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Research article

The association between different physical activity (PA) patterns and cardiometabolic index (CMI) in US adult population from NHANES (2007–2016)

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ABSTRACT

Background: Physical activity (PA) is widely recommended for preventing and combating obesity, but the most effective PA pattern for treating obesity remains unclear. Cardiometabolic index (CMI), derived from waist height ratio and triglycerides to high-density lipoprotein-cholesterol ratio, is a novel indicator for evaluating obesity. However, the relationship between different PA patterns and CMI remains unelucidated.
Objective: This study aimed to explore the association between different PA patterns and CMI in U. S. adults.
Methods: Participants with complete information in CMI, PA patterns, and other covariates in the National Health and Nutrition Examination Survey database (2007–2016) were included in this study. Multivariate linear regression models were utilized to explore the relationship between PA patterns and CMI. Moreover, stratified analyses, interaction tests and restricted cubic spline (RCS) regression analysis were used to investigate the stability and nonlinearity of the association, respectively.
Results: A total of 16,442 adults were included in this study. After adjusting for all potential covariates, only the regularly active group was significantly associated with CMI reduction ($\beta = -0.13$, 95% CI: 0.19 to -0.07, $P < 0.0001$), while the weekend warriors group did not achieve equivalent CMI reduction ($\beta = -0.09$, 95% CI: 0.32 to 0.14, $P = 0.4204$). Subgroup analyses and

Abbreviations: BMI, body mass index; CMI, cardiometabolic index; CVD, cardiovascular disease; MPA, moderate-intensity physical activity; NHANES, National Health and Nutrition Examination Survey; PA, physical activity; PAQ, physical activity questionnaire; PIR, poverty income ratio; RA, regularly active; RCS, restricted cubic spline; TG/HDL-C, triglycerides to high-density lipoprotein-cholesterol; VPA, vigorous-intensity physical activity; WHtR, waist height ratio; WWs, weekend warriors.

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interaction tests revealed that the CMI-PA association was more pronounced in the subgroup with age≤45 or >60, with higher education level, and who are current drinkers. Furthermore, RCS analysis indicated that total PA in a week was significantly, nonlinearly associated with CMI in non-inactive adults, and that a total of PA more than 330 min can reap favorable CMI reduction.
Conclusion: Being regularly active is associated with significant CMI reduction, while being weekend warriors and insufficiently active do not achieve equivalent benefits. For non-inactive individuals, engaging in PA for more than 330 min weekly helps to reduce CMI effectively.

1. Introduction

Obesity is becoming a serious metabolic disease that affects 650 million adults and poses great health and economic burdens globally [1,2]. It has been proved to be directly associated with metabolic syndrome [3], and serves as an independent risk factor for the occurrence and development of various diseases, including type 2 diabetes mellitus, fatty liver, atherosclerosis, respiratory diseases, and cancers [4,5]. Therefore, studies focusing on elucidating pathogenesis, finding evaluation biomarkers, or exploring effective interventional strategies is urgently needed worldwide.

For the treatment or prevention of obesity, finding a reliable and accurate evaluator which can serve as metabolic monitor is one of the pivotal prerequisites for developing interventional strategies and assessing therapeutic effects. Previous studies have demonstrated that the harm of obesity is determined by the metabolic disturbance, including insulin resistance, dyslipidemia, hypertension, glucose intolerance, etc. [6], and those obese persons without such metabolic abnormalities (also termed metabolically healthy obesity/-metabolically normal obesity) didn't get increased risks for developing cardiometabolic diseases [7]. Therefore, components reflecting the metabolic status should be taken into consideration in developing optimal indicators to evaluate the onset and progression of obesity. Moreover, except for the metabolic alteration, the change of body anthropometrics is another noticeable characteristic for obese individuals. Cardiometabolic Index (CMI) is a new indicator which effectively incorporates the marker of body anthropometrics with metabolism, namely waist height ratio (WHtR) and triglycerides to high-density lipoprotein-cholesterol (TG/HDL-C) ratio [8]. Previously studies have demonstrated its potent associations with various metabolic diseases, such as metabolic associated fatty liver disease [9], atherosclerotic diseases [10], diabetes mellitus [11], hypertension [12], and so on. Besides, a recent study revealed that CMI, as opposed to other indicators (including waist-to-hip ratio, body mass fat index, waist-to-height ratio, etc.), represented the most accurate and reliable index in detecting the risk of developing metabolic syndrome in obese women [13]. Although CMI has been proved to be an optimal indicator for evaluating obesity, few studies have explored the role of CMI as an evaluation index during obesity management.

Amounting evidences have confirmed the beneficial role of physical activity (PA) in lowering the risks of obesity and obesity-related diseases. The 2020 guidelines from the World Health Organization recommend that all adults should perform at least 150–300 min of moderate-intensity PA (MPA), or 75–150 min of vigorous-intensity PA (VPA), or some equivalent combination of MPA and VPA, per week [14]. According to the latest report by the American College of Sports Medicine, various programs can be undertaken to achieve the recommended PA levels, and the programs of exercise for weight loss, personal training, functional fitness, body weight exercises, outdoor activities, home exercise training, wearable technology and strength training with free weights are identified as the top 8 global health and fitness trends for 2022 [15]. However, with the social competition becoming more severe and the living tempo becoming faster, it may be not easy to perform physical activities regularly as WHO recommended. So, some individuals instead choose to complete the recommended physical activities in one or two sessions per week, and thus they are called "weekend warriors" (WWs) [16]. Up to now, although a certain amount of studies have reported that WWs may reap equivalent benefits as regularly active (RA) in lowering the risks for various diseases, including cardiovascular disease [17], depression [18], mental disorder [19], arterial stiffness [20], etc., there are still other studies which get inconsistent conclusion regarding the metabolic benefits of WWs [21]. The study performed by Yun Seo Jang et al. based on the data from Korea National Health and Nutrition Examination Survey revealed that the inactive (OR, 1.38; 95%CI, 1.25–1.53) and WWs (OR, 1.28; 95%CI, 1.02–1.65) groups showed a significant higher likelihood to develop metabolic syndrome as opposed to the RA group [21]. Besides, the results from Tuija Leskinen et al. also indicate that consistently highly active group, instead of WWs group, leads to favorable reduction in cardiometabolic biomarkers, including body mass index, waist circumference, and blood pressure [22]. Given this, although the effectiveness of PA in reducing fat accumulation and preventing obesity has been widely accepted, it remains unclear whether WWs and RA lead to comparable benefits in improving obesity-related metabolic disorders.

