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Substituting time spent in physical activity and sedentary time and its association with cardiovascular disease among northwest Chinese adults

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A R T I C L E I N F O

Keywords:
Physical activity
Sedentary behavior
Cardiovascular disease
Isotemporal substitution model
Regional population

A B S T R A C T

Objectives: To examine the association between physical activity (PA) and leisure-time sedentary time and cardiovascular disease (CVD).
Methods: This cross-sectional study used baseline data from the Regional Ethnic Cohort Study in Northwest China from June 2018 to May 2019. PA and leisure-time sedentary time were self-reported. Logistic regression models analyzed the association of PA and leisure-time sedentary time with CVD prevalence individually and jointly. Restricted cubic spline analyses assessed dose-response relationships. Isotemporal substitution models were used to investigate substituting leisure-time sedentary time, light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA) with CVD prevalence.
Results: The prevalence of CVD was 31.8 %. Compared to the lowest quartile, participants in the highest quartile of total PA had a 32 % lower CVD prevalence (odds ratio [OR]: 0.68, 95 % confidence interval [CI]: 0.62–0.74; *P* for trend <0.001). The fully adjusted OR for the highest quartile of leisure-time sedentary time compared to the lowest quartile was 1.09 (1.01–1.18; *P* for trend =0.04). An L-shaped dose-response relationship was observed between PA and CVD prevalence. An active lifestyle and reduced daily leisure-time sedentary time were associated with a 26 % (0.74 [0.63–0.86]) lower CVD prevalence. Additionally, substituting 30 min/day of leisure-time sedentary time with equivalent MVPA was associated with a 2 % (0.98 [0.97–0.99]) reduction in CVD prevalence. Substituting sedentary time with LPA was associated with a lower CVD prevalence in females.
Conclusions: An active lifestyle was associated with a lower prevalence of CVD in regional populations, suggesting a feasible strategy for CVD prevention and regional health promotion.

1. Introduction

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality globally, including in China (Liu et al., 2019). Prior studies reported significant regional variations in CVD risk factors (Li et al., 2020), underscoring the need for prevention strategies tailored to specific geographical areas and lifestyles.

Physical activity (PA) and sedentary behavior are associated with various health conditions in adults (Bull et al., 2020; Lavie et al., 2019). However, PA levels have declined, and sedentary time has increased in China and worldwide in recent decades, mainly due to urbanization, changes in transportation, and lifestyle shifts (Dumith et al., 2011). As a modifiable CVD risk factor, PA patterns and levels vary between countries and within China (Li et al., 2020). Previous studies reported higher levels of PA and lower sedentary time were related to reduced CVD risk (Bennett et al., 2017; Liu et al., 2020), while other studies reported

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inconsistent results (Cao et al., 2022). The 24-h movement behaviors composition paradigm considers that increasing one behavior decreases another, which impacts various health outcomes (Janssen et al., 2020; Rosenberger et al., 2019). Studies indicate that substituting sedentary time with PA in those with ≥5 h/day reduces CVD risk (Liu et al., 2020). Additionally, sex disparities in the association between PA and CVD remain controversial, with some studies reporting a protective effect of PA in males but not in females (Shortreed et al., 2013), while others observe the opposite trend (Bennett et al., 2017; El Saadany et al., 2017). Furthermore, the association between physical activity and health outcomes in urban-rural settings still needs further investigation (Li et al., 2024; Wang et al., 2022). However, limited research has explored these associations in large-scale regional populations with distinctive characteristics (Li et al., 2022).

Therefore, this study aimed to examine: (1) the associations of total PA, light intensity PA (LPA), moderate-to-vigorous PA (MVPA), and leisure-time sedentary time with CVD and its subtypes prevalence; (2) the joint association of total PA levels and leisure-time sedentary time with CVD prevalence; (3) the substitution association of PA and leisure-time sedentary time with CVD prevalence, with subgroup analysis by sex and urban-rural setting.

2. Methods and materials

2.1. Study design and population

This cross-sectional study used data from the baseline study of the subcohort study of the Regional Ethnic Cohort Study in Northwest China, which was conducted in Shaanxi province, one of five targeted provinces in Northwest China. The baseline survey was conducted between June 2018 and May 2019 through face-to-face interviews (Li et al., 2022). All participants provided written informed consent. The study was approved by the Human Research Ethics Committee of the Xi'an Jiaotong University Health Science Center (Approval No: XJTU2016–411). The flow chart of participant selection is shown in **Supplementary Fig. 1**. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline (**Supplementary Table 1**).

2.2. Assessment of PA and leisure-time sedentary time

Time spent in daily PA, including occupational, commuting, household, and sports activities, and leisure-time sedentary time were assessed using a questionnaire. The questionnaire was validated in previously published research (Chen et al., 2011; Du et al., 2013) and the specific questions can be found in **Supplementary Text 1**.

PA intensity was classified by metabolic equivalent task (MET) value, estimated as the energy cost of an activity divided by resting energy expenditure, according to the Compendium of Physical Activities (Ainsworth et al., 2011) (**Supplementary Table 2**). Daily PA categories included vigorous (≥ 6.0 METs), moderate (3.0–5.9 METs), and light (1.5–2.9 METs) intensities (Liu et al., 2020). MVPA was calculated as the sum of time spent on vigorous physical activity (VPA) and moderate physical activity (MPA). Besides, weighted MVPA was defined as the sum of time spent on VPA weighted by two and MPA (Liu et al., 2020). Total PA was the sum of LPA and MVPA, expressed as hours per day (h/day).

