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EDITED BY

Bojan Masanovic,
University of Montenegro, Montenegro

REVIEWED BY

Narlon C. Boa Sorte Silva,
University of British Columbia, Canada
Célia Kingsbury,
Université de Montréal, Canada
Kam Pui Eric Lee,
The Chinese University of Hong
Kong, China

*CORRESPONDENCE

Xingqi Wang
6020160037@jsnu.edu.cn
Yujia Liu
liuyujia89@jsnu.edu.cn

†These authors have contributed
equally to this work and share first
authorship

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Association between physical activity dimensions and the risk of hypertension among middle and older adults: A cross-sectional study in China

Linlin Zhou^{1†}, Wei Feng^{2†}, Na Xiang³, Yue Cheng¹, Xudong Ya¹,
Mingxia Wang¹, Xingqi Wang^{4*} and Yujia Liu^{1*}

¹Institute of Physical Education, Jiangsu Normal University, Xuzhou, China, ²Department of Physical Education, Suzhou University, Suzhou, China, ³Caoxian People's Hospital, Heze, China, ⁴School of Life Science, Biomedical R&D Center, Jiangsu Normal University, Xuzhou, China

Background: It is known that insufficient physical activity is associated with the risk of hypertension, but the relationship to different physical activity dimensions within hypertension risk remains to be elucidated.

Objective: The objective of this study is to identify the association between physical activity intensity, frequency, duration, and volume with hypertension risk. Meanwhile, a dose-response experiment is conducted to determine the relationship between physical activity level and hypertension risk.

Methods: Data came from the 2018 China Health and Retirement Longitudinal Study (CHARLS, 2018), which included 14266 participants over the age of 45. Binary logistic regression models were established to assess the associations between different dimensions of physical activity and the risk of hypertension. Restricted cubic spline analysis was used to examine possible non-linear associations between physical activity volume and hypertension risk.

Results: For frequency, lower hypertension risk was associated with performing vigorous physical activity 6–7d/w (OR 0.82, 95%CI 0.73–0.93) and moderate physical activity 6–7d/w (OR 0.89, 95%CI 0.80–0.99). No significant association between any light physical activity frequency and hypertension was observed before and after being adjusted. For the duration, lower hypertension risk was observed in performing vigorous physical activity ≥ 240 min/d (OR 0.85, 95%CI 0.75–0.97) and moderate physical activity ≥ 240 min/d (OR 0.83, 95%CI 0.71–0.97). For volume, the risks of hypertension in the participants who reported TPA in the 3th and 4th of quantiles were reduced by 18% (OR 0.82, 95%CI 0.72–0.95) and 22% (OR 0.78, 95%CI 0.68–0.91). A non-linear dose-response association between total physical activity and the risk of hypertension was shown among all of the participants (P non-linearity < 0.05).

Conclusion: Higher frequency and longer duration of vigorous physical activity or moderate physical activity were significantly associated with a lower risk of hypertension. Higher physical activity levels were associated with a lower risk of hypertension and there was an inverse non-linear dose-response relationship between weekly total physical activity and the risk of hypertension.

These findings provide further proof that hypertension could be prevented through increased physical activity.

KEYWORDS

hypertension risk, middle and older adults, restricted cubic spline, dose-response relationship, physical activity

Introduction

Hypertension is one of the most common chronic diseases worldwide (1), and it is the leading risk factor for cardiovascular disease (2). Hypertension can lead to serious health problems such as heart disease, stroke, as well as possible death if left uncontrolled (3). About 1 billion people are living with hypertension worldwide (4), and more than 1.56 billion people will have elevated hypertension in 2025 (1, 5). Likewise, hypertension is common in China. A large-scale epidemiological survey in 2013 showed that the prevalence of hypertension among Chinese adults was as high as 27.8% (6). Studies have shown that many factors are related to the risk of hypertension such as obesity, alcohol consumption, sodium intake, and physical inactivity (7–10). However, previous data showed that more than 40% of the elderly in China are still physically inactive (11). In addition, the prevalence of hypertension increases with age (12). Promoting adequate physical activity in middle-aged and older adults to prevent hypertension is a key issue.

