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Research article

The association between physical activities combined with dietary habits and cardiovascular risk factors

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A R T I C L E I N F O

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Additive interaction

A B S T R A C T

Objectives: The aim of this study was to investigate the association between physical activities combined with dietary habits and cardiovascular risk factors in adults from Nanjing, China.
Methods: The cross-sectional survey conducted in 2017 involved a sample of 60 283 individuals aged ≥18 years in Nanjing municipality, China. The sampling method used was multistage stratified cluster sampling. The primary outcomes from multivariate logistic regression analysis with adjusted potential confounders were the relationships between physical activities combined with dietary habits and cardiovascular risk variables. Relative excess risk due to interaction (RERI), attributable proportion due to interaction (AP), and synergy index (S) were used to assess an additive interaction between dietary habits and physical activities.
Results: After adjusting potential confounders, cardiovascular risk factors were significantly associated with the association of physical inactivity and unhealthy diet, with the highest odds ratios (ORs) for low density lipoprotein-cholesterol (HLDL-c) (1.64, 95% CI [1.47, 1.84]) and hypertension (1.55, 95% CI [1.46, 1.64]). Additive interactions between physical inactivity and unhealthy diet were found in on cardiovascular risk factors of higher low-density lipoprotein-cholesterol (HLDL-c) (S, 2.57; 95% CI [1.27, 5.21]), type 2 diabetes (T2D) (S, 1.96; 95% CI [1.23, 3.13]), dyslipidemia (S, 1.69; 95% CI [1.08, 2.66]) and hypertension (S, 1.46; 95% CI [1.12, 1.89]). Their RERI was 0.39 (95% CI [0.18, 0.60]), 0.22 (95% CI [0.09, 0.35]), 0.11 (95% CI [0.03, 0.19]) and 0.17 (95% CI [0.06, 0.28]), respectively. OR of being HLDL-c, T2D, hypertension and dyslipidemia in participants of physical inactivity and unhealthy diet was 24%, 15%, 11% and 8.3%, respectively. Multiplicative interaction was detected in obesity, hypertension, T2D and HLDL-c.
Conclusion: An unhealthy diet and physical inactivity were strongly linked to cardiovascular risk factors. This study also showed that an unhealthy diet and physical inactivity combined to produce an additive effect on T2D, hypertension, HLDL-c, and dyslipidemia, suggesting a higher risk than the total of these factors, especially HLDL-c. Preventive strategies aimed at reducing cardiometabolic risks such as hypertension, T2D, HLDL-c, and dyslipidemia are necessary for targeting physical inactivity and unhealthy diet.

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1. Introduction

The majority of deaths in China are caused by non-communicable diseases (NCDs). In 2019, they were responsible for 90.1% (9.60 million) of the 10.65 million deaths and 85.1% (0.325 billion) of the 0.382 billion disability-adjusted life years (DALYs) that occurred in Chinese people [1]. In China, the leading cause of deaths from cardiovascular diseases (CVDs) and disability-adjusted life years (DALYs) are caused by stroke and ischemic heart disease (IHD). In 2019, these conditions caused 4.58 million deaths (43.03% of all deaths) and 91.9 million DALYs (24.05% of all DALYs) [1]. China aims to cut the number of premature deaths from NCDs by one-third by 2030. In that case, there is an urgent need to concentrate on adopting current cost-effective therapies and health policies [2]. Various dietary-related dangers combined with a decline in physical activities have likely contributed to the sharp rise in incidence of NCDs [3,4]. There is mounting evidence linking unhealthy diet and physical inactivity to NCDs, especially CVDs [5] and metabolic syndromes (MetS) [6]. US cohort studies suggest that a healthy lifestyle with regular exercise and a balanced diet could reduce about 33% of cardiovascular deaths [7]. Cardiometabolic health is favorable with moderate to vigorous physical activities [8]. Additionally, numerous studies have demonstrated that exercise lowers non-traditional cardiovascular risk factors in adolescents, including inflammatory markers and irregular heart rate [9–11].