2.3. Covariates

Age was calculated from the birth and survey dates. Other sociodemographic variables included sex (male and female), region (urban and rural), household annual income (<¥10,000, ¥10,000-50,000, ¥50,000-100,000, and ≥ ¥100,000), and education (no formal school, primary school, middle school, and college and above). Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters (kg/m^2) (Zhou, 2002). Self-reported alcohol consumption was categorized into never/almost never, occasionally, and usually. Smoking status was self-reported as non-smoker, former smoker, or current smoker. The dietary score was derived from the frequency of intake for five food components, with each component scored as 0 (non-adherence) or 1 (adherence). Adherence corresponds to a higher intake of vegetables (daily), fruits (daily), legumes (≥4 d/week), fish (≥1 d/week), and restricted intake of red meat (<7 d/week) (Zhu et al., 2019). The total diet score thus ranged from 0 to 5. Details for the collection and definition of alcohol consumption, smoking habits, and diet are described in **Supplementary Text 2**. General health status was self-reported and categorized as excellent, good, fair, and poor. Additionally, type 2 diabetes, mental health issues (including depression, anxiety, and others), cancer, emphysema, and kidney disease (Huang et al., 2022; Watts et al., 2022) were also self-reported and classified as present or absent.

2.4. Outcome ascertainment

The primary outcome of this study was CVD, encompassing stroke, ischemic heart disease (IHD), and hypertension, with other CVDs such as pulmonary heart disease and rheumatic heart disease as secondary outcomes. CVD-related outcomes were assessed through the question, "*Has a doctor ever told you that you had had a stroke/IHD (including acute myocardial infarction, angina, and others)/hypertension/pulmonary heart disease/rheumatic heart disease? (yes/no).*" Besides, according to the 2018 Chinese hypertension guidelines, hypertension was defined as having a systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg during the physical examination (Liu, 2020). Participants meeting any of these criteria were classified as having hypertension. Finally, those reporting any of the aforementioned conditions were defined as CVD prevalence.

2.5. Statistical analyses

For baseline characteristics, normally distributed continuous variables were presented as means with standard deviations (SDs), non-normally distributed continuous variables as medians with interquartile ranges (IQRs), and categorical variables as frequencies with percentages.

In this study, PA and leisure-time sedentary time (h/day) were categorized into quartiles, with the lowest quartile serving as the reference category. Logistic regression models were employed to explore the cross-sectional associations between total PA, different PA intensities, leisure-time sedentary time, and CVD prevalence, with results reported as odds ratios (ORs) with 95 % confidence intervals (CIs). Model 1 was crude, and Model 2 adjusted for sociodemographic factors (age, sex, region, household annual income, education). Model 3 additionally included lifestyle-related variables (BMI, alcohol consumption, smoking habits, diet score, general health status), and Model 4 (main analysis) mutually adjusted PA and leisure-time sedentary time based on Model 3. Trend tests were conducted using the median values of PA and leisure-time sedentary time categories as continuous variables in regression (Ba et al., 2021; Lin et al., 2023), and dose-response relationships were assessed by restricted cubic spline analyses. The best-fit model was selected based on the Akaike Information Criteria (AIC), and linearity tested using the Wald test (Desquilbet and Mariotti, 2010). Exposures were also categorized into tertiles, cross-classifying participants into nine categories (PA time hours per day tertiles 1, 2, and 3 × sedentary time hours per day tertiles 1, 2, and 3) to test the joint effect of PA and leisure-time sedentary time. Those participants in the highest group of leisure-time sedentary time and the lowest group of the PA were defined as the most inactive group (reference group).

The isotemporal substitution model (ISM) estimated the effect of replacing one physical activity type with another PA type for the same amount of time, maintaining the total time constant (Mekary et al., 2009). In this model, LPA, MVPA, and total time (the sum of leisure-time sedentary time and the time spent on PA) were included. Total time is constant by dropping the behavior of interest from the model with 30 min/day as a substitution unit. Subgroup analyses were further conducted across sex and region (urban and rural) after testing the interaction of sex and region.

Sensitivity analyses included (1) multiple imputations to test the robustness of the results from missing data (proportions ranged from 0.00 % to 10.37 %). (2) use of weighted MVPA as an alternative calculation method in the main analysis and ISM. (3) adjustments were made for type 2 diabetes, mental health issues, cancer, emphysema, and kidney disease, considering their potential to limit PA and leisure-time sedentary time (Ho et al., 2022).

All analyses were performed using SAS version 9.4 software (SAS Institute Inc., Cary, NC), with figures generated in R software, version 4.3.1. A two-sided $P < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of the study population

Among the participants, 22,793 (60.7 %) were female, with a median age of 51.0 years (IQR 40.0–59.0). The study identified 11,937 cases of CVD (31.8 %). Participant characteristics across total PA quartiles and leisure-time sedentary time quartiles are detailed in Table 1 and Supplementary Table 3. Participants with higher total PA tended to be younger; more often female and urban residents; and less likely to smoke or drink alcohol. They also exhibited lower BMIs, higher education levels, greater household annual income, were more likely to report excellent health status, and had lower prevalence of CVD, type 2 diabetes, cancer, and emphysema. The basic characteristics of participants included in the analysis and those excluded are summarized in Supplementary Table 4.

