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Association of weekend warriors and other physical activity patterns with hypertension in NHANES 2007–2018

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To accommodate the fast-paced nature of modern life, the "Weekend Warriors (WW)" has emerged as a novel physical activity (PA) indicator. This study aims to investigate the relationship between WW and other PA patterns with hypertension, thereby addressing a significant research gap. Data from 30,697 participants in the National Health and Nutrition Examination Survey conducted between 2007 and 2018 were analyzed. We employed multiple regression analyses to examine the relationships among WW, other PA patterns, PA duration, PA intensity, and hypertension, with data stratified by various characteristics. Results showed that compared to the inactive group, the insufficiently PA pattern (OR = 0.9, 95% CI 0.8, 1.0), the WW group (OR = 0.9, 95% CI 0.7, 1.1), and the regularly active group (OR = 0.8, 95% CI 0.8, 0.9) were all negatively associated with hypertension, with the WW group showing a trend towards a reduced prevalence of hypertension (*P* for trend < 0.01). This association was particularly evident among middle-aged and older adults aged 41–80 years. Additionally, total moderate-to-vigorous physical activity (MVPA) time, as well as moderate and vigorous PA intensity, showed "L"-shaped and "U"-shaped relationships with hypertension, with inflection points at 2640 MET minutes, 45%, and 62%, respectively. Our study provides insights for selecting suitable PA patterns but indicates the need for further research.

Keywords Physical activity, Weekend warriors, Hypertension, NHANES

Hypertension is a prevalent chronic disease. Pathological studies have shown that excessive pressure from flowing blood on the vessel walls can cause severe damage or even failure of vital organs, including the heart, brain, and kidneys. The global prevalence of hypertension has doubled over the past 30 years, now affecting approximately 1.3 billion people[1]. It is projected that the global prevalence of hypertension will reach 30% by 2025[2]. Consequently, the World Health Organization (WHO) describes hypertension as "a silent killer"[1]. Extensive research has identified high salt intake[3], obesity[4], smoking[5], genetic factors[6], and insufficient physical activity as potential risk factors for hypertension. Thus, modifying these controllable factors is crucial for preventing and managing hypertension.

Physical activity (PA) is acknowledged as a protective factor in reducing the risk of chronic diseases, preventing cancer, cardiovascular diseases, and dementia, as well as improving cognitive function in older adults[7]. Literature suggests that 5–13% of the risk of hypertension can be attributed to a lack of PA[8]. Numerous randomized controlled trials have confirmed that PA can reduce blood pressure[9–12]. A total of 150–300 min of moderate-intensity physical activity (MPA), 75–150 min of vigorous-intensity physical activity (VPA), or an equivalent combination of both (moderate-to-vigorous physical activity, MVPA) are recommended in the health improvement standards set by the "Physical Activity Guidelines for Americans" and the WHO.[1,13]. Additionally, the National Health Service (NHS) in the UK recommends that MVPA be evenly distributed over 4–5 days per week. However, to achieve the recommended exercise duration amidst the demands of a fast-paced work environment, some individuals have adopted a pattern of condensing their MVPA into 1–2 days per week, a behavior referred to as the "weekend warriors" (WW) approach[14]. Previous studies on WW have found that, compared to inactive individuals, the all-cause mortality rate of WW is comparable to that of a regularly active PA pattern[15]. Another study suggests that, upon meeting the recommended amount of physical activity, WW

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shows no significant difference in its effect on all-cause and cardiovascular disease mortality compared to other PA patterns[14]. Similar results were observed in depression[16] and obesity[17]. However, a significant gap remains in research on the relationship between WW and hypertension. Previous studies on the potential benefits of PA have integrated physical fitness and its related factors, such as cardiorespiratory fitness (CRF), muscle mass, and strength levels, into stratified analyses. One study examining the relationship between PA and mortality risk reported that increased PA offered more significant benefits for subgroups with the lowest strength and poorest CRF [18]. While the independent relationship between PA and hypertension is relatively well established, the extent to which physical fitness modify this association remains insufficiently explored. Furthermore, recent research has confirmed the protective effects of PA on hypertension[19]; however, the shape of the dose–response curve between them remains unclear[20].

Therefore, this study selected information from 30,697 participants in the NHANES database and classified the population into four PA patterns. We analyzed the associations between different PA patterns, total MVPA, and various PA intensities with hypertension. Threshold effects of total MVPA, MPA intensity, and VPA intensity on hypertension were also examined. To further refine our analysis, we conducted age-stratified assessments to understand how different PA patterns relate to hypertension across age groups. The primary objective was to investigate the link between PA and hypertension, offering a scientific foundation for future intervention studies.

Methods

Data accession and study population

The National Health and Nutrition Examination Survey (NHANES), guided by the Centers for Disease Control and Prevention (CDC), draws a nationally representative sample of the U.S. civilian population to study various aspects of health and nutrition. All data used in this study are sourced from NHANES and approved by the Research Ethics Review Board of the National Center for Health Statistics. Detailed data and informed consent information are available on the NHANES website (https://www.cdc.gov/nchs/nhanes/index.htm). The data for this study were obtained from three sections of the NHANES database. The demographics section provided basic demographic variables collected via questionnaires. The examination section included body mass index (BMI) calculations (weight in kg divided by height in m^2) and blood pressure measurements conducted at a mobile examination center. The questionnaire section gathered data on hypertension, high cholesterol, smoking, sedentary behavior, and PA through survey responses.