Therefore, this study aims to explore the relationship between CMI and PA patterns, specifically focusing on exploring whether the PA pattern of WWs leads to equivalent CMI reduction compared to RA pattern. Our findings may provide valuable reference for the general public to choose their suitable PA pattern to achieve the recommended PA levels.

2. Methods

2.1. Database and study population

The information used in this study can be obtained from the NHANES website (https://www.cdc.gov/nchs/nhanes/index.htm). The National Health and Nutrition Examination Survey (NHANES) is a comprehensive study conducted by the Centers for Disease

Control and Prevention (CDCP) and the National Center for Health Statistics (NCHS) in the United States. This survey is a nationally representative, population-based survey designed to assess the health and nutritional status of adults and children. Before the interviews and tests, all participants provided informed consent, and the NCHS Ethical Review Committee approved the data collection procedures for NHANES. Data in this study were derived from the five continuous NHANES cycles from 2007 to 2008 to 2015–2016. A total of 50,588 respondents were included in the data collection. After excluding individuals with missing data on CMI, PA, and covariates, the final analytical sample comprised 16,442 patients. Fig. 1 presents a flowchart describing the criteria used for participants selection.

2.2. Physical activity categories

In this study, physical activity (PA) was assessed using the physical activity questionnaire (PAQ) in NAHANES, which asked participants about the frequency and duration of vigorous and moderate physical activities, workouts, and leisure activities lasting at least ten consecutive minutes per week. The calculation of PA includes exercise frequency (number of times per week) and duration (length of time). Studies have found that 1 min of high-intensity activity is equivalent to 2 min of moderate-intensity activity [23]. Therefore, the PA calculation formula is 2*vigorous PA + moderate PA [24]. Based on the formula, the total PA time per week was calculated, and PA patterns were classified into four categories: inactive (no vigorous or moderate PA), insufficiently active (<150 min per week of total PA), WWs (at least 150 min per week of total PA in 1 or 2 sessions), and RA (at least 150 min per week of total PA in more than 2 sessions).

2.3. Cardiometabolic index and covariates

CMI was used as a continuous variable in this study. The following formula is used to calculate CMI : CMI = WHtR × [TG (mmol/L)/HDL-C (mmol/L), WHtR = waist circumference (cm)/height (cm) [11]. Covariates were selected based on clinical expertise and previous studies. The following covariates were included in this study, including age, gender, race, education, marital status, diabetes, smoking, drinking, cardiovascular disease (CVD), hypertension, poverty income ratio (PIR), body mass index (BMI), and so on. Gender is divided into male and female, and age is categorized as follows: ≤45, 45–60, and >65. Race was classified as Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, or other races. Education level was categorized as less than high school, high school or equivalent, and some college or above. Marital status was categorized as married, never married and others (including living with partner, divorced, separated, or widowed). Household income is evaluated by the index of PIR. Diabetes was categorized as yes/no/borderline by answering the question of "Doctor told you have diabetes?". Smoking status were divided into three group, including never smoker, former smoker and current smoker, based on the self-reported questionnaire information as previously described [25]. Those who had not smoked 100 cigarettes in their lifetime were classified as never-smokers, and those who had smoked 100 cigarettes in their lifetime but had quitted smoking now were defined as former smokers, while those who had smoked 100 cigarettes in their lifetime and were still smoking now were defined as current smokers. Similarly, drinking status was classified into four categories as previously described [26], including never drinkers, former drinkers, current drinkers and missing. Those who had not get 12 drinks in their lifetime were defined as never-drinkers, and those who had 12 drinks in their lifetime but had quitted drinking were classified as former drinkers, and those who had 12 drinks in their lifetime and were still having at least one drink during the past 12 months were defined as current drinkers, and those who with missing data on drinking were classified as the missing group. BMI is calculated using the following formula: BMI = weight (kg)/height^2 (m^2), and it was divided into three categories: ≤25, 25–30, and >30. The occurrence of CVD outcomes, including congestive heart failure (CHF), coronary heart disease (CHD), angina, cardiac arrest, and stroke, can be determined by diagnosing the five major CVD events through self-reporting. Participants who answered yes to the question, "Have you ever been told by a physician that you had CHD/CHF/angina/a heart attack or a stroke?" were identified as

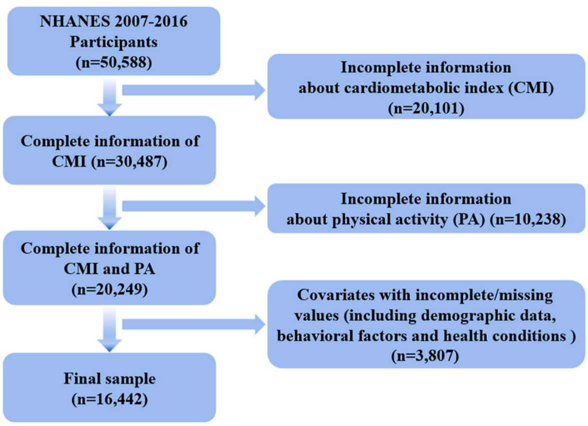

Fig. 1. Flowchart of NHANES participants screening. **Abbreviation:** NHANES, National Health and Nutrition Examination Survey; PA, Physical activity; CMI, cardiometabolic index.

having CVD. Hypertension was diagnosed based on the answer to the question of "Ever told you had high blood pressure?", and those who answered yes were identified as having hypertension.