3.2. The association between PA and leisure-time sedentary time and CVD prevalence

Table 2 illustrates the association of total PA, its categories, and leisure-time sedentary time with CVD prevalence. Compared to the lowest quartile of time spent on total PA, the highest quartile had a 32 % lower CVD prevalence(95 %CI, 0.62–0.74; P_{trend} <0.001). Higher levels of MVPA and LPA per day were also associated with a lower CVD prevalence, with adjusted ORs of 0.66 (95 %CI, 0.60–0.73; P_{trend} <0.001) and 0.84 (95 %CI, 0.74–0.97; P_{trend} = 0.004), respectively. These results remained consistent after further adjustment for related diseases. Conversely, the adjusted OR for the highest quartile of sedentary compared to the lowest was 1.09 (95 %CI, 1.01–1.18; P_{trend} = 0.04). However, this association was not statistically significant after adjusting for related diseases ($OR_{adjusted}$: 1.03; 95 %CI: 0.95–1.12; P_{trend} = 0.57)). Additionally, there was a nonlinear "L" shape association between PA and the prevalence of CVD (*P* for nonlinear relationship <0.001), and a U-shaped relationship between MVPA and CVD prevalence (*P* for nonlinear relationship <0.001). These associations persisted even after adjustments for related diseases. However, the dose-response relationship between leisure-time sedentary time and CVD prevalence was not significant after adjusting for related diseases (Fig. 1).

Using the secondary outcomes (**Supplementary Table 5–8**), participants in the highest quartile of total PA had a lower prevalence of stroke ($OR_{adjusted}$: 0.69; 95 %CI: 0.53–0.91), IHD ($OR_{adjusted}$: 0.72; 95 % CI: 0.57–0.91), and hypertension ($OR_{adjusted}$: 0.71; 95 %CI: 0.66–0.78), respectively. Higher levels of MVPA per day were associated with a lower stroke and hypertension prevalence, while LPA did not show significant results. Conversely, those in the highest quartile of daily leisure-time sedentary time had a 29 % higher stroke prevalence ($OR_{adjusted}$: 1.29; 95 %CI: 1.02–1.63) and a 12 % higher hypertension prevalence ($OR_{adjusted}$:1.12; 95 %CI: 1.03–1.21). Joint analysis indicated that the highest tertile of total PA combined with the lowest tertile of sedentary was associated with a 26 % lower CVD prevalence ($OR_{adjusted}$:0.74; 95 %CI: 0.63–0.86; *P* for interaction =0.07) compared to the reference group (Fig. 2). Sensitivity analysis confirmed these findings (Supplementary Table 9).

Table 1
Basic characteristics of the study population among Northwest China adults by quartiles of totle physical hours per day from 2018 to 2019 (n = 37,493).

Characteristics	Total physical activity (h/day)			
	<4.0	4.0–8.4	8.4–11.2	≥11.2
	(n = 8404)	(n = 10315)	(n = 9593)	(n = 9181)
Median (IQR)				
Age, year	56.0 (50.0–64.0)	56.0 (49.0–62.0)	45.0 (34.0–54.0)	42.0 (33.0–52.0)
BMI, kg/m^2	23.7 (21.6–25.9)	23.8 (21.6–26.0)	23.5 (21.4–25.9)	23.5 (21.3–25.8)
Diet score	2.0 (1.0–2.0)	2.0 (1.0–3.0)	2.0 (1.0–3.0)	2.0 (1.0–3.0)
***n* (%)**				
Sex				
Male	3120 (37.1)	3069 (29.8)	4624 (48.2)	3908 (42.6)
Female	5284 (62.9)	7246 (70.3)	4969 (51.8)	5273 (57.4)
Region				
Urban	855 (10.2)	1288 (12.5)	5367 (56.0)	5581 (60.8)
Rural	7549 (89.8)	9027 (87.5)	4226 (44.1)	3600 (39.2)
Education				
No formal school	1382 (16.5)	1837 (17.8)	591 (6.2)	420 (4.6)
Primary school	1854 (22.1)	2424 (23.5)	1044 (10.9)	891 (9.8)
Middle school	4471 (53.3)	4978 (48.3)	2795 (29.3)	2496 (27.3)
College and above	678 (8.1)	1060 (10.3)	5109 (53.6)	5322 (58.3)
Household annual income				
<10,000	1277 (16.2)	1138 (11.7)	658 (8.1)	663 (8.4)
10,000-50,000	4880 (61.8)	6230 (64.3)	3377 (41.4)	3160 (40.2)
50,000-100,000	1406 (17.8)	1837 (19.0)	1953 (23.9)	1834 (23.3)
≥100,000	331 (4.2)	491 (5.1)	2171 (26.6)	2204 (28.0)
Smoking habits				
Non-smoker	6238 (76.0)	8012 (80.0)	6171 (67.7)	6246 (71.2)
Ceased smoker	299 (3.6)	347 (3.5)	592 (6.5)	501 (5.7)
Current smoker	1670 (20.4)	1656 (16.5)	2350 (25.8)	2027 (23.1)
Alcohol consumption				
Never or almost never	6720 (80.3)	8265 (80.4)	4897 (51.3)	4828 (52.8)
Occasionally	1295 (15.5)	1669 (16.2)	3981 (41.7)	3735 (40.9)
Usually	358 (4.3)	343 (3.3)	668 (7.0)	576 (6.3)
Self-reported general health status				
Excellent	2295 (27.4)	2567 (25.0)	3753 (39.3)	3788 (41.5)
Good	2912 (34.8)	3700 (36.0)	2651 (27.7)	2393 (26.2)
Fair	2716 (32.5)	3520 (34.2)	2840 (29.7)	2631 (28.8)
Poor	448 (5.4)	496 (4.8)	311 (3.3)	317 (3.5)
CVD	3703 (44.1)	3804 (36.9)	2424 (25.3)	1976 (21.5)
Type 2 diabetes	288 (3.6)	342 (3.5)	197 (2.1)	156 (1.7)
Mental health issues	87 (1.1)	125 (1.3)	227 (2.4)	244 (2.7)
Cancer	35 (0.5)	53 (0.5)	28 (0.3)	38 (0.4)
Emphysema	29 (0.4)	15 (0.2)	18 (0.2)	10 (0.1)
Kidney disease	32 (0.4)	39 (0.4)	43 (0.5)	46 (0.5)