This study analyzes NHANES data from 2007 to 2018, covering 59,842 individuals. Initially, 25,072 participants under 20 were excluded. Subsequently, 45 individuals with missing PA data, 4 with missing hypertension data, and 4,024 with missing covariate data were excluded. Ultimately, 30,697 participants were included in the analysis. The detailed screening process is illustrated in Fig. 1.

Classification of PA patterns

The classification of PA patterns was based on the WHO guidelines, using the metabolic equivalent of task (MET) to determine whether individuals met the recommended activity levels[21]. MET is a standard unit for measuring the intensity of PA, defined as the ratio of metabolic rate during a specific activity to the resting metabolic rate. MPA typically have a MET value of 4, while VPA have a MET value of 8, depending on the intensity of the activity[22]. Weekly MET minutes are calculated by multiplying the duration of the activity (in minutes) by the MET value of the activity. For example, if an individual engages in 150 min of MPA per week, their MET minutes would be: 150 min × 4 MET = 600 MET minutes. Similarly, if the individual engages in 75 min of VPA, their MET minutes would be: 75 min × 8 MET = 600 MET minutes.

PA patterns were initially divided into three categories according to total PA levels: (1) Inactive group: individuals who performed no MPA or VPA; (2) Insufficiently active group: individuals who failed to achieve the recommended 600 MET minutes of weekly activity (e.g., less than 150 min of MPA or less than 75 min of VPA per week); (3) Active group: individuals who met the recommended 600 MET minutes per week by fulfilling at least one of the following criteria: (a) 150 min of MPA per week, (b) 75 min of VPA per week, or (c) an equivalent combination of MPA and VPA (600 MET minutes). Subsequently, the active group was further classified into two subgroups based on activity frequency: the WW group (active 1–2 days per week) and the regularly active group (active 3 or more days per week).

Additionally, the total weekly PA duration (total MVPA) is determined by summing the MET minutes of MPA and VPA (MPA duration × 4 + VPA duration × 8). The proportion of MPA intensity is calculated as the MET minutes of MPA divided by total MVPA, while the proportion of VPA intensity is calculated as the MET minutes of VPA divided by total MVPA.

Evaluation of hypertension

Four diagnostic criteria were used for hypertension, with fulfillment of any one criterion sufficient for a hypertension diagnosis: (1) a physician has previously diagnosed the individual with hypertension, (2) the individual has been advised to take antihypertensive medication, (3) the average systolic blood pressure (SBP) from three measurements exceeds 140 mmHg, or (4) the average diastolic blood pressure (DBP) from three measurements exceeds 90 mmHg.

Covariates

The covariates include demographic and other variables. Demographic variables comprise age (20–40, 41–60, 61–80 years), gender, race/ethnicity (Mexican America, other Hispanic, Non-Hispanic White, Non-Hispanic Black, other Race), education level (less than high school, high school or equivalent, college or above), marital status (married/living with partner, widowed/divorced/separated, never married), and poverty income ratio (≤ 1.3, 1.3–3.5, > 3.5). Other variables included BMI; smoke, categorized based on the response to the question