2.4. Statistical analysis

All statistical analyses were performed by R software (version 4.2.3) in this study. The baseline characteristics of the study population were presented based on the grouping of PA patterns. Continuous variables of age, PIR, BMI, total PA and sedentary time were presented as median (Q1-Q3, interquartile) due to their non-normal distribution characteristics. Categorical variables were expressed as numbers and percentages. The differences of baseline characteristics among different groups were compared using Rao-Scott chi-squared test or Kruskal-Wallis test. Multivariate linear regression models were employed to investigate the relationship between PA patterns and CMI. Besides, subgroup analyses, interaction tests and restricted cubic spline (RCS) regression analysis were also performed to confirm the robustness and nonlinearity of the association between PA and CMI, respectively. Statistical significance was defined by a two-sided P value < 0.05.

Table 1
Participants characteristics according to physical activity patterns.

Characteristics	Overall (n = 16,442)	Inactive (n = 12,910)	Insufficiently active (n = 128)	Weekend warrior (n = 130)	Regularly active (n = 3274)	*P*-value
Age, years	49 (20–80)	52 (20–80)	41 (20–79)	34 (20–76)	38 (20–80)	<0.001
PIR	1.88 (0.00–5.00)	1.87 (0.00–5.00)	2.86 (0.05–5.00)	2.14 (0.10–5.00)	2.98 (0.00–5.00)	<0.001
BMI, kg/cm^2	28.20 (13.18–84.87)	28.70 (13.18–84.87)	26.20 (16.50–56.43)	26.16 (17.50–56.70)	26.50 (16.00–58.76)	<0.001
Total PA, minutes	149.89 (0.00–708)	0 (0–0)	110 (90–120)	240 (180–360)	540 (360–900)	<0.001
Sedentary time, minutes	300 (180–480)	300 (180–480)	420 (240–600)	300 (180–480)	360 (180–480)	<0.001
CMI	0.64 (0.35–1.20)	0.69 (0.38–1.27)	0.50 (0.25–0.95)	0.53 (0.30–0.98)	0.44 (0.25–0.86)	<0.001
Gender, n (%)						<0.001
Male	7950 (48.35%)	5935 (45.97%)	58 (45.31%)	104 (80.00%)	1853 (56.60%)	
Female	8492 (51.65%)	6975 (54.03%)	70 (54.69%)	26 (20.00%)	1421 (43.40%)	
Race, n (%)						<0.001
Mexican American	2761 (16.79%)	2340 (18.13%)	20 (15.62%)	17 (13.08%)	384 (11.73%)	
Other Hispanic	1889 (11.49%)	1556 (12.05%)	8 (6.25%)	19 (14.62%)	306 (9.35%)	
Non-Hispanic White	6737 (40.97%)	5154 (39.92%)	47 (36.72%)	56 (43.08%)	1480 (45.20%)	
Non-Hispanic Black	3376 (20.53%)	2670 (20.68%)	26 (20.31%)	18 (13.85%)	662 (20.22%)	
Other Race	1679 (10.21%)	1190 (9.22%)	27 (21.09%)	20 (15.38%)	442 (13.50%)	
Education level, n (%)						<0.001
Less than high school	4746 (28.87%)	4429 (34.31%)	16 (12.50%)	22 (16.92%)	279 (8.52%)	
High school/ equivalent	3768 (22.92%)	3218 (24.93%)	18 (14.06%)	25 (19.23%)	507 (15.49%)	
	7928 (48.22%)	5263 (40.77%)	94 (73.44%)	83 (63.85%)	2488 (75.99%)	
Marital status, n (%)						<0.001
Married	8453 (51.41%)	6692 (51.84%)	75 (58.59%)	63 (48.46%)	1623 (49.57%)	
Never married	2956 (17.98%)	1943 (15.05%)	26 (20.31%)	36 (27.69%)	951 (29.05%)	
Others	5033 (30.61%)	4275 (33.11%)	27 (21.09%)	31 (23.85%)	700 (21.38%)	
Diabetes, n (%)						<0.001
Yes	2147 (13.06%)	2000 (15.49%)	7 (5.47%)	5 (3.85%)	135 (4.12%)	
No	13,945 (84.81%)	10,618 (82.25%)	118 (92.19%)	125 (96.15%)	3084 (94.20%)	
Borderline	350 (2.13%)	292 (2.26%)	3 (2.34%)	0 (0.00%)	55 (1.68%)	
Smoking, n (%)						<0.001
Never smoker	8995 (54.71%)	6699 (51.89%)	93 (72.66%)	68 (52.31%)	2135 (65.21%)	
Former smoker	3772 (22.94%)	3042 (23.56%)	18 (14.06%)	30 (23.08%)	682 (20.83%)	
Current smoker	3675 (22.35%)	3169 (24.55%)	17 (13.28%)	32 (24.62%)	457 (13.96%)	
Drinking, n (%)						<0.001
Never Drinker	2293 (13.95%)	2005 (15.53%)	10 (7.81%)	9 (6.92%)	269 (8.22%)	
Former Drinker	2897 (17.62%)	2567 (19.88%)	16 (12.50%)	9 (6.92%)	305 (9.32%)	
Current Drinker	10,033 (61.02%)	7343 (56.88%)	93 (72.66%)	102 (78.46%)	2495 (76.21%)	
Missing	1219 (7.41%)	995 (7.71%)	9 (7.03%)	10 (7.69%)	205 (6.26%)	
CVD, n (%)						<0.001
No	15,034 (91.44%)	11,609 (89.92%)	124 (96.88%)	124 (95.38%)	3177 (97.04%)	
Yes	1408 (8.56%)	1301 (10.08%)	4 (3.12%)	6 (4.62%)	97 (2.96%)	
Hypertension, n (%)						<0.001
No	10,487 (63.78%)	7677 (59.47%)	101 (78.91%)	113 (86.92%)	2596 (79.29%)	
Yes	5955 (36.22%)	5233 (40.53%)	27 (21.09%)	17 (13.08%)	678 (20.71%)	