Increased physical activity (PA) was effective in the treatment and prevention of hypertension, this viewpoint has been confirmed by many studies (13–15). An inverse dose-response association between levels of PA and hypertension was demonstrated in a meta-analysis (16). But this association may vary according to sex and age. An early study suggested that increased total amount of energy expenditure during PA was statistically associated with reduced risk of hypertension among men but not among women (17). Additionally, Cohen et al. (18) found age differences in the association between PA and hypertension, the association between high levels of PA and the prevention of hypertension was weaker among older women when compared to younger women. What's more, there were also inconsistent results regarding the association between the intensity of PA and the risk of hypertension. It was reported that vigorous physical activity (VPA) is associated with a reduced risk of hypertension, and VPA was far more effective than moderate physical activity (MPA) or light physical activity (LPA) in the prevention of hypertension (19). An earlier study, however,

found that the addition of VPA cannot offer additional benefits in the prevention of hypertension (20). The optimal prescription (intensity, duration, frequency and volume) for the prevention and treatment of hypertension remains elusive.

Further investigation of the association between physical activity to hypertension is still required. We hypothesized that higher intensity, frequency, duration and volume of physical activity would each be associated with reduced hypertension risk. Therefore, this study aimed to assess the association of hypertension with various dimensions of PA and to assess whether there were gender and age differences in the dose-response relationship between PA and the risk of developing hypertension.

Materials and methods

Participants

This cross-sectional study was done based on the China Health and Retirement Longitudinal Study (CHARLS) survey in 2018. CHARLS is a nationally representative survey of Chinese middle-aged and elderly people conducted by the National School for Development (China Center for Economic Research) in collaboration with Peking University's Institute for Social Science Survey. The survey covers 450 urban communities and rural areas in 28 provinces, municipalities, and autonomous regions in China. It was approved by the Biomedical Ethics Review Committee of Peking University (approval number: IRB00001052-11015), and informed consent was required of all participants.

To be included in this study, participants (age \geq 45 years) should have complete data on physical activity record, gender, place of residence, marital status, educational level, sleep status, smoking status, drinking status, annual income, hypertension record. Participants younger than 45 years or with missing data for any of the above will be excluded.

Among 19,752 participants in 2018, we excluded 226 participants aged $<$ 45 years, 5,243 participants with missing hypertension diagnoses data, 12 participants with missing sleep data, and 5 participants with missing smoking data. Finally, 14,266 participants were included in this cross-sectional study. Based on the *post hoc* analysis of sample power using G Power 3.1, the present study population provided a statistical power of 0.99.

Abbreviations: PA, physical activity; CHARLS, China Health and Retirement Longitudinal Study; RCS, restricted cubic spline; VPA, vigorous physical activity; MPA, moderate physical activity; LPA, light physical activity; TPA, total physical activity; MET, Metabolic equivalent of task; OR, Odds ratio; Cis, confidence intervals.

Physical activity

A modified version of the validated International Physical Activity Questionnaire Short Form (IPAQ-SF) (21) was used to measure participants' physical activity (see [Supplementary material](#)). Each participant was asked, "Do you usually take this type of activity for at least 10 min every week?" Specific types of physical activity include (1) VPA: activities that cause shortness of breath and may include carrying heavy stuff, digging, hoeing, aerobic workout, bicycling at a fast speed, and riding a cargo bike or motorcycle. (2) MPA: activities that make you breathe faster than usual and may include carrying light stuff, bicycling at a normal speed, mopping, Tai-Chi, and speed walking. (3) LPA: such as walking from one place to another place at a workplace or home, and taking a walk for leisure, sports, exercise, or entertainment. If participants answered "no", they would be considered as not engaged in this type of PA during the week. If participants answered "yes", they were further asked about the frequency and duration of each PA intensity. The frequency of PA ranged from 0–7 d/w and was divided into 4 levels: no activity (0 d/w); 1–2 d/w; 3–5 d/w; and 6–7 d/w. The duration of PA was categorized into 5 levels by CHARLS: no activity; 10–29 min/d; 30–119 min/d; 120–239 min/d; and ≥ 240 min/d. Metabolic equivalent of task (MET) was cited to calculate the volume of physical activity with considerations of intensity. Resting energy expenditure during quiet sitting was defined as one MET. According to the Physical Activity Guidelines Advisory Committee Scientific Report of 2018 (22), we assigned 6.0 METs, 3.1 METs, and 1.6 METs for 1 min of VPA, MPA, and LPA, respectively. The weekly PA volume for each intensity category equals the product of PA frequency, the daily duration of PA, and the value assigned for each category. The total volume of PA (TPA) equals the sum of VPA, MPA, and LPA. Finally, the TPA was classified by quartiles.