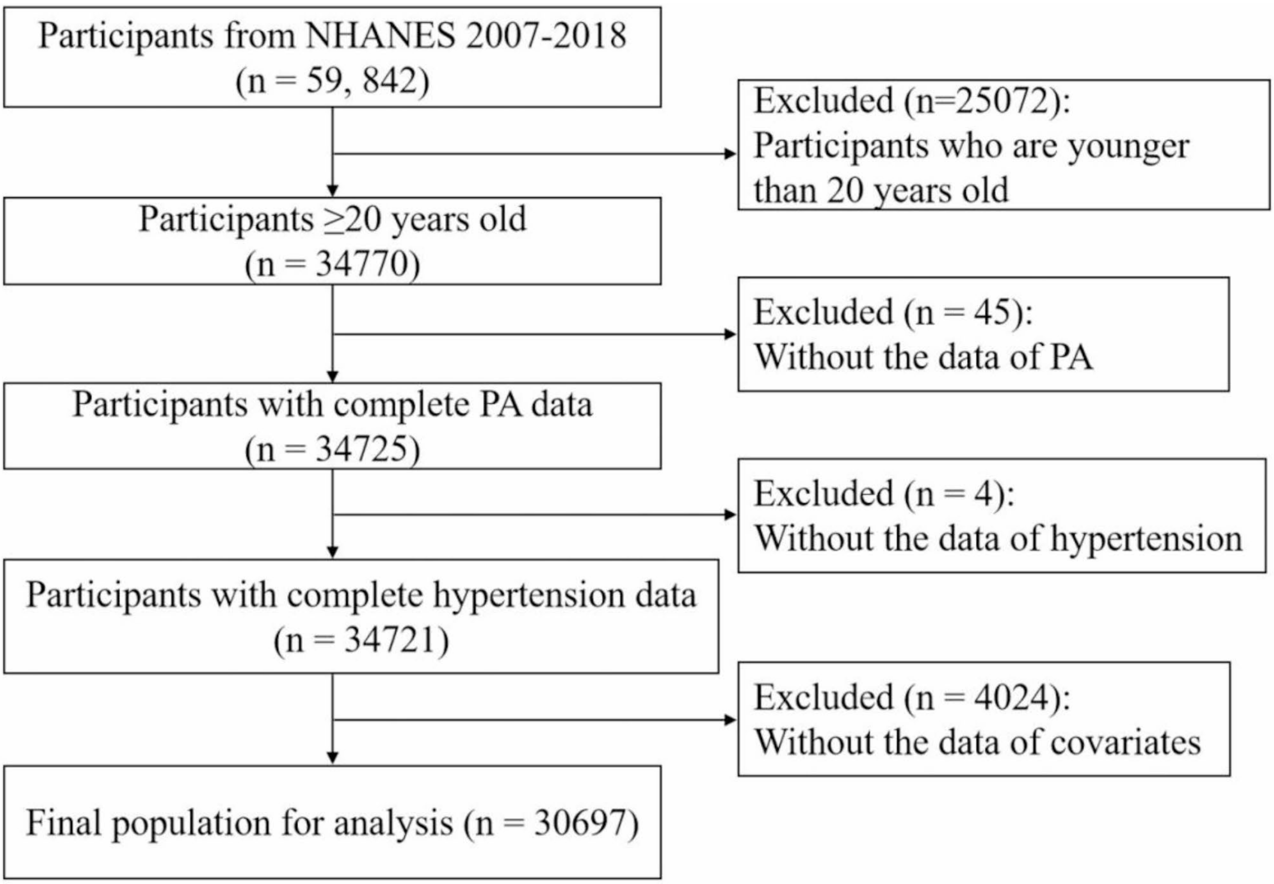

Fig. 1. Flow chart of participant selection. NHANES, National health and nutrition examination survey; PA, Physical activity.

"Have you smoked more than 100 cigarettes in your lifetime?"; and the presence of high cholesterol, defined by the response to the question "Have you ever been told by a doctor or other health professional that your blood cholesterol level was high?" Sedentary behavior (SB) was defined as the total time spent sitting during the day, encompassing activities such as transportation, reading, playing cards, watching television, or using a computer.

Statistical analysis
Following CDC guidelines, this research used R (version 4.1.2) and EmpowerStats (www.empowerstats.com) for statistical analysis. Missing values for categorical variables were excluded, while those for continuous variables were imputed using the median or mean. To minimize sampling errors, data was weighted according to NHANES analytical guidelines for accuracy. For continuous variables (age, PIR, BMI, SB, total MVPA, MP intensity, VP intensity), weighted means and weighted linear regression were used. For categorical variables (gender, age group, race, education, marital status, PIR group, smoke, high cholesterol, total MVPA group, MP intensity group, VP intensity group), weighted percentages and weighted chi-square tests were calculated. Three models were constructed: Model 1 excluded all covariates; Model 2 incorporated gender, age, and race/ethnicity; and Model 3 further included marital status, education, PIR, BMI, smoke, high cholesterol, and SB. Furthermore, we employed logistic regression models to examine the relationship between PA and hypertension. Smooth curve fitting was used to observe the weekly relationship between total MVPA, intensity, and hypertension, identifying inflection points and analyzing threshold effects with a generalized linear model. Subgroup analyses and interaction tests identified influencing factors and high-risk populations, exploring the stability of the relationship between PA patterns and hypertension.

Results
Participant demographics
Table 1 displays the basic characteristics of the 30,697 participants included in the study. Among these participants, 48% were male, while 52% were female. Significant differences were observed in various variables, including gender, age, ethnicity, education, marital status, PIR, smoke, high cholesterol, BMI, and SB, across different PA patterns (all $P < 0.01$). The WW PA pattern was more prevalent among individuals aged 20–40 years, male, never married, do not have high cholesterol and less SB time. Regularly PA patterns were more frequently observed among individuals have college and higher diploma, PIR > 3.5, no smoke and have lower BMI.

