.70–0.96)	0.86 (0.74–1.01)
LTPA ≥ 1 time/week, not daily	279 / 4.75	0.68	0.85 (0.76–0.96)	0.93 (0.82–1.05)	0.81 (0.71–0.91)	0.83 (0.73–0.94)
Daily LTPA	1,091 / 4.48	0.46	0.62 (0.58–0.66)	0.69 (0.65–0.75)	0.63 (0.59–0.68)	0.67 (0.62–0.72)

Note: Hazard ratios (HRs) and 95% confidence intervals (CIs) were estimated using Cox regression. No LTPA was the reference category. For mortality from diabetes, cause-specific Cox regression was used; deaths from causes other than diabetes were censored at the date of death. Model 1 was adjusted for age and sex. Model 2 was additionally adjusted for educational attainment and marital status. Model 3 was further adjusted for smoking status, alcohol consumption, BMI category, baseline cardiovascular/cerebrovascular disease, hypertension, and diabetes. Model 4 was additionally adjusted for study city. Abbreviations: CI, confidence interval; HR, hazard ratio; LTPA, leisure-time physical activity.

Among participants reporting LTPA, longer duration per session and more years of LTPA were also associated with lower mortality after additional adjustment for LTPA frequency. Each 10-minute increase in session duration was associated with *HRs* of 0.96 (95%*CI*, 0.95–0.96) for all-cause mortality and 0.95

(95%*CI*, 0.92–0.97) for mortality from diabetes; the corresponding *HRs* per 5-year increase in years of LTPA were 0.97 (95%*CI*, 0.97–0.98) and 0.95 (95%*CI*, 0.91–0.99). (Supplementary Table 2).

3.2. Subgroup analysis

Subgroup analyses for mortality from diabetes showed evidence of interaction with sex, smoking status, BMI, baseline diabetes status, and study city (all *P* for interaction ≤ 0.001), with weaker evidence for age (*P* for interaction = 0.039) and hypertension (*P* for interaction = 0.047). No clear evidence of interaction was observed for education, marital status, alcohol consumption, or baseline cardiovascular/cerebrovascular disease (all *P* for interaction > 0.05).

Frequency-specific interaction tests showed heterogeneity across LTPA frequency categories for sex, BMI, and baseline diabetes status, whereas heterogeneity by smoking status and study city was confined to selected frequency categories. For age and hypertension, the overall interaction appeared to be driven primarily by specific LTPA frequency categories.

Among subgroups showing evidence of interaction, inverse associations were stronger among women than men (for daily LTPA, *HR* 0.58, 95%*CI* 0.52–0.65 in women vs 0.80, 95%*CI* 0.71–0.91 in men). Associations tended to be weaker among current smokers than among never smokers, although frequency-specific evidence of interaction was observed for occasional and daily LTPA but not weekly LTPA; estimates among former smokers were less precise. For baseline diabetes status, differences were more apparent at lower LTPA frequencies, whereas the association with daily LTPA was similar among participants with and without baseline diabetes. For BMI, the interaction pattern was not consistent across LTPA frequency categories. Associations also varied across study cities, with the strongest and most consistent inverse associations in Shenzhen, intermediate associations in Luzhou, and less consistent associations in Zaozhuang. Detailed subgroup-specific estimates are shown in Fig. 1, and global and frequency-specific interaction tests are presented in Supplementary Table S3.

3.3. Sensitivity analysis

Sensitivity analyses showed broadly similar patterns to the primary analysis. Associations with all-cause mortality remained after excluding participants with ≤ 2 years of follow-up or baseline diabetes. For mortality from diabetes, daily LTPA remained inversely associated with mortality in all sensitivity analyses, while associations for occasional and LTPA ≥ 1 time/week but not daily were less consistent, particularly after excluding participants with baseline diabetes. Fine–Gray competing-risk analyses yielded a similar overall pattern. (Table 3).