According to *the 2008 Physical Activity Guidelines* for Americans, an individual should engage in moderate-intensity aerobic activity for at least 150 min or vigorous-intensity aerobic activity for 75 min per week [12]. However, 43.3% of Americans are physically sedentary, an exceedingly common condition worldwide [13]. Similar figures are found in Shenzhen, China, where the percentage of people who are not physically active is 63.1% [14], and in Shanghai, where the percentage is only 18.4% of participants engaged in physical activities [15]. In 1990, there were 0.95 million (95% UI: 0.46 to 1.93 million) DALYs in China because of low physical inactivity; by 2019, that figure has risen to 2.51 million (95% UI: 1.20 to 4.84 million) [1].

With the economic boom, the dietary pattern of Chinese people has already changed [16]. The daily intake of vegetables and fruits is lower than the recommended level, but meat and salt are consumed in excess [17]. Long-term prospective observational studies have shown a potential causal relationship between certain dietary components (including fruits, vegetables, trans fat, and salt) and non-communicable diseases like diabetes, colon cancer, and cardiovascular diseases [18,19]. In 2019, the second leading modifiable risk factor for attributable CVDs burden was dietary risks. In China, dietary risks were responsible for 1.76 million (95% UI: 1.30 to 2.30 million) annual mortality and 39.05 million (95% UI: 29.19 to 49.71 million) annual DALYs [20]. Consuming a high intake of grains, beans, and veggies can reduce the risk of getting cardiometabolic disease [17]. In the current investigation, we examined 5 dietary components based on previously identified risky dietary factors for CVDs [21] and related studies in Nanjing, China [22,23].

Most prior studies focused on the single relationship between dietary habits and metabolic syndromes such as obesity, high blood pressure, dyslipidemia, and hyperglycemia or between physical activities and metabolic syndromes [24–26]. Metabolic syndromes have been identified as risk factors for several chronic diseases, including diabetes, renal disease, and cardiovascular diseases. The analysis of the literature reveals that the association between physical activities combined with dietary habits and cardiometabolic indicators are scant. Thus, the current study aims to investigate their relationship and interaction with cardiometabolic risk factors in Chinese individuals from Nanjing.

2. Methods

2.1. Study design and participants

The Chronic Diseases and Risk Factors Survey in Nanjing, which took place between January 2017 and June 2018, was a population-based, cross-sectional study conducted in Nanjing, in the eastern Chinese province of Jiangsu. The multistage stratified random cluster sampling method was adopted to obtain a representative sample of individuals in the general population over the age of 18 [27]. Firstly, five districts were random, taking into consideration the districts' geographic location and level of economic and cultural development. Secondly, four rural townships or urban streets from each chosen district were randomly chosen by probability proportion to size (PPS). Thirdly, three administrative villages or neighborhood communities from each township/street were selected based on PPS. Fourthly, one residential group with at least 50 households was randomly drawn by a simple random sampling from each chosen administrative village/neighborhood community. Finally, one eligible individual was randomly selected by a Kish grid from each chosen household. Inclusion criteria: (i) aged 18 years and older; (ii) lived in local villages/communities for at least 6 months; (iii) agreed to participate in all procedures and signed the informed consent. Exclusion criteria: (i) communal residences (e.g., university dormitory, military unit, nursing home); (ii) patients with severe diseases or cognitive, language, or mental disorders who could not participate in the interview; (iii) pregnancy. This study was approved by the Academic and Ethical Committee of Nanjing Municipal Center for Disease Control and Prevention (Nanjing CDC).

2.2. Sample size

The sample size of this study was roughly 58 250, based on the 10.4% prevalence of diabetes among Chinese individuals over the age of 18 [27], α of 0.05, the relative error of sampling of 5%, a design effect of 4 and a non-response rate of 10%. A total of 61 098 adult residents were invited to participate in the study, and finally, 60 283 eligible individuals were recruited.

2.3. Questionnaire data collection

Anthropometric measurements, laboratory testing, and face-to-face interviews were conducted at the local community health service center in the participants' residential area to collect the date. Before collecting data via questionnaires, all investigators underwent standardized training to ensure data quality. A structured questionnaire was created that asked questions about age, gender, marital status, socioeconomic characteristics (education, occupation, and yearly household income) and lifestyle risk factors (drugs, alcohol, smoking, physical activities during leisure time, and dietary habits), as well as medical history.