Abbreviations: PA, physical activity; CVD, cardiovascular disease; BMI, body mass index; PIR, ratio of family income to poverty. Variables of age, PIR, BMI, CMI, total PA and sedentary time were presented as Median (Q1-Q3) due to their non-normal distribution characteristics.

3. Results

3.1. Baseline characteristics

As depicted in Fig. 1, a total of 50,588 participants from five different cyclical rounds were recruited for the study. Participants with incomplete information on CMI, PA, and covariates of demographic data (age, gender, race, education, PIR, marital status, BMI), behavioral factors (smoking, drinking, sedentary time), and health conditions (CVD, hypertension, diabetes) were excluded. Finally, a total of 16,442 participants were included in this study.

The baseline characteristics of participants based on different PA groups are presented in Table 1. Gender, age, race, education level, marital status, income level, diabetes, smoking status, alcohol consumption, BMI, CVD, diabetes and hypertension were all found to be significantly associated with the PA patterns. Specifically, individuals classified as WWs were more likely to be male, non-Hispanic White, have some college or above in education, be married, be non-smokers, and with no CVD, diabetes or hypertension.

3.2. The relationship between PA patterns and CMI

The results of multivariate linear regression models for PA patterns and CMI are presented in Table 2 and Fig. 2. As compared to the inactive group, only the regularly active group achieve significant CMI reduction in the non-adjusted (Model 1, $\beta = -0.32$, $P < 0.0001$), partially adjusted model (Model 2, $\beta = -0.24$, $P < 0.0001$) and fully-adjusted model (Model 3, $\beta = -0.13$, $P < 0.0001$). When the regularly active group was defined as the reference group, the groups of insufficiently active and WWs all got significant increase in CMI in model 2 ($\beta = 0.25$, $P = 0.0417$; $\beta = 0.24$, $P < 0.0001$) and model 3 ($\beta = 0.27$, $P = 0.0255$; $\beta = 0.13$, $P < 0.0001$). Although no statistically significant reduction in CMI was observed in WWs group, it is important to note that WWs group still achieve certain beneficial effects in reducing CMI, as reflected by the value of β in all models ($\beta = -0.16$, -0.22, -0.09 for model 1, 2, and 3, respectively).

3.3. Subgroup analyses

To further confirm the association between PA patterns and CMI across different subgroups, subgroup analyses based on demographic characteristics were conducted. As is shown in Table 3, the associations between PA patterns and CMI remained consistent in different subgroups for variables of gender, race, marital status, diabetes, smoking, CVD, hypertension and BMI. In contrast, interaction tests revealed that the associations between PA patterns and CMI were modified by the variables of age, education level and drinking, with the associations between RA and CMI being more pronounced in three subgroups, including age ≤45 or age >60 (P interaction = 0.0473), with high school or above in education level (P interaction = 0.0014), and current drinkers (P interaction = 0.0166).

3.4. Non-linear relationship between total PA in a week and CMI

RCS analysis was employed to examine the relationship between total PA in a week and CMI in non-inactive individuals. The results, as depicted in Fig. 3, revealed a significant, nonlinear, negative correlation between PA and CMI ($P = 0.013$, P for nonlinearity $= 0.015$). As the total PA in a week increases, CMI gradually decreases, and such negative correlation is more pronounced when the total PA is less than 330 min per week. In contrast, once the total PA in a week exceeds 330 min, the trend of CMI reduction remains consistently high without significant changes as the total PA continues to increase.

Table 2
The relationship between physical activity patterns and CMI.

	Model 1 β (95%CI) P value	Model 2 β (95%CI) P value	Model 3 β (95%CI) P value
PA pattern			
Inactive	0	0	0
Insufficiently active	−0.09 (−0.34, 0.15) 0.4505	0.01 (−0.23, 0.25) 0.9531	0.14 (−0.09, 0.37) 0.2458
Weekend warrior	−0.16 (−0.40, 0.08) 0.2042	−0.22 (−0.45, 0.02) 0.0725	−0.09 (−0.32, 0.14) 0.4204
Regularly active	−0.32 (−0.38, −0.27) <0.0001	−0.24 (−0.30, −0.19) <0.0001	−0.13 (−0.19, −0.07) <0.0001
P for trend	<0.001	<0.001	<0.001
PA pattern			
Regularly active	0	0	0
Inactive	0.17 (−0.08, 0.41) 0.1823	0.03 (−0.21, 0.27) 0.8315	0.03 (−0.20, 0.27) 0.7696
Insufficiently active	0.23 (−0.02, 0.47) 0.0684	0.25 (0.01, 0.49) 0.0417	0.27 (0.03, 0.50) 0.0255
Weekend warrior	0.32 (0.27, 0.38) <0.0001	0.24 (0.19, 0.30) <0.0001	0.13 (0.07, 0.19) <0.0001
P for trend	<0.001	<0.001	<0.001

Abbreviations: PA, physical activity; CMI, cardiometabolic index; CVD, cardiovascular disease; BMI, body mass index; PIR, ratio of family income to poverty.
Model 1 was the univariate model in which no covariates were adjusted; Model 2 was adjusted for demographic covariates, including age, gender, race, education, PIR, and marital status; Model 3 was adjusted for variables of age, gender, race, education, PIR, and marital status, BMI, smoking, drinking, diabetes, CVD and hypertension.