Hypertension

Hypertension was defined based on self-reported medical history and measurement of blood pressure (systolic blood pressure ≥ 140 mmHg or diastolic blood pressure ≥ 90 mmHg). Participants were asked the question "Have you been diagnosed with hypertension by a doctor?" We considered that the individual had hypertension when the response was "yes".

Covariates

Covariates in the present study were age, sex (male, female), marital status (married, separated/divorced/widowed, never married), education (junior high school or less, senior high

school and vocational school, college or higher), residency (urban, rural), smoking status (current smoker, quit smoking, never smoked), drinking frequency (≤ 1 /month, > 1 /month, never) and sleep duration (< 7 h, 7–8 h, ≥ 8 h), annual income (< 5000 yuan, 5000–10000 yuan, 10000–30000 yuan, 30000–50000 yuan, ≥ 50000 yuan).

Statistical analysis

The software STATA16.0 was used for data processing and analysis. Categorical variables were expressed as counts and percentages and were compared using the Pearson's chi-squared test. Continuous data are expressed as mean \pm SD and analyzed with Student's *t*-test. Binary logistic regression analysis was used to explore the associations between various dimensions of PA and the risk of hypertension, while adjusting for potential confounders. Model 1 was adjusted for demographic characteristics (including age, sex, marital status, education, residency); Model 2 was further adjusted for health-related behaviors (smoking status, drinking frequency, sleep duration). A restricted cubic spline (RCS) was used to assess the dose-response relationship between the risk of hypertension and PA, using the 25th, 50th, and 75th percentiles of the TPA as fixed knots. The RCS models were adjusted for age, sex, marital status, education, residency, smoking status, drinking frequency and sleep duration. Analyses stratified by sex and age were conducted. Missing data were imputed using multiple imputation by chained equations. To test the robustness of the results, we performed a sensitivity analysis with imputed data. All tests were two-tailed, and a probability value of $p < 0.05$ was considered statistically significant. Graph Pad prism 8 was used to draw cubic splines.

Results

Baseline characteristics

[Table 1](#) showed the demographic data of participants. Among 14 266 participants in this study, 2,175 (15.25%) reported having hypertension. The risk of hypertension was significantly correlated with age ($P < 0.001$), sex ($P = 0.006$), marital status ($P < 0.001$), smoking status ($P < 0.001$) and annual income ($P = 0.019$). However, there was no significant difference in drinking frequency, residency, education, and sleep duration between participants with and without hypertension (all $P > 0.05$). Compared with non-hypertensive participants, hypertensive patients had lower weekly TPA. Women and older adults had lower weekly TPA ([Supplementary Table S1](#)).

TABLE 1 Baseline characteristics of participants.