Education level was divided into three categories: elementary (years of schooling <7 years), secondary (7–12 years), and beyond secondary (>12 years). The yearly household income per capita calculation entails dividing the aggregate household income by the entire count of family members, which is categorized into three groups: lower, middle, and higher. The physical activity level (PAL) was determined by the International Physical Activity Questionnaire (IPAQ) [12,28]. The four PAL domains—physical activity at work, at home, transportation, and leisure—were assessed and assigned a metabolic equivalent of task (MET). 4 and 8 METs, respectively, were used to represent moderate and vigorous activities. Based on a weekly average of 600 MET minutes, PAL was categorized as either physical inactivity (defined as <600 MET minutes) or physical activity (defined as ≥ 600 MET minutes). The amount of food and beverages consumed over the preceding year, as well as the frequency of consumption (daily, weekly, monthly, yearly, or never), were measured using a validated semi-quantitative food frequency questionnaire (FFQ) [29]. Examples of serving sizes were given to the participants, and they were asked to report how many serves they typically consumed of food and drink per time. Individuals were classified as having unhealthy dietary habits if they met three or more of the following criteria [30,31]: less than 400 g of fruits and vegetables per day, less than 300 g of dairy products per day, less than 25 g of bean products (e.g., tofu, dry beans, bean sprouts, soy chicken, and bean curd sheets), more than 100 g of red meat (like pork, beef, and mutton) per day, and more than 5 g of salt per day [32].

Participants were further divided into four groups: physical activities and healthy diet, physical activities and unhealthy diet, physical inactivity and healthy diet, and physical inactivity and unhealthy diet, with the first group as the reference.

2.4. Physical examinations

Each participant was instructed to wear light clothing and maintain an erect stance while barefoot in to measure their height and weight. The mid-point in a horizontal plane between the inferior margin of the last rib and the iliac crest was used to calculate the waist circumference (WC). The maximum protrusion level of the buttocks was used to measure the hip circumference (HC). The body weight (kg) divided by the square of the height (m) yields the body mass index (BMI). After 10 min of rest, three blood pressure (BP) readings were taken by skilled professionals using an electronic sphygmomanometer (OMRON HBP-1300, Japan). The mean value of the last two BP measurements was recorded.

2.5. Blood sample collection and biochemical analyses

Participants were collected venous blood samples after fasting overnight for at least 10 h. The glucose oxidase method was used to measure fasting blood glucose (FBG). Low-density lipoprotein cholesterol (LDL-c), high-density lipoprotein cholesterol (HDL-c), triglyceride (TG), and total cholesterol (TC) were measured utilizing an immunoassay analyzer (Abbott Laboratories, Illinois, USA).

2.6. Definition of cardiovascular risk factors

Participants were categorized into underweight (BMI<18.5 kg/m^2), normal (18.5 kg/m^2≤BMI<24.0 kg/m^2), overweight (24.0 kg/m^2≤BMI<28.0 kg/m^2), and obesity (BMI≥28.0 kg/m^2) according to the Chinese-specific cut-off point of BMI [33]. For men, center obesity was defined as WC ≥ 95 cm, and for women, WC ≥ 90 cm [33]. Diabetes was defined as FPG ≥7.0 mmol/L, and/or self-reported current treatment with anti-diabetes medication (insulin or oral hypoglycemic agents) [34]. Hypertension was defined as an average mean systolic BP (SBP) ≥140 mmHg and/or an average diastolic BP (DBP) ≥90 mmHg, and/or self-reported current treatment with antihypertensive medication in the past two weeks [35]. Dyslipidemia was defined as having at least one of the following in the field survey: LDL-C ≥4.1 mmol/L, HDL-C <1.0 mmol/L, TG ≥ 2.3 mmol/L, TC ≥ 6.2 mmol/L, and/or self-reported history of dyslipidemia and/or the use of antilipemic medication [36].

2.7. Statistical analysis

Numbers and proportions were expressed for categorical data, while mean ± standard deviation (SD) was utilized for continuous variables. The Chi-square test and variance analysis methods were applied to examine differences in categorical and continuous data, respectively. The weighted means or prevalence rates were determined by the weight coefficients to represent the total Nanjing adults aged 18 years and older. Weight coefficients included the sampling weight for differential selection probabilities, as well as the post-stratification weights, which harmonized the standard population of the 2009 Nanjing Sixth National Population Census in terms of age and gender composition [37].