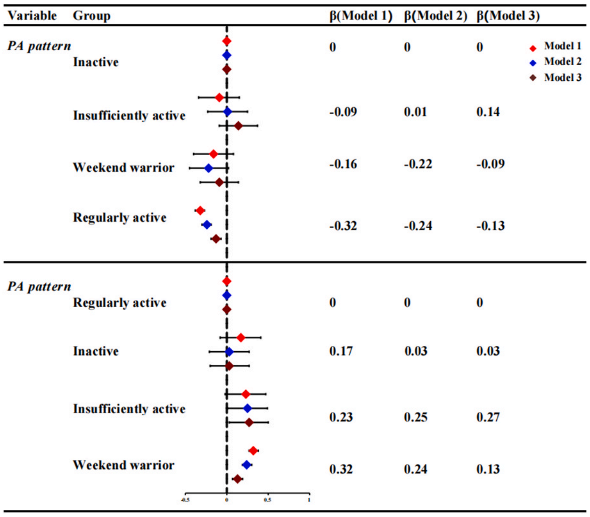

Fig. 2. The forest plot revealed the association between PA patterns and CMI in adults. Model 1 was the univariate model in which no covariates were adjusted; Model 2 was adjusted for demographic covariates, including age, gender, race, education, PIR, and marital status; Model 3 was adjusted for variables of age, gender, race, education, PIR, and marital status, BMI, smoking, drinking, diabetes, CVD and hypertension. **Abbreviations:** PA, physical activity; CMI, cardiometabolic index; CVD, cardiovascular disease.

The non-linear relationship between total PA in a week and CMI in different subgroups were also performed in this study. As shown in Fig. 4, no significant and nonlinear associations were found between total PA per week and CMI in the subgroup of insufficiently active (P for overall = 0.993, P for nonlinearity = 0.976) (Fig. 4A) and WWs (P for overall = 0.499, P for nonlinearity = 0.358) (Fig. 4B), while significant and nonlinear association was observed in the subgroup of RA group (P for overall <0.0001, P for nonlinearity = 0.037) (Fig. 4C). As opposed to total PA per week, a significant, positive, and linear association between sedentary time and CMI was identified by RCS analysis (Fig. 5).

4. Discussion

In this study, we mainly focused on exploring the association of PA pattern and CMI. Our results firstly indicated that only the RA group achieved significant CMI reduction, while WWs group did not reap equivalent significant CMI reduction. Subgroup analyses revealed that the associations between RA and CMI remained consistent in all strata, and variables of age, education level, and drinking were found to have significant modification effect on the associations, which were more pronounced in the subgroup of participants with age≤45 or >60, with higher education level, and who are current drinkers. Furthermore, RCS analysis indicated that total PA in a week was significantly, nonlinearly associated with CMI in non-inactive adults, and that total PA more than 330 min per week can reap the optimal CMI reduction. In contrast, a significant, positive, and linear association between sedentary time and CMI was identified by RCS analysis. Additionally, RCS analysis in different PA subgroups revealed that significant and non-linear relationship between total PA in a week and CMI was identified only in RA group, but not in insufficiently active or WWs group. Together, our results indicated that being regularly active (especially with total PA per week >330 min) leads to favorable CMI reduction, but WWs also bring some benefits in reducing CMI.

Previous studies have suggested that the detrimental effects from obesity lie in the metabolic disturbances, such as insulin resistance, dyslipidemia, hypertension, glucose intolerance, and so on [6]. A meta-analysis has revealed that metabolically healthy obese adults do not show increased risks for CVD or elevated inflammation levels [27,28]. Therefore, in this study, CMI, a comprehensive indicator which integrated anthropometrics measure (WHtR) with lipid metabolism index (TG/HDL-C ratio), was selected to evaluate the effectiveness of different PA patterns on obesity. WHtR has been proved to be a better screening tool than other anthropometric indexes (such as waist circumference, BMI) for adults in assessing cardiometabolic risks [29]. Besides, other studies have revealed that the value of 0·5 for WHtR is a suitable global boundary value for predicting CVD and diabetes [30]. Numerous studies have revealed the favorable and stable association between TG/HDL-C ratio, CVD, diabetes and metabolic syndrome [31–33]. Elevated baseline TG/HDL-C ratio was reported to associate with significantly higher risk of these diseases after adjusting for the well-established potential risk factors. These evidences have suggested that an indicator which incorporates WHtR and TG/HDL-C ratio together can better reflect the anthropometric and metabolic alterations in the obese population.

The essential role of PA and exercise in improving cardiometabolic health and preventing obesity has been widely recognized and emphasized by numerous physicians and healthcare professionals [34]. In our study, we found that only being regularly active can achieve significant CMI reduction, while being WWs didn't get similar CMI reduction. Previously, several studies have demonstrated that being WWs or regularly active usually reap equivalent health benefits in various aspects, including reducing all-cause/CVD/cancer mortality [35], increasing sleep efficiency [36], improving cardiovascular outcomes [37], alleviating mental

Table 3
The relationship between PA patterns and CMI in subgroups.