Table 3
Sensitivity analyses of associations of LTPA frequency with all-cause mortality and mortality from diabetes

Outcome /Analysis / Exposure	**Events / Mean follow-up (years)**	**Mortality rate / 1,000 person-years**	**HR (95% CI)**	***P* value**
Mortality from diabetes				
Follow-up > 2 years				
No LTPA	3,011 / 5.69	0.659	1.00	
Occasional LTPA (< 1 time/week)	118 / 4.86	0.455	0.86 (0.71–1.04)	0.122
LTPA ≥ 1 time/week, not daily	197 / 4.96	0.485	0.81 (0.70–0.94)	0.005
Daily LTPA	834 / 4.62	0.357	0.73 (0.67–0.80)	< 0.001
Excluding baseline diabetes				
No LTPA	1,030 / 5.30	0.255	1.00	
Occasional LTPA (< 1 time/week)	54 / 4.59	0.243	0.93 (0.70–1.24)	0.626
LTPA ≥ 1 time/week, not daily	80 / 4.75	0.234	0.88 (0.69–1.12)	0.305
Daily LTPA	329 / 4.48	0.166	0.66 (0.57–0.78)	< 0.001
Fine-Gray competing-risk analysis				
No LTPA	4,045 / 5.27	0.862	1.00	
Occasional LTPA (< 1 time/week)	169 / 4.57	0.634	0.88 (0.75–1.03)	0.124
LTPA ≥ 1 time/week, not daily	279 / 4.75	0.675	0.86 (0.76–0.98)	0.021
Daily LTPA	1,091 / 4.48	0.46	0.70 (0.65–0.76)	< 0.001
All-cause mortality				

Note: Hazard ratios (*HRs*) and 95% confidence intervals (*CIs*) were estimated using the fully adjusted model (Model 4), with no LTPA as the reference category. Sensitivity analyses excluded participants with ≤ 2 years of follow-up. For mortality from diabetes, cause-specific Cox models censored deaths from causes other than diabetes. Fine–Gray models treated these deaths as competing events and are reported as subdistribution hazard ratios (*sHRs*).

Outcome /Analysis / Exposure	Events / Mean follow-up (years)	Mortality rate / 1,000 person-years	HR (95% CI)	*P* value
Follow-up > 2 years				
No LTPA	104,599 / 5.69	22.898	1.00	
Occasional LTPA (< 1 time/week)	3,550 / 4.86	13.691	0.88 (0.85–0.92)	< 0.001
LTPA ≥ 1 time/week, not daily	5,730 / 4.96	14.105	0.83 (0.81–0.86)	< 0.001
Daily LTPA	23,216 / 4.62	9.931	0.71 (0.69–0.72)	< 0.001

Note: Hazard ratios (*HRs*) and 95% confidence intervals (*CIs*) were estimated using the fully adjusted model (Model 4), with no LTPA as the reference category. Sensitivity analyses excluded participants with ≤ 2 years of follow-up. For mortality from diabetes, cause-specific Cox models censored deaths from causes other than diabetes. Fine–Gray models treated these deaths as competing events and are reported as subdistribution hazard ratios (*sHRs*).

Discussion

In this large prospective cohort of Chinese adults aged 65 years or older, LTPA frequency was associated with mortality from diabetes, with inverse associations most evident among participants reporting LTPA at least once a week and particularly among those reporting daily LTPA. The association with occasional LTPA was less consistent for mortality from diabetes, whereas inverse associations were observed across LTPA frequency categories for all-cause mortality. The overall pattern was generally supported by the sensitivity analyses.

Previous studies have reported inverse associations between exercise or LTPA frequency and mortality among older adults [6][13][14]. In NHANES III, higher LTPA frequency was associated with lower mortality among adults aged 65–79 years and those aged ≥ 80 years [13] Similarly, a prospective cohort study of Japanese adults aged 65–84 years reported inverse associations between the frequency of LTPA and all-cause and cardiovascular mortality[14]. Annual health examination data from older Taipei residents also showed lower all-cause mortality with higher exercise frequency[6][13][14]. These studies focused primarily on all-cause or cardiovascular mortality rather than mortality from diabetes[6][13][14]. Our findings therefore extend this evidence by showing that LTPA frequency operationalized from information routinely recorded during community health examinations was prospectively associated with mortality from diabetes in a general population of Chinese older adults.