Taking into consideration potential confounding variables, multivariate linear regression analyses were performed to identify the relationship between physical activities combined with dietary habits and continuous outcomes. Standardized beta coefficients with corresponding 95% confidence intervals (95% CIs) were calculated. Multivariate logistic regression analyses were used to identify the association between physical activities combined with dietary habits and binary outcomes. The results were presented as Odds ratio (OR) with the corresponding 95% CI. All models were adjusted for age, gender, education, occupation, income, smoking and drinking. Statistical analyses were conducted by SPSS software (version 20; IBM, Armonk, NY, USA). Statistical power analyses were performed using the 'pwr' R package [38]. 80% statistical power is the commonly accepted level [39]. All P-values had a two-tailed significance level of <0.05.

A multiplicative interaction was assessed through the term of physical activities dietary habits interaction in the multivariate logistic regression models. The additive interaction was analyzed using Excel 2019 software developed by Andersson et al. [40]. Relative risk due to interaction (RERI), attributable proportion (AP), synergy index (S) were calculated using the regression coefficients and covariance matrix obtained from the multi-variate logistic regression analyses.

$$RERI = \mathrm{OR}_{11} - OR_{10} - OR_{01} + 1 \tag{1}$$

$$S = (OR_{11} - 1) \ / \ [(OR_{01} - 1) + (OR_{10} - 1)] \tag{2}$$

$$AP = \mathrm{RERI} \ / OR_{11} \tag{3}$$

where OR_{11} is the ratio in the group with exposures a and b (1 = exposed, 0 = unexposed) compared with the doubly unexposed group.

Table 1
Social-demographic and anthropometric characteristics of participants classified by physical activities and dietary habits.

Characteristics	Physical activities		Physical inactivity		*P* value
	Healthy diet	Unhealthy diet	Healthy diet	Unhealthy diet	
Social-demographic characteristics					
Age (n, %)					<0.001
18–34 years	2023 (30.2)	6046 (39.6)	3717 (35.8)	11376 (40.7)	
35–59 years	2992 (44.8)	6402 (41.8)	4595 (44.3)	11543 (41.3)	
>60 years	1669 (25.0)	2836 (18.6)	2066 (19.9)	5018 (18.0)	
Sex (n, %)					<0.001
Male	3520 (52.7)	8299 (54.3)	4815 (46.4)	13214 (47.3)	
Female	3164 (47.3)	6985 (45.7)	5563 (53.6)	14723 (52.7)	
Marriage (n, %)					<0.001
Single	1310 (17.3)	3157 (21.9)	1624 (13.9)	4465 (16.7)	
Married/living with a partner	5981 (79.1)	10807 (75.0)	9582 (82.3)	21166 (79.4)	
Separated/divorced/widowed	270 (3.6)	443 (3.1)	444 (3.8)	1034 (3.9)	
Socioeconomic characteristics					
Annual household income per capita (thousand yuan)	40.1 (37.6)	39.4 (31.2)	38.0 (35.1)	35.2 (33.6)	<0.001
Education level (n, %)					<0.001
<7 years	654 (9.8)	1034 (6.8)	1136 (10.9)	2634 (9.4)	
7–12 years	3291 (49.2)	6493 (42.5)	5149 (49.6)	12087 (43.3)	
>12 years	2739 (41.0)	7757 (50.7)	4093 (39.5)	13216 (47.3)	
Occupation (n, %)					<0.001
Blue collar	2016 (30.2)	4472 (29.3)	3876 (37.3)	10162 (36.4)	
White collar	1983 (29.7)	5278 (34.5)	3056 (29.4)	9089 (32.5)	
Unemployed/retired/student	2685 (40.1)	5534 (36.2)	3446 (33.3)	8686 (31.1)	
Obesity-related variables					
BMI (kg/m^2)	23.54 (3.32)	23.81 (3.40)	23.56 (3.22)	23.98 (3.24)	<0.001
BMI classification (n, %)					<0.001
<18.5 kg/m^2	220 (3.3)	617 (4.0)	424 (4.1)	1290 (4.6)	
18.5–23.9 kg/m^2	3314 (49.6)	8313 (54.4)	5293 (51.0)	14935 (53.5)	
24.0–27.9 kg/m^2	2427 (36.3)	5018 (32.8)	3519 (33.9)	9148 (32.7)	
≥28.0 kg/m^2	723 (10.8)	1336 (8.7)	1142 (11.0)	2564 (9.2)	
WC (cm)	81.15 (9.72)	81.63 (9.79)	81.29 (9.42)	82.30 (9.41)	<0.001
HC (cm)	93.46 (9.63)	94.24 (9.10)	94.06 (9.07)	94.85 (8.84)	<0.001
Metabolism-related variables					
SBP (mmHg)	122.89 (19.47)	124.04 (21.25)	123.40 (16.95)	125.13 (16.81)	<0.001
DBP (mmHg)	77.01 (15.05)	77.92 (14.96)	77.06 (10.79)	78.09 (14.04)	<0.001
FBG (mmol/L)	5.25 (1.47)	5.26 (1.61)	5.27 (1.47)	5.36 (1.52)	<0.001
TC (mmol/L)	4.56 (1.10)	4.67 (1.07)	4.55 (1.11)	4.70 (1.17)	<0.001
TG (mmol/L)	1.49 (1.09)	1.50 (1.19)	1.47 (1.13)	1.51 (1.14)	0.623
HDL-c (mmol/L)	1.49 (0.54)	1.45 (0.50)	1.46 (0.51)	1.43 (0.50)	<0.001
LDL-c (mmol/L)	2.59 (0.85)	2.66 (0.86)	2.61 (0.87)	2.71 (0.88)	<0.001