Characteristics	Inactive	Insufficiently active	Weekend warrior	Regularly active	P for interaction
Gender					0.2297
Male	Reference	−0.09 (−0.48, 0.30) 0.6505	−0.08 (−0.37, 0.21) 0.5958	−0.17 (−0.26, −0.08) 0.0002	
Female	Reference	0.29 (0.03, 0.56) 0.0310	−0.23 (−0.66, 0.20) 0.2995	−0.08 (−0.15, −0.01) 0.0237	
Age					0.0473
≤45	Reference	−0.12 (−0.43, 0.20) 0.4749	−0.24 (−0.52, 0.04) 0.0911	−0.15 (−0.22, −0.07) 0.0002	
45-60	Reference	0.49 (0.01, 0.96) 0.0465	−0.03 (−0.69, 0.63) 0.9242	−0.12 (−0.25, 0.02) 0.0886	
>60	Reference	0.43 (−0.10, 0.96) 0.1106	0.70 (0.15, 1.25) 0.0130	−0.14 (−0.25, −0.03) 0.0128	
Race					0.4349
Mexican American	Reference	−0.27 (−0.85, 0.32) 0.3754	0.13 (−0.51, 0.77) 0.6892	−0.20 (−0.35, −0.05) 0.0108	
Other Hispanic	Reference	0.26 (−0.90, 1.42) 0.6646	0.15 (−0.61, 0.91) 0.6969	0.02 (−0.20, 0.24) 0.8547	
Non-Hispanic White	Reference	0.31 (−0.12, 0.74) 0.1585	−0.16 (−0.55, 0.24) 0.4383	−0.10 (−0.20, 0.00) 0.0586	
Non-Hispanic Black	Reference	0.17 (−0.12, 0.47) 0.2439	−0.13 (−0.48, 0.23) 0.4844	−0.09 (−0.16, −0.02) 0.0146	
Other Race	Reference	0.06 (−0.31, 0.44) 0.7469	−0.13 (−0.56, 0.30) 0.5668	−0.16 (−0.28, −0.04) 0.0079	
Education					0.0014
Less than high school	Reference	0.14 (−0.64, 0.93) 0.7182	0.32 (−0.35, 0.99) 0.3497	−0.04 (−0.23, 0.16) 0.7246	
High school or equivalent	Reference	1.19 (0.61, 1.76) <0.0001	−0.30 (−0.79, 0.19) 0.2247	−0.15 (−0.27, −0.03) 0.0170	
Some college or above	Reference	−0.08 (−0.32, 0.16) 0.5252	−0.17 (−0.42, 0.09) 0.2029	−0.15 (−0.21, −0.09) <0.0001	
Marital status					0.5323
Married	Reference	0.29 (−0.01, 0.59) 0.0567	0.05 (−0.28, 0.37) 0.7830	−0.10 (−0.18, −0.02) 0.0125	
Never married	Reference	−0.02 (−0.45, 0.41) 0.9250	−0.06 (−0.42, 0.31) 0.7571	−0.10 (−0.20, −0.01) 0.0360	
Others	Reference	−0.13 (−0.68, 0.42) 0.6427	−0.40 (−0.91, 0.12) 0.1324	−0.20 (−0.33, −0.07) 0.0019	
Diabetes					0.8648
Yes	Reference	−0.06 (−1.69, 1.58) 0.9469	0.11 (−1.82, 2.03) 0.9148	−0.36 (−0.77, 0.05) 0.0825	
No	Reference	0.15 (−0.06, 0.35) 0.1563	−0.09 (−0.29, 0.11) 0.3791	−0.12 (−0.17, −0.07) <0.0001	
Smoking					0.4726
Never smoker	Reference	0.13 (−0.13, 0.38) 0.3333	0.03 (−0.27, 0.33) 0.8687	−0.11 (−0.17, −0.04) 0.0025	
Former smoker	Reference	0.03 (−0.56, 0.61) 0.9331	−0.14 (−0.60, 0.32) 0.5537	−0.18 (−0.29, −0.06) 0.0029	
Current smoker	Reference	0.39 (−0.34, 1.12) 0.2900	−0.32 (−0.86, 0.22) 0.2410	−0.20 (−0.37, −0.04) 0.0131	
Drinking					0.0166
Never Drinker	Reference	0.03 (−0.85, 0.90) 0.9537	−0.22 (−1.14, 0.71) 0.6437	−0.05 (−0.24, 0.14) 0.6008	
Former Drinker	Reference	1.45 (0.65, 2.25) 0.0004	0.23 (−0.82, 1.29) 0.6642	−0.18 (−0.38, 0.03) 0.0914	
Current Drinker	Reference	−0.02 (−0.27, 0.24) 0.8960	−0.09 (−0.33, 0.15) 0.4634	−0.14 (−0.20, −0.08) <0.0001	
Missing	Reference	−0.35 (−1.01, 0.31) 0.3037	−0.38 (−1.01, 0.25) 0.2321	−0.10 (−0.27, 0.06) 0.2181	
CVD					0.2862
No	Reference	0.11 (−0.11, 0.34) 0.3218	−0.10 (−0.33, 0.12) 0.3733	−0.13 (−0.18, −0.07) <0.0001	
Yes	Reference	0.94 (−0.83, 2.71) 0.2967	0.27 (−1.18, 1.73) 0.7116	−0.37 (−0.76, 0.02) 0.0612	
Hypertension					0.7594
Yes	Reference	0.09 (−0.45, 0.63) 0.7488	−0.09 (−0.78, 0.59) 0.7856	−0.24 (−0.37, −0.12) 0.0001	
No	Reference	0.16 (−0.09, 0.40) 0.2183	−0.07 (−0.31, 0.16) 0.5365	−0.10 (−0.16, −0.04) 0.0017	
BMI categorical					0.1573
≤25	Reference	−0.04 (−0.19, 0.11) 0.6149	−0.10 (−0.25, 0.05) 0.2115	−0.08 (−0.12, −0.04) 0.0002	
25-30	Reference	−0.02 (−0.44, 0.39) 0.9177	0.20 (−0.20, 0.60) 0.3293	−0.11 (−0.21, −0.01) 0.0326	
>30	Reference	0.52 (−0.04, 1.07) 0.0679	−0.33 (−0.91, 0.24) 0.2517	−0.22 (−0.34, −0.09) 0.0007	