Abbreviations: **IQR**, interquartile range; **BMI**, body mass index (calculated as weight in kilograms divided by height in meters squared); **CVD**, cardiovascular disease. For some variables, the sum of categories was not equal to the total due to missing data. RMB (yuan) was used to estimate household income.

3.3. The substitution association between PA and leisure-time sedentary time and CVD prevalence

Table 3 demonstrated that substituting 30 min/day of leisure-time sedentary time with equivalent MVPA was related to a 2 % lower CVD prevalence (95 %CI: 0.97–0.99). Substituting 30 min/day of LPA with equivalent MVPA was associated with a 1 % lower CVD prevalence (95

Table 2
Logistic regression analyses of the association between physical activity and leisure-time sedentary time and cardiovascular disease prevalence among Northwest China adults from 2018 to 2019 (n = 37,543).

	CVD cases, n (%)	Model 1[a*]	Model 2	Model 3	Model 4	Model 5
		OR (95 %*CI*)				
Total PA (h/day)						
<4.0	3703 (44.1)	1.00	1.00	1.00	1.00	1.00
4.0–8.4	3804 (36.9)	0.74 (0.70–0.79)	0.79 (0.74–0.84)	0.77 (0.72–0.83)	0.76 (0.71–0.81)	0.76 (0.71–0.81)
8.4–11.2	2424 (25.3)	0.43 (0.40–0.46)	0.74 (0.69–0.80)	0.74 (0.68–0.79)	0.73 (0.67–0.79)	0.74 (0.68–0.80)
≥11.2	1976 (21.5)	0.35 (0.33–0.37)	0.68 (0.63–0.74)	0.68 (0.63–0.74)	0.68 (0.62–0.74)	0.68 (0.63–0.74)
P value (for trend)		<0.001	<0.001	<0.001	<0.001	<0.001
MVPA (h/day)						
<0.9	1901 (30.8)	1.00	1.00	1.00	1.00	1.00
0.9–2.9	2040 (37.2)	1.33 (1.23–1.44)	1.01 (0.93–1.10)	0.99 (0.91–1.09)	0.98 (0.89–1.07)	0.95 (0.86–1.04)
2.9–8.0	2040 (36.3)	1.28 (1.19–1.39)	0.78 (0.72–0.85)	0.77 (0.70–0.85)	0.75 (0.68–0.83)	0.74 (0.67–0.82)
≥8.0	1542 (26.0)	0.79 (0.73–0.86)	0.67 (0.61–0.73)	0.69 (0.63–0.76)	0.66 (0.60–0.73)	0.68 (0.61–0.75)
P value (for trend)		<0.001	<0.001	<0.001	<0.001	<0.001
LPA (h/day)						
<2.0	2265 (37.6)	1.00	1.00	1.00	1.00	1.00
2.0–4.0	4355 (38.2)	1.03 (0.96–1.09)	1.09 (1.02–1.17)	1.07 (0.99–1.15)	1.03 (0.94–1.12)	1.03 (0.94–1.13)
4.0–9.0	3253 (33.8)	0.85 (0.79–0.91)	1.02 (0.94–1.10)	0.97 (0.90–1.06)	0.98 (0.89–1.09)	0.98 (0.88–1.09)
≥9.0	1928 (19.0)	0.39 (0.36–0.42)	0.94 (0.85–1.03)	0.94 (0.85–1.05)	0.84 (0.74–0.97)	0.86 (0.75–0.99)
P value (for trend)		<0.001	0.009	0.02	0.004	0.01
Sedentary time (h/day)						
<2.0	1699 (31.9)	1.00	1.00	1.00	1.00	1.00
2.0–3.0	3082 (31.7)	0.99 (0.92–1.06)	1.04 (0.96–1.13)	1.04 (0.96–1.13)	1.05 (0.97–1.14)	1.03 (0.94–1.12)
3.0–4.0	2516 (31.3)	0.97 (0.90–1.05)	1.06 (0.97–1.15)	1.03 (0.95–1.12)	1.04 (0.96–1.14)	1.01 (0.92–1.11)
≥4.0	4142 (33.0)	1.05 (0.98–1.13)	1.14 (1.06–1.23)	1.09 (1.00–1.18)	1.09 (1.01–1.18)	1.03 (0.95–1.12)
P value (for trend)		0.03	<0.001	0.03	0.04	0.57

Abbreviations: **PA**, Physical activity; **CVD**, Cardiovascular disease; **OR**, Odds ratio; **CI**, Confidence interval; **MVPA**, Moderate-to-vigorous physical activity; **LPA**, Light physical activity.