The weighted means or prevalence rates were calculated using the weight coefficients.
Physical activities and healthy diet group was considered as the reference.
Except for the age, sex, education level, occupation and BMI classification, other data were expressed as mean (standard deviation).
Blue collar referred as farmers, factory workers, forestry workers, fishers, salespersons, houseworkers and vehicle drivers; White collar referred as office workers, professional and technical personnel and government official staffs; BMI, body mass index; WC, waist circumference; HC, hip circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; HDL-c, high density lipoprotein-cholesterol; LDL-c, low density lipoprotein-cholesterol.

If an additive interaction between the two risk factors is absent, the 95% CI of RERI and AP should contain 0, and the 95% CI of S should contain 1.

3. Results

3.1. Social-demographic and anthropometric characteristics of participants

The present study included 60 283 eligible individuals, 29 848 (49.5%) males and 30 435 (50.5%) females. The participants had an average age of 43.7 ± 16.4 years. Irrespective of dietary habits, individuals categorized as physically active demonstrated an increased probability of having a higher income, being male, exhibiting a lower WC and BMI, and consequently, a reduced prevalence of obesity in comparison to those who were physically inactive. The metabolic indicators generally improved as well, except DBP and TG. Individuals who were categorized as having unhealthy diets, regardless of their PAL status, were more likely to have higher levels of education and HC than those who adhered to a healthy diet. The highest annual household income per capita, HDL-c, and lowest BMI, HC and SBP were detected in participants of the physical activities and healthy diet group (Table 1).

3.2. The association between physical activities combined with dietary habits and cardiovascular risk factors

The results of the linear regression analysis indicated a significant association between physical inactivity, an unhealthy diet, or a combination of physical inactivity and an unhealthy diet, and obesity as well as metabolic indicators. The group that engaged in physical activities and had an unhealthy diet (standardized β, 0.43; 95% CI [0.22, 0.64]), the group that engaged in physical inactivity and had a healthy diet (standardized β, 0.59; 95% CI [0.39, 0.79]), and the group that engaged in physical inactivity and had an unhealthy diet (standardized β, 1.18; 95% CI [0.93, 1.43]) exhibited a significant correlation with hip circumference (HC). Except for TG, diet and physical inactivity were positively correlated with markers linked to metabolism(Table 2).

3.3. The influences of physical activities and dietary habits on cardiovascular risk factors

According to our findings, individuals in the physical inactivity and unhealthy diet groups had higher rates of dyslipidemia, HLDL-c, hypertension, T2D, and HTG than those in the physical activities and healthy diet groups. Moreover, a notable difference was observed in the metabolic indicators between the group in terms of risk and the reference group for high-density lipoprotein cholesterol (HLDL-c) (odds ratio [OR], 1.64; 95% confidence interval [CI], [1.47–1.84]). Specifically, the low diet and inactive lifestyle group exhibited a greater risk for HLDL-c (Table 3).