Characteristic	Total (N = 14,266)	Hypertension (N = 2,175)	Non-hypertension (N = 12,091)	P-value
Age, years, n (%)				<0.001
<65	9,483	1,224 (56.28)	8,259 (68.31)	
≥65	4,783	951 (43.72)	3,832 (31.69)	
Sex, n (%)				0.006
Male	6,903	1,111 (51.08)	5,792 (47.90)	
Female	7,363	1,064 (48.92)	6,299 (52.10)	
Marital status, n (%)				<0.001
Married or cohabiting	12,371	1,801 (82.80)	10,570 (87.42)	
Separated, divorced or widowed	1,808	364 (16.74)	1,444 (11.94)	
Never married	87	10 (0.46)	77 (0.64)	
Drinking frequency, n (%)				0.192
≤1/month	3,905	575 (26.44)	3,330 (27.54)	
>1/month	1,132	158 (7.26)	974 (8.06)	
Never	9,229	1,442 (66.30)	7,787 (64.40)	
Smoking status, n (%)				<0.001
Current smoker	4,076	585 (26.90)	3,491 (28.87)	
Quit	1,891	385 (17.70)	1,506 (12.46)	
Never	8,299	1,205 (55.40)	7,094 (58.67)	
Residency, n (%)				0.667
Urban	4,003	602 (27.68)	3,401 (28.13)	
Rural	10,263	1,573 (72.32)	8,690 (71.87)	
Education, n (%)				0.566
Junior high school or less	12,421	1,909 (87.77)	10,512 (86.94)	
Senior high school or vocational school	1,723	248 (11.40)	1,475 (12.20)	
College or higher	122	18 (0.83)	104 (0.86)	
Sleep duration, hours, n (%)				0.339
< 7	7,921	1,239 (56.97)	6,682 (55.26)	
7-8	2,507	370 (17.01)	2,137 (17.67)	
≥ 8	3,838	566 (26.02)	3,272 (27.06)	
Annual income, yuan, n (%)				0.019
< 5000	8,972	1,430 (65.75)	7,542 (62.38)	
5000–30000	2,973	430 (19.77)	2,543 (21.03)	
30000–50000	1,444	199 (9.15)	1,245 (10.30)	
≥ 50000	877	116 (5.33)	761 (6.29)	
TPA, MET-min/week, mean (SD)	5,122 (5629)	4,520 (5365)	5,230 (5669)	<0.001

Logistic regression analysis of physical activity and hypertension

Total physical activity and the risk of hypertension

Table 2 shows the results of logistic regression analysis between TPA and the risk of hypertension. Participants who reported TPA in the 3th and 4th of quartiles had a 25% (OR 0.75, 95%CI 0.65–0.86) and 31% (OR 0.69, 95%CI 0.60–0.79) lower risk of hypertension compared to the first quartile of

TPA. After adjusting for confounding factors including age, sex, marital status, education, residency, smoking status, drinking frequency, sleep duration and annual income, the risks of hypertension in the participants who reported TPA in the 3th and 4th of quartiles were reduced by 18% (OR 0.82, 95%CI 0.72–0.95) and 22% (OR 0.78, 95%CI 0.68–0.91), respectively (all $P < 0.01$). The reduction in the risk of hypertension in participants with TPA in second quartile was not statistically significant before and after adjustment ($P > 0.05$). In addition, an inverse association between the TPA level and the risk

TABLE 2 Logistic regression analysis for the associations between TPA and the risk of hypertension.

TPA	N	Univariate		Model 1		Model 2	
		OR (95% CI)	P-value	OR (95% CI)	P-value	OR (95% CI)	P-value
Q1	2,591	1		1		1	
Q2	4,542	0.91 (0.79, 1.03)	0.136	0.95 (0.83, 1.08)	0.421	0.96 (0.84, 1.09)	0.526
Q3	3,564	0.75 (0.65, 0.86)	<0.001	0.82 (0.71, 0.94)	0.004	0.82 (0.72, 0.95)	0.007
Q4	3,569	0.69 (0.60, 0.79)	<0.001	0.77 (0.67, 0.89)	<0.001	0.78 (0.68, 0.91)	0.001
P for trend		<0.001		<0.001		0.001	

OR, odds ratio; CI, confidence interval; Model 1 was adjusted for age, sex, education, marital status, and residency; Model 2 was further adjusted for smoking status, drinking frequency, sleep duration and annual income.

of hypertension was observed in all three models (P for trend < 0.001).

Frequency of PA and the risk of hypertension

Table 3 indicates the binary logistic regression results for the associations between PA frequency and the risk of hypertension. Compared with inactivity, there was an association between taking part in VPA 1–2 d/w (OR 0.80, 95%CI 0.65–0.99) and the risk of hypertension, but the association became insignificant after adjustment for confounders (Model 1: OR 0.85, 95%CI 0.69 to 1.06; Model 2: OR 0.86, 95%CI 0.69 to 1.07). Taking part in VPA 6–7 d/w (OR 0.77, 95%CI 0.68–0.87) was associated with a lower risk of hypertension, and the association remained statistically significant after adjusting for confounders (Model 1: OR 0.81, 95%CI 0.72–0.92; Model 2: OR 0.82, 95%CI 0.73–0.93). Taking part in MPA 6–7 d/w (OR 0.81, 95%CI 0.73–0.89) was associated with a lower risk of hypertension. After adjustment for confounders, the association attenuated slightly but remained significant (Model 1: OR 0.89, 95%CI 0.80–0.99; Model 2: OR 0.89, 95%CI 0.80–0.99). No association between any LPA frequency and hypertension was observed before and after adjusting.