Characteristic	N (%)[1]	n = 174,801,285[2]	Inactive n = 80,858,849[2]	Insufficient active n = 28,384,226[2]	Weekend warrior n = 7,688,190[2]	Regularly active n = 57,870,019[2]	*P*-value
N	30,697		16,237 (52.9%)	4496 (14.7%)	1157 (3.8%)	8807 (28.7%)	
Age	30,697						< 0.01
20–40		9827 (35%)	4045 (28%)	1417 (33%)	564 (48%)	3801 (44%)	
41–60		10,409 (38%)	5549 (39%)	1652 (42%)	352 (34%)	2856 (36%)	
61–80		10,461 (26%)	6643 (32%)	1427 (25%)	241 (18%)	2150 (20%)	
Gender	30,697						< 0.01
Male		14,687 (48%)	7328 (45%)	1948 (44%)	809 (71%)	4602 (50%)	
Female		16,010 (52%)	8909 (55%)	2548 (56%)	348 (29%)	4205 (50%)	
Ethnicity	30,697						< 0.01
Mexican America		4176 (7.9%)	2484 (9.5%)	524 (6.3%)	141 (7.7%)	1027 (6.5%)	
Other Hispanic		3185 (5.8%)	1834 (6.4%)	429 (4.9%)	117 (6.1%)	805 (5.3%)	
Non-Hispanic White		12,523 (67%)	6393 (63%)	1920 (70%)	488 (69%)	3722 (70%)	
Non-Hispanic Black		6701 (11%)	3657 (13%)	952 (10%)	246 (9.8%)	1846 (10%)	
Other Race		4112 (8.3%)	1869 (8.0%)	671 (8.7%)	165 (7.4%)	1407 (8.5%)	
Education	30,697						< 0.01
No high school diploma		7167 (15%)	5168 (23%)	743 (10%)	191 (10%)	1065 (6.9%)	
High school diploma		6835 (22%)	4062 (27%)	951 (21%)	265 (24%)	1557 (17%)	
College diploma or higher		16,695 (63%)	7007 (50%)	2802 (69%)	701 (66%)	6185 (76%)	
Marital status	30,697						< 0.01
Married/living with partner		18,305 (64%)	9539 (63%)	2789 (67%)	698 (62%)	5279 (64%)	
Widowed/divorced/separated		7105 (19%)	4351 (22%)	1040 (19%)	186 (15%)	1528 (14%)	
Never married		5287 (17%)	2347 (15%)	667 (14%)	273 (23%)	2000 (21%)	
PIR	30,697						< 0.01
< = 1.3		8637 (19%)	5510 (25%)	1043 (15%)	272 (16%)	1812 (14%)	
> 1.3, < = 3.5		13,401 (40%)	7415 (44%)	1955 (39%)	504 (40%)	3527 (35%)	
> 3.5		8659 (41%)	3312 (30%)	1498 (46%)	381 (44%)	3468 (51%)	
Smoke	30,697						< 0.01
Yes		13,339 (44%)	7690 (48%)	1818 (42%)	527 (46%)	3304 (37%)	
No		17,358 (56%)	8547 (52%)	2678 (58%)	630 (54%)	5503 (63%)	
High cholesterol	30,697						< 0.01
Yes		11,394 (36%)	6466 (39%)	1794 (38%)	326 (28%)	2808 (31%)	
No		19,303 (64%)	9771 (61%)	2702 (62%)	831 (72%)	5999 (69%)	
BMI, kg·m^{-2}	30,697	29.3 ± (6.9)	30.3 ± (7.4)	29.4 ± (6.9)	28.5 ± (6.3)	27.8 ± (6.0)	< 0.01
SB	30,697	373.6 ± (202.8)	383.4 ± (209.1)	379.6 ± (203.3)	346.3 ± (198.0)	360.6 ± (193.1)	< 0.01
Total MVPA, MET·min/week	30,697	860.4 ± (1,536.0)	0.0 ± (0.0)	330.5 ± (138.1)	1,269.5 ± (631.1)	2,268.1 ± (1,971.9)	< 0.01
MPA intensity	30,697	0.3 ± (0.4)	0.0 ± (0.0)	0.9 ± (0.3)	0.5 ± (0.5)	0.5 ± (0.4)	< 0.01
VPA intensity	30,697	0.2 ± (0.4)	0.0 ± (0.0)	0.1 ± (0.3)	0.5 ± (0.5)	0.5 ± (0.4)	< 0.01

Table 1. Demographic and clinical profile of participants. BMI, Body mass index; PA, Physical activity; PIR, Poverty income ratio; SB, sedentary behavior; MVPA, Moderate-to-vigorous physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity. [1]N not Missing (unweighted). [2]n (unweighted) (%); Mean ± (SD).

Association between different PA patterns and hypertension

As shown in Table 2, in Model 3, the insufficiently active group (OR = 0.9, 95% CI 0.8, 1.0) and the regularly active group (OR = 0.8, 95% CI 0.8, 0.9) demonstrated a negative association with hypertension compared to the inactive group. However, the WW group did not show a significant association with hypertension (OR = 0.9, 95% CI 0.7, 1.1) but exhibited a trend toward reduced prevalence of hypertension (*P* for trend < 0.01).

According to Table 3, compared to total MVPA < 600 MET minutes, total MVPA within 600–3600 MET minutes was negatively associated with hypertension (OR = 0.9, 95% CI 0.8, 0.9), while no significant difference was observed when total MVPA exceeded 3600 MET minutes (OR = 0.9, 95% CI 0.7, 1.1). For MPA and VPA intensity, compared to a 0% intensity level, varying intensity proportions in Model 3 showed significant negative associations with hypertension (all $P < 0.05$). For MPA intensity, individuals with a 0–50% intensity had an OR (95% CI) of 0.8 (0.7, 0.9), while those with a 51–100% intensity had an OR (95% CI) of 0.9 (0.8, 1.0). Similarly, for VPA intensity, individuals with a 0–50% intensity had an OR (95% CI) of 0.7 (0.6, 1.0), and those with a 51–100% intensity had an OR (95% CI) of 0.8 (0.8, 0.9).

PA Pattern	Model 1[a]		Model 2[b]		Model 3[c]	
	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value
Inactive	1 [Reference]		1 [Reference]		1 [Reference]	
Insufficiently active	0.7 (0.6, 0.7)	< 0.01	0.8 (0.7, 0.8)	< 0.01	0.9 (0.8, 1.0)	0.01
Weekend warrior	0.5 (0.4, 0.6)	< 0.01	0.7 (0.6, 0.9)	0.00	0.9 (0.7, 1.1)	0.15
Regularly active	0.5 (0.4, 0.5)	< 0.01	0.6 (0.6, 0.7)	< 0.01	0.8 (0.8, 0.9)	0.00
P for trend		< 0.01		< 0.01		< 0.01

Table 2. Association between different PA patterns and hypertension. [a]Model 1 was a univariate model with no adjustments for covariates. [b]Model 2 was adjusted for age, race/ethnicity and gender. [c]Model 3 was adjusted for age, race/ethnicity, gender, PIR, education, smoke, marital status, high cholesterol, BMI, SB. PA, Physical activity; OR, Odds ratio; CI, Confidence interval.