Abbreviations: PA, physical activity; CMI, cardiometabolic index; CVD, cardiovascular disease; BMI, body mass index; PIR, ratio of family income to poverty. The variables adjusted for subgroup analyses were consistent with Model 3 in Table 2 except the stratifying variable.

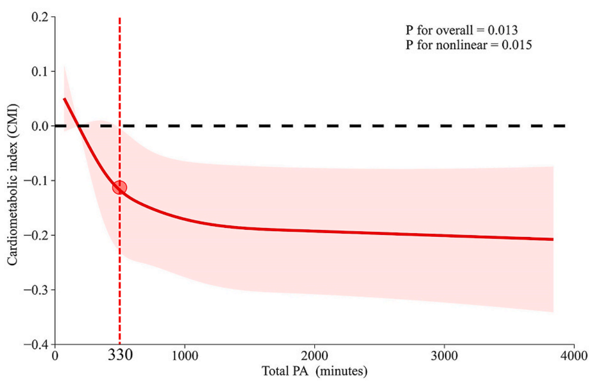

Fig. 3. Identification of the association between total PA in a week and CMI in non-inactive individuals by RCS analysis. Variables of age, gender, race, education, PIR, and marital status, BMI, smoking, drinking, diabetes, CVD and hypertension were adjusted. **Abbreviations:** PA, physical activity; CMI, cardiometabolic index; RCS, restricted cubic spline; CVD, cardiovascular disease.

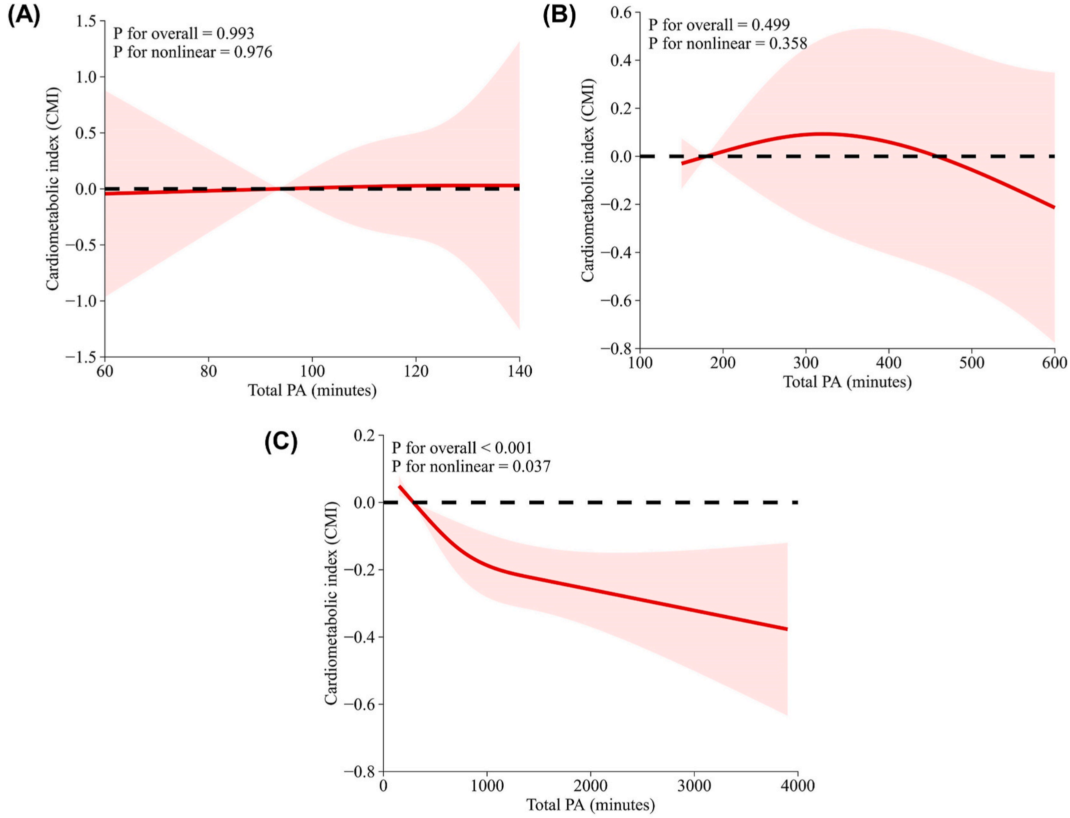

Fig. 4. RCS analyses to explore the association between total PA and CMI in different subgroups. (A) Insufficiently active group, (B) Weekend warriors group, (C) Regularly active group. Variables of age, gender, race, education, PIR, and marital status, BMI, smoking, drinking, diabetes, CVD and hypertension were adjusted. **Abbreviations:** PA, physical activity; CMI, cardiometabolic index; RCS, restricted cubic spline; CVD, cardiovascular disease.