Duration of PA and the risk of hypertension

Lower risk of hypertension was observed in participants spending 30–119 min (OR 0.82, 95%CI 0.67–0.99) or over 240 min per day (OR 0.79, 95%CI 0.69–0.89) for VPA. Spending 120–239 min (OR 0.84, 95%CI 0.73–0.98) or over 240 min (OR 0.74, 95%CI 0.63–0.86) on MPA each time was correlated with smaller odds of hypertension. Participants performing over 240 min LPA each time had a lower risk of hypertension (OR 0.83, 95%CI 0.70–0.97). After adjusting for age, sex, marital status, education, residency, smoking status, drinking frequency and sleep duration, spending over 240 min on VPA each time and over 240 min on MPA each time was correlated with smaller odds of hypertension (Table 3).

Dose-response relationship between TPA and hypertension

Figure 1 displays the RCS regression analysis result. We observed a non-linear dose-response association between TPA and the risk of hypertension among all of the participants (P non-linearity < 0.05). As the increase of TPA per week, the OR of hypertension markedly decreased. The point estimate of the risk ratio reached 0.85 (95% CI = 0.75–0.95) for activity at 3000 MET-minutes per week, indicating that the probability of having hypertension was 15% lower at that level of physical activity. When TPA reached 4500 MET-minutes per week, the risk of hypertension decreased by 19% (OR 0.81, 95%CI 0.70–0.93). The risk of hypertension no longer decreased significantly when the TPA was increased further.

Subgroup and sensitivity analysis

As shown in Supplementary Figure S1, after sex stratification, there was a linear dose-response association between TPA and the risk of hypertension in male participants (P non-linearity > 0.05). The OR of hypertension decreased sharply as the TPA per week increased. However, no significant relationship was found in female participants. In the age-stratified analyses (Supplementary Figure S2), a nonlinear dose-response relationship was observed in those aged 45–64 (P non-linearity < 0.05). A linear dose-response relationship was observed in those aged ≥ 65 (P non-linearity > 0.05). All of the dose-response relationships revealed an inverse relationship between TPA and the risk of hypertension.

Missing values were imputed by multiple imputation, 19,466 participants were included in the sensitivity analysis. A non-linear dose-response relationship between TPA and the risk of hypertension was similar to the main analysis (Supplementary Figure S3).

TABLE 3 Logistic regression analysis for the associations between PA and the risk of hypertension.