3.4. The interactions between physical activities and dietary habit on cardiovascular risk factors

Additive interactions between physical inactivity and unhealthy diet were found on cardiovascular risk factors of hypertension (S,

Table 2
The association between physical activities combined with healthy habits and cardiovascular risk factors.

Cardiovascular risk factors	Physical activities			Physical inactivity				Statistical power %
	Healthy diet	Unhealthy diet		Healthy diet		Unhealthy diet		
		β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI)	*P*	
BMI	Reference	−0.04 (−0.04, 0.11)	0.334	0.10 (−0.03, 0.18)	<0.001	0.21 (0.13, 0.30)	<0.001	91.70
WC	Reference	−0.07 (−0.29, 0.15)	0.554	0.34 (0.13, 0.55)	0.001	0.64 (0.38, 0.90)	<0.001	83.10
HC	Reference	0.43 (0.22, 0.64)	<0.001	0.59 (0.39, 0.79)	<0.001	1.18 (0.93, 1.43)	<0.001	88.27
SBP	Reference	−0.17 (−0.59, 0.25)	0.433	1.20 (0.80, 1.61)	<0.001	1.18 (0.68, 1.68)	<0.001	80.63
DBP	Reference	0.30 (−0.03, 0.63)	0.077	0.40 (0.09, 0.72)	0.013	0.67 (0.28, 1.06)	0.001	89.06
FPG	Reference	0.05 (0.01, 0.08)	0.010	0.06 (0.02, 0.10)	0.006	0.06 (0.03, 0.09)	<0.001	86.49
TC	Reference	0.03 (0.01, 0.06)	0.010	0.06 (0.03, 0.08)	<0.001	0.11 (0.08, 0.14)	<0.001	81.04
TG	Reference	−0.00 (−0.03, 0.03)	0.925	0.01 (−0.02, 0.03)	0.480	0.01 (−0.02, 0.04)	0.543	84.94
HDL-c	Reference	−0.02 (−0.04, −0.01)	<0.001	−0.02 (−0.03, −0.01)	<0.001	−0.06 (−0.07, −0.04)	<0.001	93.26
LDL-c	Reference	0.03 (0.01, 0.05)	<0.001	0.05 (0.03, 0.07)	<0.001	0.10 (0.0, 0.12)	<0.001	87.82

Models were adjusted for age, gender, education, occupation, income, smoking and drinking.
BMI, body mass index; WC, waist circumference; HC, hip circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; HDL-c, high density lipoprotein-cholesterol; LDL-c, low density lipoprotein-cholesterol; CI, confidence interval.
80% statistical power is the commonly accepted level.

Table 3
The odds ratio for cardiovascular risk factors determined by physical activities and dietary habits.

Cardiovascular risk factors	Physical activities			Physical inactivity				Statistical power %
	Healthy diet	Unhealthy diet		Healthy diet		Unhealthy diet		
		OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	
Obesity	Reference	1.00 (0.96, 1.05)	0.840	1.01 (0.97, 1.06)	0.539	1.13 (1.07, 1.19)	<0.001	81.53
Central obesity	Reference	1.05 (1.00, 1.11)	0.049	1.05 (0.99, 1.10)	0.054	1.09 (1.03, 1.16)	0.006	85.69
Hypertension	Reference	1.14 (1.08, 1.21)	<0.001	1.23 (1.17, 1.30)	<0.001	1.55 (1.46, 1.64)	<0.001	80.50
T2D	Reference	1.02 (1.00, 1.13)	0.021	1.21 (1.12, 1.31)	<0.001	1.45 (1.32, 1.59)	<0.001	88.79
HTC	Reference	1.05 (0.96, 1.15)	0.303	1.03 (0.94, 1.12)	0.584	1.16 (1.04, 1.29)	0.006	95.65
HTG	Reference	1.07 (1.03, 1.17)	0.027	1.02 (1.00, 1.14)	0.039	1.11 (1.02, 1.21)	0.014	82.31
LHDL-c	Reference	1.03 (0.94, 1.12)	0.547	1.01 (0.93, 1.09)	0.910	1.18 (1.07, 1.30)	0.001	85.22
HLDL-c	Reference	1.13 (1.01, 1.25)	<0.001	1.13 (1.02, 1.25)	<0.001	1.64 (1.47, 1.84)	<0.001	90.79
Dyslipidemia	Reference	1.05 (1.02, 1.08)	0.010	1.07 (1.02, 1.12)	0.007	1.26 (1.19, 1.33)	<0.001	94.84