[a] Model 1, crude model. Model 2, adjusted for sociodemographic factors, including age, sex, region, household annual income, and education. Model 3, further adjusted for lifestyle-related variables, including body mass index, alcohol consumption, smoking habits, diet score, and self-reported general health status. Model 4, mutually adjusted for PA and sedentary time based on Model 3. Model 5 was sensitivity analysis, which further adjusted related diseases (including type 2 diabetes, mental health issues, cancer, emphysema, and kidney disease) based on Model 4.

[*] For some variables, the sum of categories was not equal to the total due to missing data.

%CI: 0.98–0.99). The ISM also showed linear effects for substituting leisure-time sedentary time with LPA and MVPA across various CVD types (**Supplementary Table 10**).

For the subgroup analyses, substituting 30 min/day of leisure-time sedentary with equivalent MVPA was associated with a 3 % and 2 % lower CVD prevalence in female and rural residents. Additionally, substituting 30 min/day of leisure-time sedentary time with LPA was related to a 2 % lower prevalence of CVD in females. As for interaction, we observed a significant interaction between PA and sex and region with CVD prevalence (*P* for interaction both <0.001), as well as the interaction between leisure-time sedentary time and sex in CVD prevalence (*P* for interaction <0.001). However, we did not find any significant additive interaction between leisure-time sedentary time and region in CVD prevalence (*P* for interaction =0.51) **(Supplementary Fig. 2 and 3)**. Sensitivity analysis results aligned with these results (**Supplementary Table 11–12** and **Supplementary Fig. 4**).

4. Discussion

4.1. Principal findings

This study demonstrated that increased total PA and reduced leisure-time sedentary time were associated with a lower prevalence of CVD in adults from Northwest China. We identified a nonlinear dose-response relationship between total PA and CVD prevalence, suggesting that substituting leisure-time sedentary time and LPA with MVPA could be effective strategies for CVD management.

4.2. Comparisons with other studies

The median leisure-time sedentary time observed in our study was 3 h/day, which was in line with the leisure-time sedentary time previously reported among the Chinese population (3.0 h/day) (Fan et al., 2015) but lower than in high-income countries, such as the United States (4.3 h/day) (Matthews et al., 2021). Urban-rural differences may be related to the PA and leisure-time sedentary time distributions (Wang et al., 2022; Zhang et al., 2023). The leisure-time sedentary time in urban residents (3.42 ± 2.23 h/day) was higher than that of rural residents (3.16 ± 1.88 h/day) in this study, which is similar to the results in other counties in China (Chen et al., 2012). Besides, this study used single item questionnaire to evaluate the leisure-time sedentary time, which may underestimate sedentary time as previous research published (Aunger and Wagnild, 2022). Additionally, previous studies have reported that older people tend to be more sedentary than younger individuals (Liu et al., 2020). However, in our study, we observed participants in the highest quartile of leisure-time sedentary time were older than other groups, which may be related to the Chinese traditional custom of people above 45 years of age willing to do more housework duties to take care of their posterity (Wang et al., 2022).

Previous studies reported that PA and sedentary behavior had an impact on CVD in direct or indirect ways, such as blood pressure (Liu et al., 2020), endothelial function (Soto-Rodríguez et al., 2022), and circulating metabolites (Pang et al., 2019). Our findings align with previous research on PA, sedentary time, and CVD prevalence across various populations. Another cross-sectional study conducted in Fujian province in China reported that low sedentary and high levels of MVPA related to a lower chance of abnormal heart rate recovery (OR = 0.553) (Liu et al., 2024), with similar results in another study based on patients comorbid with CVD and metabolic disease (Li et al., 2023). The results from cross-sectional studies were also inconsistent with the longitudinal study. A study based on CKB in China found that each increment of 4 MET-h/day reduced major vascular events risk by 6 % among Chinese adults (Bennett et al., 2017). As for the dose-relationship, we observed an L-shaped dose-response relationship between total PA and CVD