Several biological mechanisms may contribute to the observed association. Exercise has been shown to improve glycemic control[15], reduce insulin resistance and improve inflammatory profiles [16], reduce ectopic and visceral adiposity [17], and improve vascular endothelial function [18] in people with type 2 diabetes. With respect to frequency, current ADA guidelines recommend that aerobic activity be spread

over at least 3 days per week, with no more than 2 consecutive days without activity[19]. This recommendation is consistent with evidence that exercise-induced improvements in systemic insulin action are transient, generally lasting approximately 2–72 hours after an exercise bout [20]. At the skeletal-muscle level, exercise stimulates translocation of the glucose transporter GLUT4 to the sarcolemma and T-tubules, thereby facilitating muscle glucose uptake [21]. Taken together, the transient enhancement of insulin action and exercise-stimulated GLUT4 trafficking provide a physiological rationale for the regular repetition of activity. Consistent with this physiological rationale, a recent meta-analysis of 146 controlled exercise studies in older adults identified at least 3 sessions per week as the frequency generally associated with improvements in several metabolic and inflammatory markers, including insulin, HOMA-IR, IL-6, and TNF-α [22]. Together, these physiological and intervention-based findings support the regular repetition of activity across the week and may be relevant to the more consistent inverse associations observed with more frequent LTPA in the present study. However, the frequency thresholds identified in previous intervention studies do not map directly onto the broad LTPA frequency categories used in our study and should not be interpreted as establishing an optimal LTPA frequency or an independent causal effect of frequency itself. Because the present study did not quantify activity intensity or total weekly volume, the observed associations with frequency may reflect frequency per se, greater overall activity exposure, or other correlated characteristics of LTPA. We did not directly evaluate these mechanisms as mediators of the observed association.

As secondary analyses, we further examined session duration and years of LTPA among participants reporting LTPA. Longer session duration and more years of LTPA were associated with lower mortality after additional adjustment for LTPA frequency. In the Mexico City Prospective Study, lower all-cause mortality associated with weekend-warrior and regularly active exercise patterns was mainly observed when exercise sessions lasted at least 30–60 minutes[8]. Among adults aged 65 years or older, however, previous research considering frequency, duration, and intensity as distinct components of LTPA did not find session duration to be independently associated with mortality[23]. Evidence specifically relating self-reported session duration to mortality in older adults therefore remains limited and not entirely consistent, and the present findings should be regarded as supplementary to the primary frequency analysis. Moreover, years of LTPA represented self-reported duration of participation rather than cumulative physical activity exposure. Neither session duration nor years of LTPA should therefore be interpreted as a precise measure of physical activity dose or as defining an optimal level of activity.

Subgroup findings suggest that several participant characteristics may modify the association between LTPA frequency and mortality from diabetes, although the underlying reasons remain uncertain. Baseline diabetes status may mark differences in underlying metabolic risk, clinical management, and health behaviours that could influence the observed association with LTPA. Previous research has reported different exercise-frequency patterns in relation to all-cause mortality among individuals with and without diabetes [5]. In the present study, the similarity of the associations with daily LTPA between participants with and without baseline diabetes, despite greater differences at lower frequencies, further

suggests that any modification by baseline diabetes status may not operate uniformly across the full range of LTPA frequency. However, the mechanisms underlying this pattern were not directly assessed.

Sex showed relatively consistent evidence of interaction. A large prospective study reported greater relative reductions in all-cause and cardiovascular mortality associated with equivalent doses of LTPA in women than in men[24]. Physiological studies also indicate that biological sex may influence metabolic thresholds, fatigability, and acute and chronic responses to equivalent exercise stimuli[25], providing a possible biological basis for sex-specific associations. However, age-stratified analyses by Ji et al. showed that the sex difference was attenuated among participants aged ≥ 60 years[24], limiting the direct comparability of those findings with the present population of adults aged ≥ 65 years. Smoking status showed a less uniform interaction pattern. Tobacco smoking is associated with oxidative stress, chronic inflammation, and endothelial dysfunction[26], which could contribute to the weaker associations observed at some LTPA frequencies among current smokers, although this interpretation remains speculative. Broadly similar sex- and smoking-related patterns were observed for all-cause mortality.