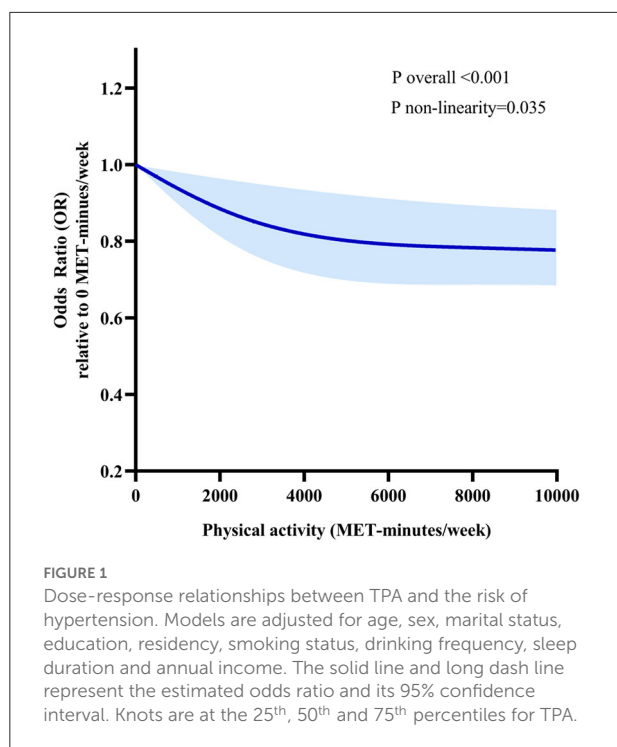
Variables	N	Univariate		Model 1		Model 2	
		OR (95% CI)	P-value	OR (95% CI)	P-value	OR (95% CI)	P-value
Frequency							
VPA							
No activity	9,374	1		1		1	
1–2 d/w	778	0.80 (0.65, 0.99)	0.043	0.85 (0.69, 1.06)	0.153	0.86 (0.69, 1.07)	0.178
3–5 d/w	1,144	0.95 (0.79, 1.12)	0.517	1.01 (0.85, 1.20)	0.902	1.02 (0.86, 1.21)	0.819
6–7 d/w	2,970	0.77 (0.68, 0.87)	<0.001	0.81 (0.72, 0.92)	0.001	0.82 (0.73, 0.93)	0.003
MPA							
No activity	7,081	1		1		1	
1–2 d/w	945	0.93 (0.77, 1.12)	0.417	0.99 (0.82, 1.19)	0.902	0.99 (0.82, 1.19)	0.885
3–5 d/w	1,460	0.88 (0.75, 1.03)	0.117	0.96 (0.82, 1.12)	0.609	0.96 (0.82, 1.13)	0.619
6–7 d/w	4,780	0.81 (0.73, 0.89)	<0.001	0.89 (0.80, 0.99)	0.034	0.89 (0.80, 0.99)	0.038
LPA							
No activity	2,380	1		1		1	
1–2 d/w	483	0.79 (0.59, 1.06)	0.117	0.83 (0.63, 1.11)	0.214	0.85 (0.64, 1.13)	0.257
3–5 d/w	1,141	1.06 (0.87, 1.28)	0.581	1.15 (0.95, 1.39)	0.162	1.17 (0.96, 1.41)	0.117
6–7 d/w	10,262	0.92 (0.81, 1.04)	0.168	0.96 (0.85, 1.09)	0.560	0.98 (0.87, 1.11)	0.744
Duration							
VPA							
No activity	9,347	1		1		1	
10–29 min/d	139	0.77 (0.47, 1.27)	0.132	0.83 (0.50, 1.37)	0.462	0.84 (0.51, 1.39)	0.509
30–119 min/d	905	0.82 (0.67, 0.99)	0.046	0.87 (0.71, 1.06)	0.176	0.88 (0.72, 1.07)	0.209
120–239 min/d	1,074	0.89 (0.75, 1.07)	0.230	0.93 (0.77, 1.11)	0.400	0.93 (0.77, 1.11)	0.419
≥240 min/d	2,774	0.79 (0.69, 0.89)	<0.001	0.84 (0.74, 0.96)	0.009	0.85 (0.75, 0.97)	0.016
MPA							
No activity	7,081	1		1		1	
10–29 min/d	824	0.84 (0.69, 1.04)	0.107	0.90 (0.73, 1.11)	0.328	0.91 (0.77, 1.12)	0.385
30–119 min/d	2,910	0.90 (0.79, 1.01)	0.083	0.99 (0.87, 1.11)	0.822	0.98 (0.87, 1.11)	0.803
120–239 min/d	1,655	0.84 (0.73, 0.98)	0.029	0.92 (0.79, 1.07)	0.257	0.91 (0.78, 1.06)	0.238
≥240 min/d	1,796	0.74 (0.63, 0.86)	<0.001	0.82 (0.71, 0.96)	0.014	0.83 (0.71, 0.97)	0.017
LPA							
No activity	2,380	1		1		1	
10–29 min/d	1,353	1.09 (0.92, 1.31)	0.313	1.13 (0.95, 1.36)	0.168	1.15 (0.96, 1.37)	0.138
30–119 min/d	5,768	0.95 (0.83, 1.08)	0.442	0.99 (0.87, 1.14)	0.951	1.01 (0.89, 1.16)	0.849
120–239 min/d	2,658	0.87 (0.75, 1.01)	0.076	0.90 (0.77, 1.06)	0.201	0.92 (0.78, 1.07)	0.274
≥240 min/d	2,107	0.83 (0.70, 0.97)	0.023	0.91 (0.77, 1.07)	0.258	0.92 (0.78, 1.09)	0.363

OR, odds ratio; CI, confidence interval; Model 1 was adjusted for age, sex, education, marital status, and residency; Model 2 was further adjusted for smoking status, drinking frequency, sleep duration, annual income.