Dimension	Model 1[a]		Model 2[b]		Model 3[c]	
	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value
Total MVPA (MET·min/week)[d]						
< 600	1 [Reference]		1 [Reference]		1 [Reference]	
600–3600	0.5 (0.5, 0.6)	< 0.01	0.7 (0.6, 0.7)	< 0.01	0.9 (0.8, 0.9)	< 0.01
≥ 3600	0.4 (0.3, 0.5)	< 0.01	0.6 (0.5, 0.8)	< 0.01	0.9 (0.7, 1.1)	0.15
P for trend		< 0.01		< 0.01		< 0.02
MPA intensity (%)[e]						
0	1 [Reference]		1 [Reference]		1 [Reference]	
0–50	0.4 (0.3, 0.4)	< 0.01	0.6 (0.5, 0.7)	< 0.01	0.8 (0.7, 0.9)	0.00
51–100	0.9 (0.8, 0.9)	< 0.01	0.8 (0.7, 0.9)	< 0.01	0.9 (0.8, 1.0)	0.02
P for trend		< 0.01		< 0.01		< 0.01
VPA intensity (%)[f]						
0	1 [Reference]		1 [Reference]		1 [Reference]	
0–50	0.4 (0.3, 0.5)	< 0.01	0.6 (0.4, 0.8)	0.00	0.7 (0.6, 1.0)	0.04
51–100	0.4 (0.3, 0.4)	< 0.01	0.6 (0.6, 0.7)	< 0.01	0.8 (0.8, 0.9)	0.00
P for trend		< 0.01		< 0.01		< 0.01

Table 3. Association of total MVPA and different PA intensities with hypertension (weighted). [a]Model 1 was a univariate model with no adjustments for covariates. [b]Model 2 was adjusted for age, race/ethnicity and gender. [c]Model 3 was adjusted for age, race/ethnicity, gender, PIR, marital status, smoke, education, high cholesterol, BMI, SB. [d]Total MVPA was categorized into three groups: (1) < 150 min, (2) 150–750 min, (3) ≥ 750 min. [e]MPA Intensity was divided into three categories: (1) Low-intensity: ≤ 0%, (2) Moderate-intensity: 0–50%, (3) High-intensity: 51–100%. [f]VPA Intensity was divided into three categories: (1) Low-intensity: ≤ 0%, (2) Moderate-intensity: 0–50%, (3) High-intensity: 51–100%. MVPA, Moderate-to-vigorous physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; OR, Odds ratio; CI, Confidence interval.

Threshold effects of total weekly physical activity duration and intensity on hypertension

The relationship between total MVPA and hypertension is characterized by a "L" shape curve, as depicted in Fig. 2a. Conversely, the relationships of MPA intensity and VPA intensity with hypertension both exhibit "U" shaped curves (Figs. 2b and c, respectively). These patterns suggest varying impacts of PA duration and intensity on hypertension risk. Further analysis of threshold effects (Table 4) reveals that for total MVPA below 2640 MET minutes, there is a significant decrease in hypertension incidence; specifically, a 0.01% reduction per MET minutes increase in activity ($P < 0.01$). In the case of MPA intensity, a significant decrease of 50% in hypertension incidence occurs when intensity is below 45% ($P < 0.01$). Above this threshold, however, each additional percentage point of intensity raises the incidence rate by 60% ($P < 0.01$). For VPA intensity, each unit increase below 62% leads to a 30% reduction in hypertension incidence ($P < 0.01$). Above this intensity level, the association with hypertension risk is not statistically significant ($P = 0.15$).

Subgroup analysis

We categorized participants to assess the relationship between PA patterns and hypertension prevalence among diverse groups. Analysis revealed varying impacts of PA patterns across different age demographics (Supplementary Fig. S1 online). Utilizing subgroup analysis, we developed generalized linear models for these groups, detailed in Table 5. Upon adjusting for covariates, in the 20–40 age group, no significant association was observed between hypertension and any PA patterns compared to inactivity (all $P > 0.05$). This pattern