BMI also showed evidence of interaction, but the absence of a clear monotonic pattern across BMI categories argues against interpreting this finding as a simple gradient according to body size. In older adults, BMI may incompletely characterize body composition because aging is accompanied by changes in fat mass and fat distribution[27]; sarcopenic obesity further illustrates how similar BMI values may represent substantially different combinations of adiposity, muscle mass, and physical function[28]. Previous evidence regarding BMI as a modifier of the LTPA–mortality association has also been inconsistent. In the Northern Manhattan Study, inverse associations between LTPA and mortality were more evident among participants with BMI < 30 kg/m²[29], whereas a large pooled analysis of Asian cohorts found no clear modification by BMI[30]. These findings support a cautious interpretation of the BMI interaction observed in the present study rather than a simple inference that LTPA is more strongly associated with mortality at a particular BMI level.

Study city also showed substantial heterogeneity, with the strongest and most consistent inverse associations observed in Shenzhen and less consistent associations in Zaozhuang. Such variation may reflect differences in population composition, lifestyle, environmental exposures, access to health care, or other unmeasured regional characteristics. Because these factors were not comprehensively characterized in the present analyses, the sources of between-city heterogeneity cannot be determined.

By contrast, evidence of interaction by age and hypertension was weaker and was not consistent across LTPA frequency categories. Given their borderline global interaction P values and the absence of adjustment for multiple subgroup comparisons, these findings may be particularly susceptible to chance and should be interpreted cautiously. Baseline cardiovascular or cerebrovascular disease showed no clear evidence of interaction, broadly consistent with Asian cohort evidence showing inverse associations between LTPA and mortality across groups with different baseline comorbidity profiles[30]. Notably, that pooled Asian analysis also found no clear modification of the LTPA–mortality association

by sex, smoking status, or BMI [28], differing from some of the subgroup patterns observed in the present study and further underscoring the need for caution. More generally, the large number of subgroup and frequency-specific interaction tests increases the possibility of chance findings, particularly when interaction patterns are not consistent across exposure categories[31]. The subgroup findings in the present study should therefore be considered exploratory and require confirmation in other populations.

The principal strengths of this study lie in its exposure setting and outcome focus. LTPA frequency was operationalized from information routinely recorded during community health examinations for older adults, allowing us to examine whether a simple behavioural measure already available in routine community health management was prospectively associated with subsequent mortality. In addition, the study focused on mortality from diabetes in a general older population, complementing previous frequency-based studies that mainly examined all-cause or cardiovascular mortality [6][13][14]. The prospective multicity cohort and multiple sensitivity analyses further allowed the consistency of the observed associations to be evaluated across different participant restrictions and analytical approaches.

Several limitations should be considered. First, LTPA was assessed using brief self-reported exercise items from the standardized community health examination[11]. Although these items are part of the National Basic Public Health Service health examination form, they were not independently validated against objective measures of physical activity in the present study. The measure captured broad categories of exercise frequency but did not include activity intensity, the exact number of sessions per week, or total weekly activity volume, and it did not capture physical activity in other domains such as transportation or household activities. Consequently, the LTPA categories should not be interpreted as precise measures of physical activity dose or as indicators of adherence to current physical activity recommendations. Session duration and years of LTPA were also self-reported, and years of LTPA reflected the reported duration of participation rather than cumulative physical activity exposure. Second, the present analyses were primarily based on baseline LTPA and did not incorporate changes in activity during follow-up. Longitudinal studies have shown that LTPA may change as adults age and that physical activity and physical function change dynamically in older populations[32][33]. Future analyses incorporating repeated assessments could therefore provide a more complete characterization of longitudinal LTPA patterns and their associations with mortality. Third, as an observational study, residual confounding and reverse causation cannot be completely excluded. Although the analyses adjusted for a range of demographic, lifestyle, anthropometric, and baseline chronic disease factors and included sensitivity analyses excluding participants with short follow-up, unmeasured or incompletely measured factors may still have influenced the observed associations. Finally, the analyses were restricted to participants with complete information on LTPA and relevant covariates. Complete-case restriction may introduce selection bias when data completeness is related to characteristics relevant to the exposure and outcome[34]. Comparisons of baseline characteristics between included and excluded participants were therefore conducted to help assess this potential source of bias.