Discussion

This cross-sectional study evaluated the association between the risk of hypertension with various dimensions of PA in middle and older-aged Chinese people. Several important findings of the current study include: (1) Higher frequency and longer duration of VPA or MPA were significantly associated with a lower risk of hypertension.

(2) There was an inverse association between TPA and risk for hypertension. (3) A non-linear dose-response relationship between TPA and the risk of hypertension was observed in all participants, the downward hypertension risk flattened when TPA was approximately 4500 MET-minutes/week. (4) There were sex and age differences in the dose-response relationship between physical activity and hypertension risk.



Intensity, frequency, and duration of PA are important factors affecting the benefits of PA. We found that VPA and MPA were associated with a lower risk of hypertension after adjustment for covariates. The result is consistent with those of previous studies, moderate-to-vigorous PA is beneficially associated with many health statuses (23). However, the association between moderate-to-vigorous PA with hypertension risk was only observed at 6–7 days per week and duration ≥ 240 min. A single session of exercise can cause a sustained drop in blood pressure, a phenomenon known as post-exercise hypotension (24). Repeated induction of post-exercise hypotension at a higher frequency may be best in hypertensive patients. Sharman et al. (25) support the idea that hypertensive patients should be physically active most days of the week for optimal health benefits. The guideline (26) also encourage adults with high blood pressure to do moderate-to-vigorous aerobic exercise most days of the week, and preferably all days.

In terms of duration, the physical activity guidelines recommend that adults should do at least 150–300 min MPA per week, or 75–150 min. VPA per week for substantial health benefits (27). Taylor-Tolbert et al. (28) found that just 45 min of acute exercise immediately reduced blood pressure load in elderly male hypertensive patients. Our findings differ significantly from the previous reports. Smith et al. (29) compared self-reported and objectively measured physical activity trajectories in prostate cancer survivors, and they found that self-reported measures greatly overestimated moderate to vigorous physical activity. However, a systematic review noted that self-reported measures of physical activity were higher or lower than directly measured physical activity levels, depending

on the measure of physical activity employed, the level of physical activity measured, and the gender of participants (30). The physical activity indicators associated with lowering hypertension in our results still need to be further validated with objective monitoring data. No significant association was observed in any frequency and duration of LPA after adjustment for confounders. Despite the evidence that even LPA is associated with numerous positive health outcomes (31), it remains unclear whether LPA can have a beneficial effect on hypertension.

Our result shows an inverse association between TPA level and the risk of hypertension, which is consistent with previous research (32, 33). Importantly, the effect of PA on hypertension is dose-dependent (16). We used RCS to explore this relationship and found the relationship to be non-linear, which decreases initially and then stabilizes. When TPA reached 3000 MET-minutes per week, the risk of hypertension decreased by 15%. The energy expenditure far exceeds the recommendations of current physical activity guidelines, suggestive that exceeding current guidelines in terms of energy expenditure incurs greater contribution. But the curve reached a plateau when TPA per week was approximately 4500 MET-mins. This is probably a volume for optimal health benefits, equivalent to 2.5 h a day of moderate-intensity, or 1.3 h a day of vigorous-intensity physical activity. A beneficial effect of physical exercise on hypertension appears in the regulation of endothelial function (34). Physical exercise augments blood flow and laminar shear stress, and it can also elicit systemic molecular pathways connected with angiogenesis and chronic anti-inflammatory action (35).

It is worth noting that sex and age differences were found in the dose-response relationship between physical activity and hypertension risk. A linear dose-response relationship between PA and hypertension was observed in the male population. No significant dose-response relationship was found in female participants, which was consistent with the findings of Haapanen et al. (17). Physical activity may differ between men and women. A previous report on the physical activity of middle and older Chinese indicated that men were more active in VPA and women were more active in MPA (36). In addition, the dose-response relationship between physical activity and the risk of hypertension in aged 45–64 participants is linear, but it was non-linear in those aged ≥ 65 participants. The age difference in the relation between PA and hypertensive risk may result from an age-related increase in arterial stiffness (18). Casey et al. (37) found that the vasodilator responses were slower in older adults at all exercise intensities compared with younger adults. The decreasing physical function makes it difficult for older adults to engage in moderate-to-vigorous PA (38), which also limits the higher benefits they can get from PA.