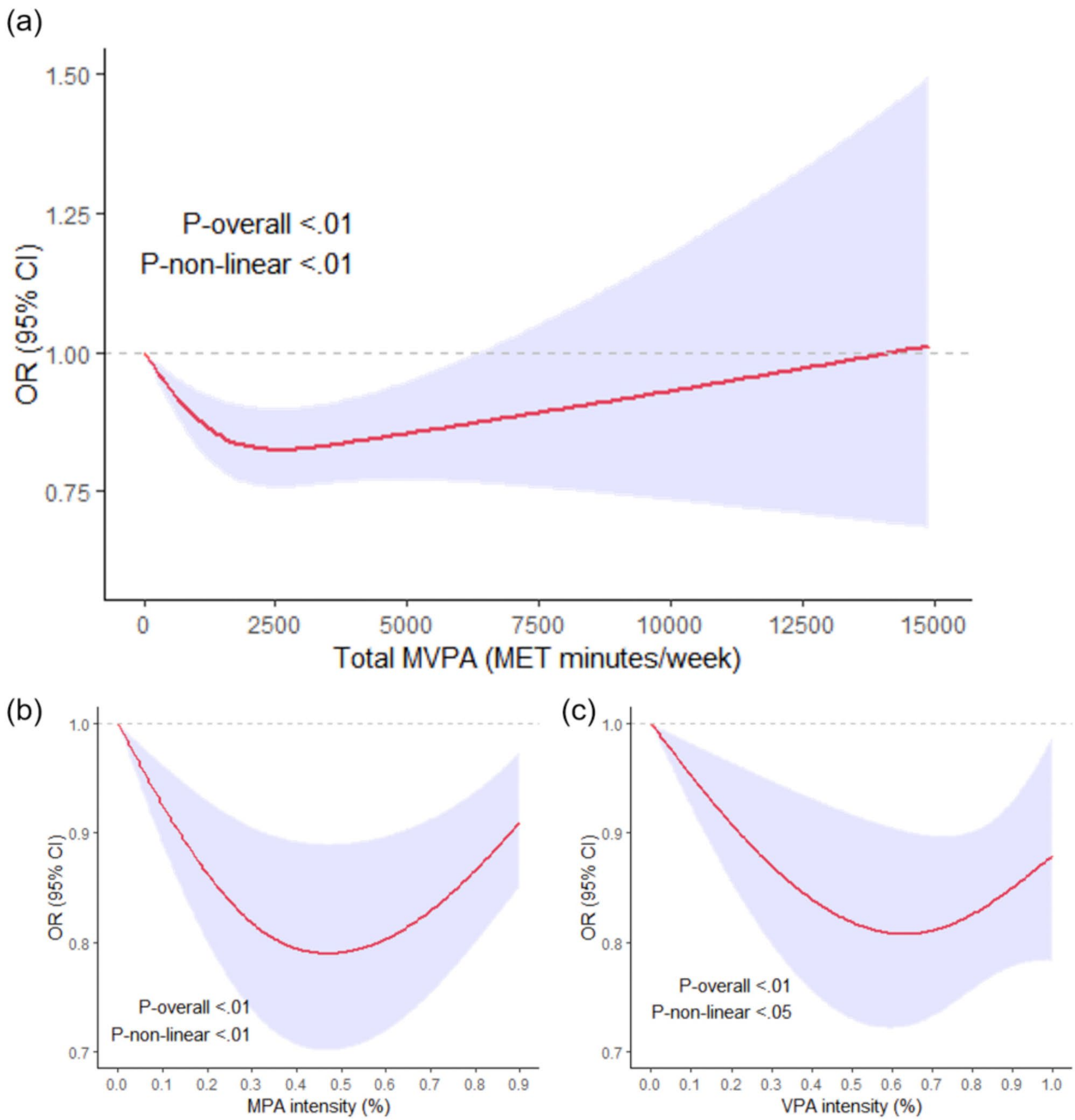

Fig. 2. Smoothed curve fitting explores the relationship between hypertension and (**a**) total MVPA (**b**) MPA intensity (**c**) VPA intensity. The model was adjusted for age, education, race/ethnicity, gender, high cholesterol, PIR, smoke, marital status, BMI, SB. PIR, Poverty income ratio; BMI, Body mass index; MVPA, Moderate-to-vigorous physical activity; PA, Physical activity; MPA, Moderate-intensity physical activity; VPA, vigorous-intensity physical activity.

persisted in the 41–60 and 61–80 age groups, where both the insufficiently active and regularly active PA patterns demonstrated significant negative correlations with hypertension (all $P < 0.05$). The WW PA pattern exhibited a trend associated with a reduction in hypertension.

Discussion

This study classified PA patterns to investigate their relationship with hypertension. The findings reveal that, relative to the inactive PA pattern, both the insufficiently active and the regularly active PA patterns are negatively associated with hypertension. It is important to note that the negative correlation between the WW PA pattern and hypertension is not significant; however, there is a trend suggesting a reduction in hypertension. Additionally, the study examined the relationships between total MVPA, MPA intensity, and VPA intensity with

		OR (95%Cl)	*P* value
Total MVPA	Linear fitting		
	All data	1.0000 (0.9999, 1.0000)	0.001
	Segmented model fitting		
	< 2640	0.9999 (0.9999, 0.9999)	< 0.01
	≥ 2640	1.0000 (1.0000, 1.0001)	0.25
	P for log likelihood ratio test	< 0.01	
MPA intensity (%)	Linear fitting		
	All data	1.0 (0.9, 1.0)	0.37
	Segmented model fitting		
	< 45	0.5 (0.4, 0.7)	< 0.01
	≥ 45	1.6 (1.3, 2.1)	< 0.01
	P for log likelihood ratio test	< 0.01	
VPA intensity (%)	Linear fitting		
	All data	0.8 (0.7, 0.9)	< 0.01
	Segmented model fitting		
	< 62	0.7 (0.5, 0.8)	< 0.01
	≥ 62	1.4 (0.9, 2.1)	0.15
	P for log likelihood ratio test	< 0.02	

Table 4. Threshold effect analysis between total MVPA and different PA intensities with hypertension (unweighted). OR, Odds ratio; CI, Confidence interval; MVPA, Moderate-to-vigorous physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity.