In conclusion, this study adds prospective evidence that LTPA frequency operationalized from information routinely recorded during community health examinations is associated with mortality from diabetes in a general population of older adults. More detailed and repeated assessments of LTPA are warranted to clarify how different dimensions and longitudinal patterns of activity relate to mortality from diabetes.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. This study was approved by the Ethics Committee of National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention in November 2023 (Approval No.202328) with a waiver of the requirement for informed consent.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Clinical trial number

Not applicable.

Funding

This study was funded by Noncommunicable Chronic Diseases-National Science and Technology Major Project (grant no. 2024ZD0524800, 2024ZD0524801)

Author Contribution

XH, PY and JX conceptualized and designed the study. XH conducted the data analysis and drafted the initial manuscript. LYang, LYu, FY, TW, JX and YZhang were responsible for data acquisition and management. YZhuang and YL contributed to data analysis and interpretation. LW, MZ and PY critically reviewed and edited the manuscript. All authors have reviewed and approved the final manuscript. PY is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Acknowledgement

The authors thank all participants in the MEHECS study for their valuable contributions. We also gratefully acknowledge the staff at the community health centers, community health stations, and Centers for Disease Control and Prevention across the four cities for their dedicated support with data collection.

Data Availability

The data used in this study are part of the ongoing Multi-city Elderly Health Examination Cohort Study (MEHECS). A long-term goal of MEHECS is to establish an open-access data resource once recruitment and data harmonization are complete. At present, individual-level data cannot be made publicly available due to ongoing data collection and institutional data governance policies.

References

1. Magliano DJ, Boyko EJ, IDF Diabetes Atlas 11th edition Scientific Committee. IDF Diabetes Atlas. 11th ed. Brussels: International Diabetes Federation; 2025.
2. Fukushima N, Kikuchi H, Sato H, Sasai H, Kiyohara K, Sawada SS, et al. Dose-response relationship of physical activity with all-cause mortality among older adults: an umbrella review. J Am Med Dir Assoc. 2024;25(3):417–30. 10.1016/j.jamda.2023.09.028.
3. Sluik D, Buijsse B, Muckelbauer R, Kaaks R, Teucher B, Johnsen NF, et al. Physical activity and mortality in individuals with diabetes mellitus: a prospective study and meta-analysis. Arch Intern Med. 2012;172(17):1285–95. 10.1001/archinternmed.2012.3130.
4. Beltran-Valls MR, Cabanas-Sánchez V, Sadarangani KP, Rodríguez-Artalejo F, Moliner-Urdiales D, Martínez-Gómez D. Physical activity and diabetes mortality in people with type 2 diabetes: a prospective cohort study of 0.5 million US people. Diabetes Metab. 2023;49(1):101410. 10.1016/j.diabet.2022.101410.
5. Shin WY, Lee T, Jeon DH, Kim HC. Diabetes, frequency of exercise, and mortality over 12 years: analysis of the National Health Insurance Service-Health Screening (NHIS-HEALS) database. J Korean Med Sci. 2018;33(8):e60. 10.3346/jkms.2018.33.e60.
6. Lai YJ, Yen YF, Chen LJ, Ku PW, Chen CC, Lin YK. Association of exercise with all-cause mortality in older Taipei residents. Age Ageing. 2020;49(3):382–8. 10.1093/ageing/afz172.
7. O'Donovan G, Lee IM, Hamer M, Stamatakis E. Association of weekend warrior and other leisure time physical activity patterns with risks for all-cause, cardiovascular disease, and cancer mortality. JAMA Intern Med. 2017;177(3):335–42. 10.1001/jamainternmed.2016.8014.
8. O'Donovan G, Petermann-Rocha F, Ferrari G, Lee IM, Hamer M, Stamatakis E, et al. Associations of the weekend warrior physical activity pattern with all-cause, cardiovascular disease and cancer