This study has the strength of including a representative sample of middle-aged and older adults in the Chinese population, which increased the statistical power. We conducted subgroup analyses based on age and sex to explore whether a difference in association could be observed in subgroups with

a different age or sex. Furthermore, the sensitivity analyses have confirmed the robustness of this study's findings. This study has some limitations. First, because of the cross-sectional design, the cause-effect relationships between PA and the risk of hypertension not be determined. Further longitudinal studies are needed to determine the direction of causality for these associations. Second, questionnaire-based assessments of physical activity may be subject to recall and social desirability bias. Although the IPAQ is widely used, validation studies have shown poor agreement with objective measures (39). Third, these data do not allow us to distinguish the source of physical activity, it's hard to determine if the observed effects are independent of the type of occupation. Moreover, we were unable to include some important covariates, such as BMI, history of metabolic conditions, salt intake, medication use, and other potential confounders that may interfere with the effect of physical activity on hypertension risk. Our results cannot be excluded from being influenced by unknown or unmeasured confounders, despite the multivariable adjustments we made. Finally, results are limited to Chinese middle-aged and elderly groups, and may not generalize to other countries or populations.

Implications

It is expected that the prevalence of hypertension will continually increase in the future as the Chinese population ages rapidly. Our findings reinforce a growing body of independent evidence that supports the effectiveness of moderate-to-vigorous-intensity physical activity in preventing and managing the risk of hypertension. This study also has significant practical implications. We analyzed the associations between multiple dimensions of physical activity and the risk of hypertension, and found gender and age differences in the dose-response relationship between accumulated physical activity over the week and the risk of hypertension. This may provide more detailed guidance for the prevention and control of hypertension in different populations. Physical activity as a non-pharmacological intervention has been shown to be effective in reducing the risk of hypertension. Objective measurement of physical activity should be considered and incorporated into the management of hypertensive patients.

Conclusion

The results of this study assessed associations between different dimensions of PA and the risk of hypertension. After adjustment for potential confounders, higher frequency and longer duration of VPA or MPA were significantly associated with a lower risk of hypertension. Higher PA levels were associated with a lower risk of hypertension and there was an inverse dose-response relationship between weekly TPA and the

risk of hypertension. When TPA reached approximately 4500 MET-minutes per week, the risk of hypertension in the overall population decreased by 19%, while continued increases in PA did not appear to produce any further marked reduction in the risk. These findings provide further proof that hypertension could be prevented through increased PA.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: <https://g2aging.org>.

Ethics statement

The studies involving human participants were reviewed and approved by the Biomedical Ethics Review Committee of Peking University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LZ, YL, and WF designed the research. LZ, WF, NX, XY, and MW performed all the statistical analysis. LZ, WF, YL, and XW interpreted the data analysis. LZ, WF, YC, YL, and XW wrote the manuscript with critical input from YL. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fpubh.2022.995755/full#supplementary-material>

SUPPLEMENTARY FIGURE S1

Dose-response relationships between TPA and the risk of hypertension for different sex groups (A) Males. (B) Females. Models were adjusted for age, marital status, education, residency, smoking status, drinking frequency, sleep duration and annual income. The solid line and long

dash line represent the estimated odds ratio and its 95% confidence interval. Knots are at the 25th, 50th, and 75th percentiles for TPA.

SUPPLEMENTARY FIGURE S2

Dose-response relationships between TPA and the risk of hypertension for different age groups (A) Participants aged < 65 years. (B) Participants aged 65 years and older. Models were adjusted for sex, age, marital status, education, residency, smoking status, drinking frequency, sleep duration and annual income. The solid line and long dash line represent the estimated odds ratio and its 95% confidence interval. Knots are at the 25th, 50th and 75th percentiles for TPA.

SUPPLEMENTARY FIGURE S3

Sensitivity analyses of dose-response relationships between TPA and the risk of hypertension. Models are adjusted for age, sex, marital status, education, residency, smoking status, drinking frequency, sleep duration and annual income. The solid line and long dash line represent the estimated odds ratio and its 95% confidence interval. Knots are at the 25th, 50th and 75th percentiles for TPA.

SUPPLEMENTARY TABLE S1

Physical activity level of participants.

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