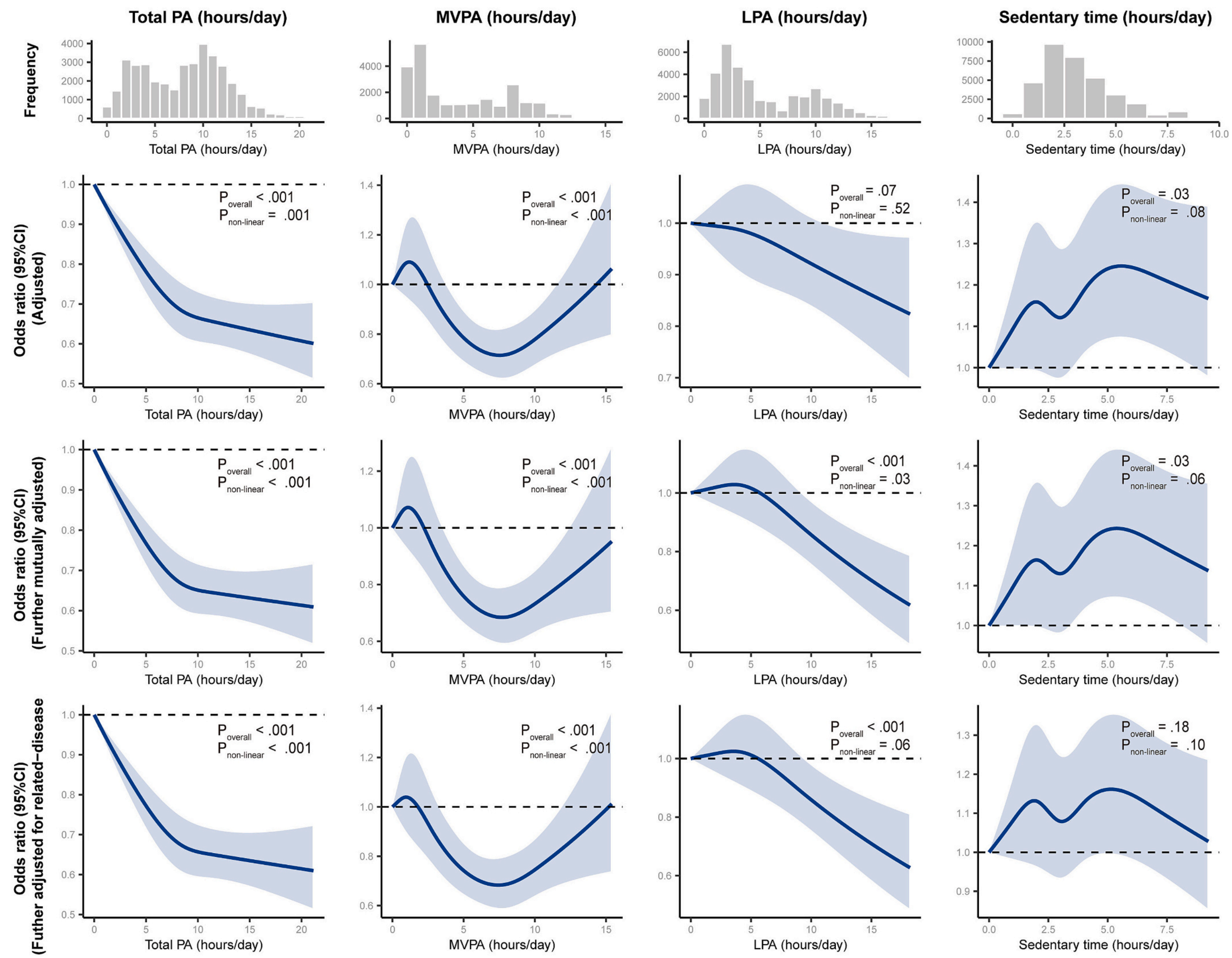

Fig. 1. Dose-response relationship between PA and leisure-time sedentary time and CVD prevalence in adults in Northwestern China from 2018 to 2019 (n = 37,543). **PA**, physical activity; **MVPA**, moderate-to-vigorous physical activity; **LPA**, light physical activity; **CI**, confidence interval. The adjusted model in the second row was adjusted for sociodemographic factors (age, sex, region, household annual income, and education), and lifestyle-related variables (BMI, alcohol consumption, smoking habits, diet score, and self-reported general health status). The results in the third row were mutually adjusted for PA and leisure-time sedentary time. The results in the fourth row were further adjusted for related diseases, including type 2 diabetes, mental health issues, cancer, emphysema, and kidney disease.

prevalence. Prior studies concluded the relationship between PA and cardiovascular outcomes as curvilinear: the largest risk reductions happen when moving from a sedentary to a moderately active lifestyle, after which more PA does not yield additional benefits (Franklin et al., 2022). Supporting this, a meta-analysis only modest risk reductions for individuals engaging in high leisure-time PA, exceeding guideline recommendations (Sattelmair et al., 2011). Secondly, we also observed a U-shaped dose-response relationship between MVPA and CVD prevalence, aligning with prior studies (Ho et al., 2022). This may reflect the fewer participants at high MVPA levels, increasing uncertainty. Long-term high-volume, high-intensity exercise may cause adverse cardiac changes, particularly in athletes (Eijsvogels et al., 2018; Franklin et al., 2022), but its impact on the general population is unclear. Nonetheless, our results support that any PA is better than none (Bull et al., 2020), emphasizing its crucial role in health.

In this study, we observed substituting 30 min/day of leisure-time sedentary time and LPA with equivalent MVPA was associated with a lower prevalence of CVD, which was consistent with previous studies. A cross-sectional study in the United States population found that substituting MVPA for other components was associated with favorable differences in cardiovascular health scores (Ji et al., 2024). As for substituting leisure-time sedentary time with other activities, we only observed a significant relationship while substituting leisure-time sedentary time with equivalent MVPA, which was in line with the results reported by a cross-sectional study previously (Ji et al., 2024). However, another cross-sectional study in the US found that substituting LPA for sedentary time was linked to favorable cardiometabolic biomarkers (Cheng et al., 2023), suggesting the role of LPA in the reallocation time during a 24-h day and its association with cardiovascular health still need further investigation.