mortality: the Mexico City Prospective Study. Br J Sports Med. 2024;58(7):359–65. 10.1136/bjsports-2023-107612.

9. Klenk J, Dallmeier D, Denkinger MD, Rapp K, Koenig W, Rothenbacher D, et al. Objectively measured walking duration and sedentary behaviour and four-year mortality in older people. PLoS ONE. 2016;11(4):e0153779. 10.1371/journal.pone.0153779.
10. Boyer WR, Ehrlich SF, Crouter SE, Churilla JR, Fitzhugh EC. Leisure-time aerobic physical activity and the risk of diabetes-related mortality: An analysis of effect modification by race-ethnicity. J Diabetes Complications. 2021;35(1):107763. 10.1016/j.jdiacomp.2020.107763.
11. National Health and Family Planning Commission of the People's Republic of China. National Basic Public Health Service Standards (Third Edition). Beijing: National Health and Family Planning Commission; 2017. [in Chinese].
12. Li Y, Yan F, Yu L, et al. Visual Acuity and Cardiovascular Mortality in 2.52 Million Older Adults in China. J Am Coll Cardiol. 2026;87:2807–23.
13. Brown RE, Riddell MC, Macpherson AK, Canning KL, Kuk JL. The association between frequency of physical activity and mortality risk across the adult age span. J Aging Health. 2013;25(5):803–14. 10.1177/0898264313492823.
14. Ueshima K, Ishikawa-Takata K, Yorifuji T, et al. Physical activity and mortality risk in the Japanese elderly: a cohort study. Am J Prev Med. 2010;38(4):410–8. 10.1016/j.amepre.2009.12.033.
15. Mannucci E, Bonifazi A, Monami M. Comparison between different types of exercise training in patients with type 2 diabetes mellitus: a systematic review and network meta-analysis of randomized controlled trials. Nutr Metab Cardiovasc Dis. 2021;31(7):1985–92. 10.1016/j.numecd.2021.02.030.
16. Hejazi K, Mohammad Rahimi GR, Rosenkranz SK. Effects of exercise training on inflammatory and cardiometabolic risk biomarkers in patients with type 2 diabetes mellitus: a systematic review and meta-analysis of randomized controlled trials. Biol Res Nurs. 2023;25(2):250–66. 10.1177/10998004221132841.
17. Sabag A, Way KL, Keating SE, et al. Exercise and ectopic fat in type 2 diabetes: a systematic review and meta-analysis. Diabetes Metab. 2017;43(3):195–210. 10.1016/j.diabet.2016.12.006.
18. Lee JH, Lee R, Hwang MH, Hamilton MT, Park Y. The effects of exercise on vascular endothelial function in type 2 diabetes: a systematic review and meta-analysis. Diabetol Metab Syndr. 2018;10:15. 10.1186/s13098-018-0316-7.
19. American Diabetes Association Professional Practice Committee for Diabetes. 5. Facilitating positive health behaviors and well-being to improve health outcomes: Standards of Care in Diabetes—2026. Diabetes Care. 2026;49(Suppl 1):S89–S131. 10.2337/dc26-S005
20. Colberg SR, Sigal RJ, Fernhall B, et al. Exercise and type 2 diabetes: the American College of Sports Medicine and the American Diabetes Association: joint position statement. Diabetes Care. 2010;33(12):e147–67. 10.2337/dc10-9990.