Models were adjusted for age, gender, education, occupation, income, smoking and drinking.
T2D, Type 2 diabetes; HTC, higher total cholesterol; HTG, higher triglycerides; LHDL-c, lower high-density lipoprotein-cholesterol; HLDL-c, higher low-density lipoprotein-cholesterol; OR, odds ratio; CI, confidence interval.
80% statistical power is the commonly accepted level.

1.46; 95% CI [1.12, 1.89]), T2D (S, 1.96; 95% CI [1.23, 3.13]), HLDL-c (S, 2.57; 95% CI [1.27, 5.21]) and dyslipidemia (S, 1.69; 95% CI [1.08, 2.66]), suggesting that the risk of hypertension, T2D, HLDL-c and dyslipidemia in participants with physical inactivity combined with unhealthy diet was 1.46, 1.96, 2.57 and 1.69 times higher than those with the single exposure to a risk factor. RERI of hypertension, T2D, HLDL-c and dyslipidemia were 0.17 (95% CI [0.06, 0.28]), 0.22 (95% CI [0.09, 0.35]), 0.39 (95% CI [0.18, 0.60]) and 0.11 (95% CI [0.03, 0.19]), respectively, suggesting that there would be 0.17, 0.22, 0.39 and 0.11 relative excess risk due to the additive interaction between physical inactivity and unhealthy diet on them. OR of hypertension, T2D, HLDL-c and dyslipidemia in participants of physical inactivity and unhealthy diet was 11%, 15%, 24% and 8.3%, respectively. Multiplicative interaction was detected in obesity, hypertension T2D and HLDL-c (Table 4).

4. Discussion

An additive model was utilized in this study to study the relationship between physical activities combined with dietary habits and cardiovascular risk factors in the adult population of Nanjing, China. Prior validation of these interactions has not been done on an additive scale. Based on our studies, individuals who engage in sedentary behavior or adhere to unhealthy dietary habits may exhibit heightened vulnerability to cardiovascular risk factors. Physical activities and dietary habits had an additive interaction with dyslipidemia, T2D, hypertension, and HLDL-c. In other words, individuals with dyslipidemia, diabetes, and hypertension may benefit more from maintaining physical activities combined with a healthy diet.

Table 4
The multiplicative interaction and additive interaction between physical activities and dietary habits on cardiovascular risk factors.

Cardiovascular risk factors	Multiplicative interaction	Additive interaction		
	OR (95% CI)	RERI (95% CI)	AP (95% CI)	S (95% CI)
Obesity	1.11 (1.03, 1.19)	0.11 (−0.03, 0.19)	0.10 (−0.03, 0.16)	7.01 (0.15, 36.07)
Central obesity	1.09 (0.998, 1.18)	−0.01 (−0.11, 0.08)	−0.01 (−0.10, 0.07)	0.86 (0.35, 2.16)
Hypertension	1.10 (1.02, 1.19)	0.17 (0.06, 0.28)	0.11 (0.04, 0.18)	1.46 (1.12, 1.89)
T2D	1.18 (1.04, 1.33)	0.22 (0.09, 0.35)	0.15 (0.07, 0.24)	1.96 (1.23, 3.13)
HTC	1.08 (0.93, 1.25)	0.09 (−0.08, 0.25)	0.07 (−0.06, 0.21)	2.12 (0.31, 14.47)
HTG	1.02 (0.93, 1.18)	0.02 (−0.06, 0.10)	0.02 (−0.06, 0.09)	1.20 (0.55, 2.59)
LHDL-c	1.14 (0.99, 1.32)	0.15 (−0.01, 0.29)	0.13 (−0.01, 0.24)	5.81 (0.09, 40.00)
HLDL-c	1.29 (1.11, 1.50)	0.39 (0.18, 0.60)	0.24 (0.12, 0.36)	2.57 (1.27, 5.21)
Dyslipidemia	1.09 (0.99, 1.19)	0.11 (0.03, 0.19)	0.08 (0.02, 0.15)	1.69 (1.08, 2.66)