Within our subgroup analysis, we observed that substituting 30 min/day of leisure-time sedentary time with an equivalent duration of LPA was linked to a lower CVD prevalence in females, whereas no such association in males. The sex difference was also reported in previous studies (Sattelmair et al., 2011). Possible explanations include biological differences, methodological considerations, or both. Biologically, differences in sex hormones and specific conditions (e.g., menopause or hormonal contraceptive use) could partly explain the potential sex-specific effects (Santos-Lozano et al., 2021). A cross-sectional study suggested that men benefit more from VPA, while women benefit from lighter-intensity activities (Asztalos et al., 2010). Methodologically, females generally have lower CVD rates (Wang et al., 2023) and the

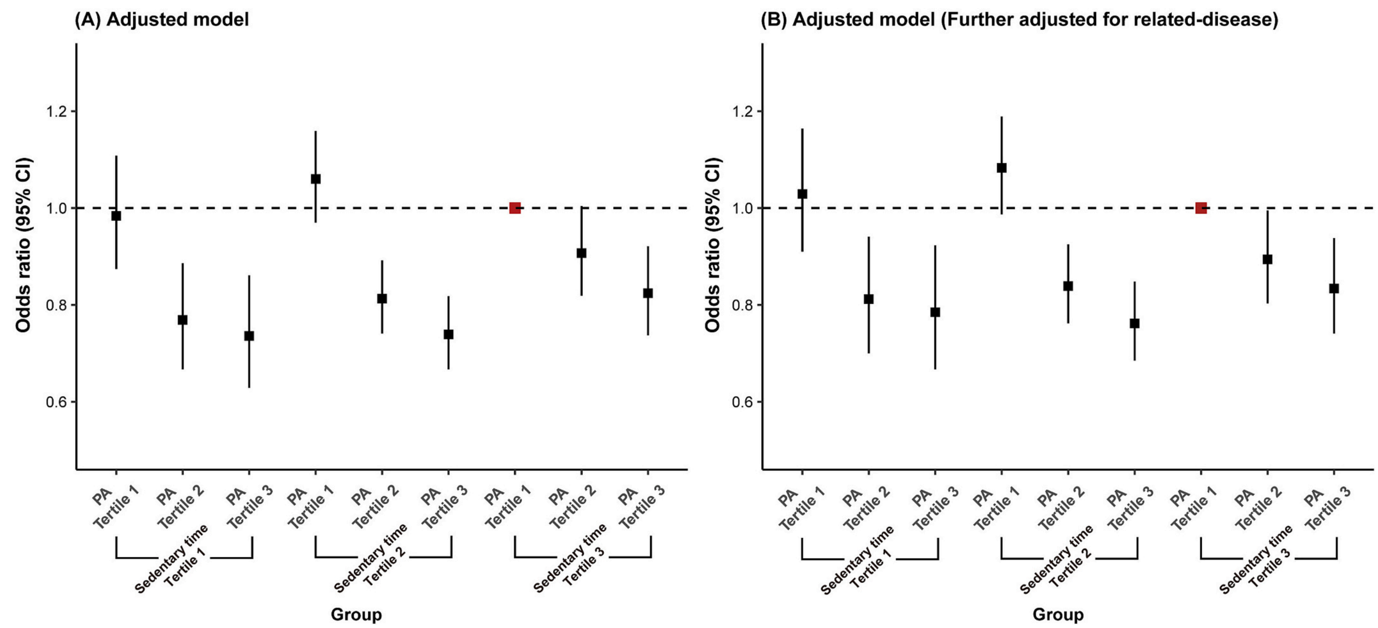

Fig. 2. Joint association of PA and leisure-time sedentary time and CVD prevalence in adults in Northwestern China from 2018 to 2019 ($n = 37{,}543$). **PA**, physical activity; **CI**, confidence interval. The red square was the reference group (participants in the highest group of leisure-time sedentary time and the lowest group of the PA). The *p*-value for interaction between PA and leisure-time sedentary time in CVD prevalence was 0.07. (A) Adjusted for sociodemographic factors (age, sex, region, household annual income, and education), and lifestyle-related variables (BMI, alcohol consumption, smoking habits, diet score, and self-reported general health status). (B) Further adjusted for related diseases, including type 2 diabetes, mental health issues, cancer, emphysema, and kidney disease. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Substitution addociation between physical activity and leisure-time sedentary time and cardiovascular disease among Northwest China adults from 2018 to 2019 (n = 37,543).