21. Richter EA, Bilan PJ, Klip A. A comprehensive view of muscle glucose uptake: regulation by insulin, contractile activity, and exercise. Physiol Rev. 2025;105(3):1867–945. 10.1152/physrev.00033.2024.
22. Sheldon R, Gan A, Tasong J, et al. Exercise-induced inflammatory and metabolic adaptations in ageing: a meta-analytic compendium. Ageing Res Rev. 2026;114:102974. 10.1016/j.arr.2025.102974. . Epub 2025 Dec 3.
23. Lan TY, Chang HY, Tai TY. Relationship between components of leisure physical activity and mortality in Taiwanese older adults. Prev Med. 2006;43(1):36–41. 10.1016/j.ypmed.2006.03.016.
24. Ji H, Gulati M, Huang TY, et al. Sex differences in association of physical activity with all-cause and cardiovascular mortality. J Am Coll Cardiol. 2024;83(8):783–93. 10.1016/j.jacc.2023.12.019.
25. Ansdell P, Thomas K, Hicks KM, Hunter SK, Howatson G, Goodall S. Physiological sex differences affect the integrative response to exercise: acute and chronic implications. Exp Physiol. 2020;105(12):2007–21. 10.1113/EP088548.
26. Hahad O, Kuntic M, Kuntic I, Daiber A, Münzel T. Tobacco smoking and vascular biology and function: evidence from human studies. Pflugers Arch. 2023;475(7):797–805. 10.1007/s00424-023-02805-z.
27. Javed AA, Aljied R, Allison DJ, Anderson LN, Ma J, Raina P. Body mass index and all-cause mortality in older adults: a scoping review of observational studies. Obes Rev. 2020;21(8):e13035. 10.1111/obr.13035.
28. Batsis JA, Villareal DT. Sarcopenic obesity in older adults: aetiology, epidemiology and treatment strategies. Nat Rev Endocrinol. 2018;14(9):513–37. 10.1038/s41574-018-0062-9.
29. Willey JZ, Moon YP, Sherzai A, Cheung YK, Sacco RL, Elkind MSV. Leisure-time physical activity and mortality in a multiethnic prospective cohort study: the Northern Manhattan Study. Ann Epidemiol. 2015;25(7):475–e4792. 10.1016/j.annepidem.2015.04.001.
30. Liu Y, Shu XO, Wen W, et al. Association of leisure-time physical activity with total and cause-specific mortality: a pooled analysis of nearly a half million adults in the Asia Cohort Consortium. Int J Epidemiol. 2018;47(3):771–9. 10.1093/ije/dyy024.
31. Wang R, Lagakos SW, Ware JH, Hunter DJ, Drazen JM. Statistics in medicine—reporting of subgroup analyses in clinical trials. N Engl J Med. 2007;357:2189–94. 10.1056/NEJMsr077003.
32. Shaw BA, Liang J, Krause N, Gallant M, McGeever K. Age differences and social stratification in the long-term trajectories of leisure-time physical activity. J Gerontol B Psychol Sci Soc Sci. 2010;65B(6):756–66. 10.1093/geronb/gbq073.
33. Metti AL, Best JR, Shaaban CE, Ganguli M, Rosano C. Longitudinal changes in physical function and physical activity in older adults. Age Ageing. 2018;47(4):558–64. 10.1093/ageing/afy025.
34. Bonander C, Strömberg U. Methods to handle missing values and missing individuals. Eur J Epidemiol. 2019;34(1):5–7. 10.1007/s10654-018-0461-1.