	Model 1[a]		Model 2[b]		Model 3[c]	
PA pattern	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value	OR (95% Cl)	*P*-value
AGE: 20–40						
Inactive	1 [Reference]		1 [Reference]		1 [Reference]	
Insufficiently active	1.0 (0.8, 1.2)	0.82	1.0 (0.8, 1.2)	0.93	1.1 (0.8, 1.4)	0.57
Weekend warrior	0.9 (0.6, 1.3)	0.54	0.8 (0.6, 1.1)	0.12	0.9 (0.6, 1.3)	0.53
Regularly active	0.7 (0.6, 0.8)	< 0.01	0.7 (0.6, 0.8)	< 0.01	0.9 (0.7, 1.0)	0.15
P for trend		< 0.01		< 0.01		< 0.01
AGE: 41–60						
Inactive	1 [Reference]		1 [Reference]		1 [Reference]	
Insufficiently active	0.7 (0.6, 0.8)	< 0.01	0.7 (0.6, 0.8)	< 0.01	0.8 (0.7, 0.9)	0.00
Weekend warrior	0.6 (0.4, 0.8)	0.00	0.6 (0.4, 0.8)	0.00	0.8 (0.5, 1.1)	0.11
Regularly active	0.5 (0.5, 0.6)	< 0.01	0.5 (0.5, 0.6)	< 0.01	0.7 (0.6, 0.9)	0.00
P for trend		< 0.01		< 0.01		< 0.01
AGE: 61–80						
Inactive	1 [Reference]		1 [Reference]		1 [Reference]	
Insufficiently active	0.6 (0.5, 0.8)	< 0.01	0.6 (0.5, 0.8)	< 0.01	0.7 (0.6, 0.9)	0.00
Weekend warrior	0.6 (0.4, 0.9)	0.01	0.7 (0.5, 1.0)	0.04	0.8 (0.5, 1.1)	0.16
Regularly active	0.6 (0.5, 0.7)	< 0.01	0.6 (0.5, 0.7)	< 0.01	0.8 (0.7, 1.0)	0.03
P for trend		< 0.01		< 0.01		< 0.01

Table 5. Association between PA patterns and hypertension across age groups. OR, Odds ratio; CI, Confidence interval. [a]Model 1 was a univariate model with no adjustments for covariates. [b]Model 2 was adjusted for age, race/ethnicity and gender. [c]Model 3 was adjusted for age, race/ethnicity, gender, PIR, marital status, smoke, education, high cholesterol, BMI, SB.

hypertension. The RCS curves indicated an "L" shaped relationship for total MVPA with hypertension, and "U" shaped relationships for MPA and VPA, with turning points at 2640 MET minutes, 45%, and 62%, respectively. Finally, age stratification analysis showed that the negative correlations of PA patterns with hypertension were not significant in the 20–40 age group, but results consistent with the unstratified models emerged in the 41–60 and 61–80 age groups.

PA has long been a key focus in the prevention and management of hypertension. A randomized clinical trial demonstrated that PA interventions effectively help control blood pressure in hypertensive patients[23].

Regular MVPA can reduce blood pressure by approximately 11/5 mmHg[24]. Several studies on exercise training have provided insights into this mechanism. On one hand, PA lowers sympathetic nervous activity, reduces plasma norepinephrine levels[25], and subsequently decreases peripheral vascular resistance[26]. On the other hand, PA enhances the release of vasodilatory substances, such as endorphins[27]. Additionally, PA can ameliorate endothelial dysfunction induced by hypertension[28]. In terms of hemodynamics, PA reduces plasma viscosity by decreasing plasma concentration[29]. Insulin resistance and hyperinsulinemia often accompany hypertension[30]. PA can enhance insulin sensitivity, thereby mitigating the impact of insulin resistance on hypertension[31]. The improvement in heart rate variability (HRV) induced by exercise is considered a key mechanism through which PA helps manage blood pressure. Studies have shown that exercise training enhances HRV in individuals with hypertension, potentially contributing to reduced blood pressure[32]. Similarly, Yugar et al. highlighted the role of HRV in hypertensive syndromes, suggesting that an increase in HRV may improve autonomic nervous regulation and reduce the risk of hypertension[33]. Furthermore, a randomized controlled trial demonstrated that combining an exercise program improved HRV in sedentary women with hypertension, providing another potential pathway through which PA may alleviate hypertension by enhancing HRV[34]. Notably, past studies have shown that WW and regularly active PA participants have similar impacts on various diseases[14–17]. However, the regularly active PA pattern is associated with sustained blood pressure-lowering effects[35]. Research on PA patterns and cardiovascular risk factors has shown that the regularly active PA pattern is linked to greater cardiovascular benefits compared to the WW PA pattern[15]. Our study is similar to a recent research, which indicated that, after reaching the recommended level of physical activity, both regularly and WW PA patterns were negatively correlated with hypertension and other cardiometabolic conditions[36]. In our study compared to the inactive PA pattern, both the insufficiently active and regularly active PA patterns were associated with a lower prevalence of hypertension. In Model 3, while the association between the WW PA pattern and hypertension did not reach statistical significance, a trend indicating a lower prevalence of hypertension was observed. Our findings align with these observations, suggesting that both WW and RA patterns are associated with a lower prevalence of hypertension, but the long-term implications of these patterns require further investigation.

Additionally, when weekly total MVPA time is within 2640 MET minutes, it is negatively correlated with hypertension. However, exceeding this limit renders the association between increased total MVPA time and hypertension insignificant. An earlier study on the impact of PA on cardiovascular disease mortality identified a similar threshold effect. The study found that when total MPA exceeds 600 min, the benefit of reducing cardiovascular mortality does not further increase with additional time[37]. Furthermore, when PA reaches 3 to 5 times the recommended duration, its mortality-reducing benefits become limited[38]. Compared to individuals with lower PA, those over 25 years old who engage in more than 450 min of total MVPA have an 86% higher risk of developing atherosclerosis in middle age[39]. People who jog for more than 2.5 h per week have also been found to lose some associated health benefits[40]. Currently, research on the adverse effects of long-term endurance exercise on hypertension is limited, with mechanisms primarily focusing on myocardial damage, such as elevated cardiac troponin levels[41], fibrosis[42], increased atrial fibrillation risk[43], and biventricular systolic and diastolic dysfunction[44]. Additionally, a study revealed that high-intensity interval aerobic training significantly enhances endothelial dilation function compared to moderate continuous training[45]. Extensive research has shown that VPA not only improves hypertension and provides cardioprotection, potentially exceeding the effects of MPA, but it is also associated with a higher incidence of acute cardiovascular events[46]. Moreover, VPA may lead to negative cardiovascular adaptations, such as accelerated coronary artery calcification and increased release of cardiac biomarkers. These effects are likely related to "U-shaped" and "L-shaped" dose–response curves[47], which were also observed in our study. These findings underscore the necessity of choosing suitable PA durations and intensities in hypertension management.