Substitution model[a]	Type of activities					
	MVPA		LPA		Sedentary time	
	OR (95 %*CI*)	*P* value	*OR* (95 %*CI*)	*P* value	*OR* (95 %*CI*)	*P* value
Replace sedentary time with						
Model 1[b]	0.96 (0.96–0.97)	<0.001	0.95 (0.94–0.96)	<0.001	Dropped	
Model 2	0.97 (0.97–0.98)	<0.001	0.99 (0.98–1.00)	0.02		
Model 3	0.98 (0.97–0.99)	<0.001	0.99 (0.98–1.00)	0.18		
Replace LPA with						
Model 1	1.01 (1.01–1.02)	<0.001	Dropped		1.05 (1.04–1.06)	<0.001
Model 2	0.98 (0.98–0.99)	<0.001			1.01 (1.00–1.02)	0.003
Model 3	0.99 (0.98–0.99)	<0.001			1.01 (1.00–1.02)	0.06
Replace MVPA with						
Model 1	Dropped		0.98 (0.97–0.98)	<0.001	1.04 (1.03–1.04)	<0.001
Model 2			1.01 (1.00–1.01)	<0.001	1.03 (1.02–1.04)	<0.001
Model 3			1.01 (1.00–1.02)	<0.001	1.02 (1.02–1.03)	<0.001

Abbreviations: **CVD**, Cardiovascular disease; **ISM**, Isotemporal substitution model; **MVPA**, Moderate-to-vigorous physical activity; **LPA**, Light physical activity; **OR**, Odds ratio; **CI**, Confidence interval.
[a] The substitution unit was 30 min/day.
[b] Model 1, crude model. Model 2, adjusted for sociodemographic factors, including age, sex, region, household annual income, and education. Model 3, further adjusted for lifestyle-related variables, including body mass index, alcohol consumption, smoking habits, diet score, and self-reported general health status.

impact of imprecisely measured or unmeasured confounders (e.g., smoking habits and diet) may be smaller in females than males (Hands et al., 2016). Nevertheless, the sex difference between PA and CVD still needs further investigation. Besides, in our study, we observed that substituting 30 min/day of leisure-time sedentary time with an equivalent duration of MVPA was associated with a lower prevalence of CVD in rural settings. Apart from the participant distribution in this study, the finding may suggest the urban-rural difference may play a role in the association between PA and leisure-time sedentary time and cardiovascular health (Bennett et al., 2017; Li et al., 2024). One plausible explanation may related to socioeconomic status disparities. A national study reported that over 70 % of workers in the MVPA group were in agriculture in rural settings, while only 19.7 % were in urban settings. Therefore, the socioeconomic status disparities might be relatively larger in urban than rural areas, which indicates the health problem the health issues arising from it cannot be easily modified by behavioural factors (Li et al., 2024). Additionally, other reasons, such as the distribution of PA and leisure-time sedentary time in urban and rural residents (Zhu et al., 2016) may also partly explain the urban-rural differences. In our sensitivity analysis, adjusting for related diseases rendered the association between leisure-time sedentary time and CVD prevalence non-significant. This difference could be related to the self-reported nature of sedentary time and the role of these diseases as mediators, modifiers, or confounders in the relationship. Nevertheless, limited by the study design, the role of related diseases in the relationship between PA and sedentary time and CVD needs further explanation.

4.3. Strengths and limitations

The major strength of this study is the large population sample from Northwest China, adhering to rigorous quality control protocols. However, several limitations exist. Firstly, it is a cross-sectional investigation, which cannot definitively rule out reverse causality or infer a causal relationship. Secondly, leisure-time sedentary time and PA were self-reported, potentially introducing measurement bias. Despite this, self-reported questionnaires offer advantages in large population studies, such as ease of administration and low cost (Ainsworth et al., 2015). Thirdly, CVD assessment was based on self-reported questionnaires, limiting systematic and detailed evaluation (e.g., graded cardiovascular health by Life's Essential 8 metrics (Wang et al., 2023a)). Fourth, although we adjusted for covariates, there might have still been residual confounding because of unknown or unmeasured factors, such as lipids and medication history) or bias (e.g., recall bias). Fifth, sedentary time in this study included only leisure activities (e.g., watching TV, using mobile devices, reading, surfing the internet) and excluded occupational sedentary behavior, which could be significant for those with desk-based jobs. Additionally, physical activity was not further analyzed by specific domains (e.g., occupational and transportation), which needed further investigation in future research. Furthermore, because the outcomes of interest in this study were relatively common (prevalence >10 %), the odds ratios may overestimate the true associations. Therefore, caution is required when interpreting the results. Finally, given that the median age was 51.0 years and the rural predominance in this study (65.01 %), the generalizability of these findings was limited.

5. Conclusions

Our results indicate that higher levels of PA and reduced leisure-time sedentary time were associated with a lower CVD prevalence by using the baseline data from a large cohort. However, these results should be translated with caution given that this is a cross-sectional study.

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CRediT authorship contribution statement

Yutong Wang: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Peiying Yang:** Writing – original draft, Formal analysis. **Huimeng Liu:** Writing – review & editing. **Suixia Cao:** Writing – review & editing. **Jingchun Liu:** Writing – review & editing. **Yating Huo:** Writing – review & editing. **Kun Xu:** Writing – review & editing. **Binyan Zhang:** Writing – review & editing. **Mengchun Wang:** Writing – review & editing. **Qian Huang:** Writing – review & editing. **Chunlai Yang:** Writing – review & editing. **Lingxia Zeng:** Writing – review & editing. **Shaonong Dang:** Writing – review & editing. **Baibing Mi:** Writing – review & editing, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102934.

Data availability

The data sets generated during and analyzed during this study are available from the corresponding author (Baibing Mi: xjtu.mi@xjtu.edu.cn) on reasonable request.

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