Figures

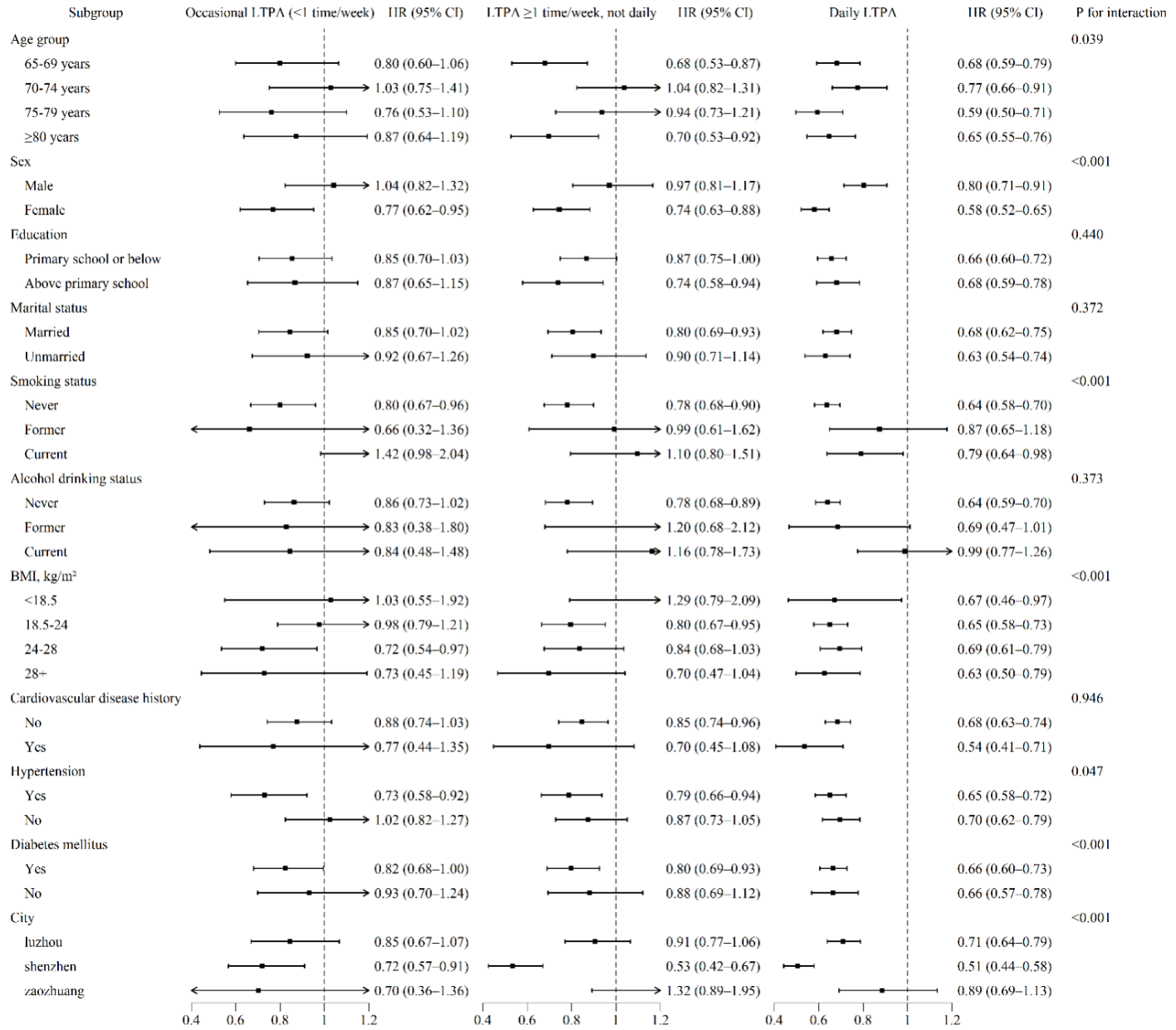


Figure 1

Associations of LTPA frequency with mortality from diabetes across subgroups

Note: Adjusted hazard ratios (*HRs*) and 95% confidence intervals (*CIs)* for mortality from diabetes according to LTPA frequency across participant subgroups. No LTPA was the reference category. Estimates were derived from cause-specific Cox regression models adjusted as specified for the fully adjusted primary model, with the subgroup variable omitted as appropriate. Global *P* values for interaction were obtained from likelihood ratio tests. Frequency-specific interaction tests are presented in Supplementary Table S3.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- 03SupplementalMaterial.docx
- SupplementalFigure2.pdf