It has been observed that age may influence the association between PA and hypertension, but no consistent conclusions have been reached. Some studies suggest that PA has minimal impact on blood pressure improvement in older adults[48]. In contrast, other studies conclude that long-term aerobic exercise significantly improves blood pressure in older adults, slows arterial aging, and enhances vascular function[49]. Our analysis of age stratification reveals that the negative correlation between PA patterns and hypertension, undetectable in young adults (ages 20–40), becomes apparent in middle-aged adults (ages 41–80). This indicates that PA is significantly more influential in preventing and managing hypertension in the middle-aged and elderly populations compared to younger adults. According to current expert consensus guidelines, aging presents two phenotypes: healthy and unhealthy. By selecting the optimal level of PA, individuals can foster healthier aging[50]. CRF and muscle health deterioration are pivotal aging characteristics. CRF experiences an accelerated decline with age—a process known as longitudinal acceleration[51]. Concurrently, the decrease in muscle health mirrors the decline in CRF[52]. Comprehensive studies have demonstrated that PA not only enhances CRF but also mitigates the deterioration of muscle health in the elderly[53]. It promotes the release of myokines, which suppress inflammatory responses, stimulate myocardial regeneration, regulate muscle development, enhance muscle function, and reduce muscle deterioration with aging[54,55]. Furthermore, a Swedish screening study reported that a ≥ 3% increase in CRF was associated with an approximately 11% reduction in hypertension incidence[56].This finding suggests that as age increases and physical fitness declines, middle-aged and older adults should engage in suitable PA to prevent and manage chronic diseases.

When exploring the association between PA patterns and hypertension, it is essential to account for several critical factors. SB is a primary concern. Research extensively indicates that increased SB raises the risk of metabolic heart disorders and cardiovascular diseases[57,58]. Observational studies have reported that individuals with high levels of SB exhibit elevated systolic and diastolic blood pressures, likely due to increased norepinephrine levels from prolonged sitting[59]. As a result, we have adjusted our statistical models to include SB. Furthermore, factors such as chronic stress from sustained tension[60], dietary and nutritional influences[61,62], and irregular sleep patterns[63] are also potential contributors to hypertension. Subsequent research should comprehensively incorporate these factors to overcome the limitations of this study.

The classification of PA in this study is socially adaptable, and research on WW provides evidence supporting public health guidelines and contributes to enhancing public health recommendations. Additionally, collecting nationally representative samples through questionnaire surveys is both efficient and valuable[64]. While investigating the relationship between different PA patterns and hypertension, we also evaluated the relationship between PA duration, intensity, and hypertension.

This study has several limitations. First, the data on PA were obtained from questionnaires, which may be subject to recall bias and could differ from data measured by accelerometers[65]. Although adjustments were made for potential confounders, unexamined influencing factors may still be present. Besides, one limitation of this study is the calculation of PA intensity as ratios of moderate to vigorous intensity activities (MPA and VPA). In extreme cases, where an individual engages in 100% VPA but no moderate activity (MPA = 0), the ratio becomes 100% VPA and 0% MPA. While mathematically correct, this may not fully reflect the overall health benefits of moderate intensity activity, which is known to play a significant role in cardiovascular health, weight management, and other health outcomes. This extreme case requires careful interpretation, and we recommend caution in generalizing the findings, especially for individuals with no moderate intensity activity. This study did not exclude the potential influence of hypertension diagnoses on PA levels, which may introduce bias into the findings. Individuals diagnosed with hypertension are likely to increase their PA based on medical recommendations. Furthermore, as a cross-sectional study, this research has limited capacity to determine a causal association between PA and hypertension, and the study population is restricted by the scope of the database.

Conclusion

Our study identified a negative association between various PA patterns and hypertension. The WW pattern demonstrated effects comparable to those of the insufficiently active and regularly active patterns, aligning with prior studies. Furthermore, an "L-shaped" relationship was observed between total MVPA and hypertension, whereas MPA and VPA intensities exhibited a "U-shaped" relationship, underscoring the critical role of suitable intensity. Lastly, the protective effects of PA were found to be more significant among middle-aged and older populations, emphasizing the need for personalized PA guidelines tailored to different age groups and activity patterns to effectively prevent hypertension.

Data availability

All data were extracted from National Health and Nutrition Examination Survey (NHANES) database. The detailed information was provided on the NHANES website (https://wwwn.cdc.gov/nchs/nhanes).

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Author contributions
Y.C. conducted the study design, performed data analysis, and drafted the manuscript. C.Z. processed the data and assisted with the data analysis. Y.Z. prepared the figures and reviewed the manuscript. C.L. organized tables and reviewed the manuscript. Y.L. assisted in study design and revised and polished the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Additional information

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