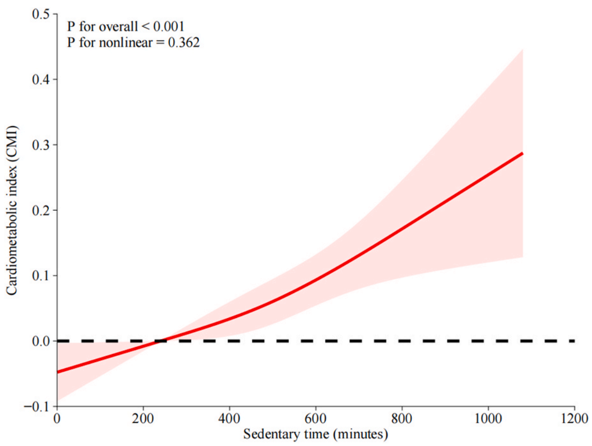

Fig. 5. Determination of the association between sedentary time in a week and CMI by RCS analysis. Variables of age, gender, race, education, PIR, and marital status, BMI, smoking, drinking, diabetes, CVD and hypertension were adjusted. **Abbreviations:** PA, physical activity; CMI, cardiometabolic index; RCS, restricted cubic spline; CVD, cardiovascular disease.

disorders [19], lowering depression risk [18], and so on. Several possible explanations may account for the different findings. The key distinctions between WWs and RA lie in the frequency and duration of PA, both of which are fundamental for the health benefits. Firstly, a previous research revealed that higher exercise frequency (number of sessions per week) in aerobic exercise or combined aerobic and resistance exercise was significantly associated with lower HbA1c levels, whereas the intensity of aerobic exercise (% of maximum heart rate) showed no significant association with the level of benefit obtained [38]. This suggests that the WWs pattern may not provide adequate benefits for individuals with T2DM. Furthermore, the study performed by Ryuki Hashida et al. also revealed that engaging in exercise for at least 40–45 min per session, three times per week for 12 weeks, regardless of whether it was aerobic or resistance exercise, led to improvements in hepatic steatosis [39]. This implies that engaging in exercise only during two sessions (as WWs) may not be sufficient to obtain significant metabolic benefits. Additionally, the results from B Fernhall et al. suggests that favorable HDL-C increase from PA appears to occur incrementally and statistical significance can be achieved when individuals undertake moderate intensity exercises, 3–5 times per week, with an energy expenditure of 1200–1600 kcal per week [40]. Hence, WWs may not sufficient to yield favorable metabolic benefits as desired, which are essential to control obesity and lower the risk of cardiometabolic diseases.

Except for the above-mentioned findings, our results also revealed that the relationship between PA patterns and CMI was modified by the variables of age, education level and drinking status. Previously, Ichiro Wakabayashi has reported that CMI was potently influenced by age, and CMI was higher in middle-aged individuals and tended to be higher as age increased [41]. This means that the CMI-PA association in middle-aged individuals may be weakened by age, which is a potential reason why the CMI-PA association was more pronounced in individuals with age$\leq$45 or $>$60 in our study. Furthermore, abundant evidences have indicated the major role of education differences in cardiometabolic risk and disease [42]. A study performed by Diego Montano suggested that individuals with no qualification (lower education level) obtained obviously higher risks for deteriorated cardiometabolic indicators, including BMI, glycated haemoglobin HbA1c, total cholesterol, etc. [42]. Education may modify the CMI-PA association in a rather complexed pattern, possibly via changing the behavioural, cognitive and attitudinal modification to PA. Additionally, two studies conducted by Ichiro Wakabayashi uncovered that drinking, especially light-to-moderate alcohol drinking, was inversely associated with CMI, thus modifying the association between CMI and diabetes, as well as hyperglycemia [43,44]. Since drinking contributes to certain CMI reduction, it is reasonable that regular activity leads to more pronounced CMI reduction in the subgroup of current drinkers.

Certain limitations in our study should be acknowledged. Firstly, due to the cross-sectional nature of the analysis, causal relationship between different PA patterns and CMI cannot be inferred. Additionally, although we adjusted for various potential confounding factors, the presence of unmeasured confounders cannot be completely ruled out. Finally, future studies should conduct more comprehensive analyses, such as integrating PA patterns with metabolomics alterations, to provide a deeper understanding of the topic.

In conclusion, our findings highlighted the significance of PA in controlling obesity and managing CMI. Being regularly active throughout a week, as opposed to only being WWs, was associated with sustained and significant reductions in CMI. Notably, a total of $\geq$330 min of PA per week appeared to be particularly effective in reducing CMI. Noteworthily, although WWs did not contribute to sustainable and significant CMI reduction after adjusted for all well-established confounding factors, it still brings certain CMI reduction for individuals practicing WWs. Therefore, for those who without abundant time performing regular activities, they can also benefit from being WWs.

Ethics approval and consent to participate

NHANES was conducted with the approval of the Ethical Review Board of the National Centre for Health Statistics, and all participants provided written informed consent. No additional ethical review board approval was required to analyze the anonymized NHANES data.

Consent for publication

Not applicable.

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Data availability statement

The dataset utilized for this study has been deposited into a publicly available repository, which can be acquired by accessing the following hyperlink: https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx.

CRediT authorship contribution statement

Hao Xue: Supervision, Software, Conceptualization. **YuChi Zou:** Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **QianKun Yang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zhao Zhang:** Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jie Zhang:** Resources, Investigation, Formal analysis, Data curation, Conceptualization. **XiaoYu Wei:** Validation, Software, Methodology, Investigation, Data curation. **JiangLing Zhou:** Software, Methodology, Investigation, Data curation. **Xiao Liang Tao:** Resources, Methodology, Investigation, Formal analysis. **ChengMin Zhang:** Software, Project administration, Conceptualization. **YiJu Xia:** Supervision, Software, Project administration, Conceptualization. **Fei Luo:** Supervision, Project administration, Funding acquisition, 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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