Models were adjusted for age, gender, education, occupation, income, smoking and drinking.
T2D, Type 2 diabetes; HTC, higher total cholesterol; HTG, higher triglycerides; LHDL-c, lower high-density lipoprotein-cholesterol; HLDL-c, higher low-density lipoprotein-cholesterol; OR, odds ratio; CI, confidence interval; RERI, relative excess risk due to interaction; AP, attributable proportion due to interaction; S, synergy index.

One of the key main preventions in the management program for cardiovascular diseases has been confirmed to be leading an active lifestyle and a balanced healthy diet [41–46]. However, the proportion of participants with insufficient physical activities, unhealthy diet, and both is as high as 63.6%, 68.1% and 44.2%, respectively, which was consistent with our findings in the representative population [23]. Female participants who had a higher education level or lower income were more likely to have an unhealthy lifestyle, which may be explained by the reason that people had a lower income were more likely to consume unhealthy foods, do insufficient physical activities and be obese [47,48]. Higher-educated adults were more likely to work long hours at sedentary employment, which could lead to high levels of stress and less opportunity for physical activities [49].

Physical activities were associated with the adiposity markers, which are known to reflect the cardiometabolic health [11]. More specifically, participants who had insufficient physical activities and a healthy diet were at greater risks for adiposity markers than those who had sufficient physical activities and an unhealthy diet, with the reference of physical activities and healthy diet group. The results also showed that metabolic markers were more affected by physical activities than dietary habits, because decreased physical activities contributed to enhance most of metabolic markers compared with the reference group. Except for TG, participants in the physical activities and healthy diet group presented increased risk factors. Previous studies have shown that moderate and vigorous physical activities are inversely associated with SBP, and high-intensity physical activities elicited a greater reduction in SBP than that of low-intensity [50,51]. In a longitudinal path analysis, residential environmental features supporting physical activities are found to be more important in influencing cardiometabolic outcomes than dietary intakes [52].

It is generally accepted that the two major modifiable risk factors for cardiometabolic diseases are unhealthy diet and physical inactivity. However, many studies employ odds ratios (ORs) to highlight risk differences because logistic regression is used for covariate adjustments. Consequently, interactions are frequently omitted from reporting on the additive scale, which is considered more reflective of biological interaction [40]. The epidemiological community has recognized that the most appropriate way to evaluate the relevance of public health is to measure interaction on an additive scale. If resources are few, therapies can be tailored to specific subgroups using the additive scale, which shows whether the influence of a risk factor will be larger in one subpopulation than in another [53]. Estimating an excess risk resulting from both exposures is made possible by measuring the interaction between physical inactivity and an unhealthy diet on an additive scale. Our study revealed that both exposures to physical inactivity and unhealthy diet had an additive effect on the OR of hypertension, T2D, HLDL-c and dyslipidemia, indicating an excess risk than the sum of them, especially HLDL-c (OR, 1.64; 95% CI [1.47, 1.84]). A significant additive interaction was identified between physical inactivity and unhealthy diet on HLDL-c, with the RERI, AP, and S and their corresponding 95% CIs of 0.39 (0.18, 0.60), 0.24 (0.12, 0.36), and 2.56 (1.27, 5.21), respectively.

Further study is required to determine how an unhealthy diet and physical inactivity raise the risk of metabolic diseases. On the other hand, physical inactivity has been found to raise the risk of numerous inflammatory physiological alterations, such as insulin resistance, dyslipidemia, endothelial dysfunction, and hypertension [54]. In persistently sedentary individuals, these alterations have been associated with an elevated risk for several ailments, such as T2D, CVDs, and various kinds of cancer [54,55]. A diet rich in processed foods that are highly desired and high in fat, salt, sugar, and flavor enhancers, along with low levels of physical activities, can aggravate systemic chronic inflammation (SCI), which can then lead to several chronic non-communicable diseases [56].

Conversely, improved TC, LDL, and SBP readings are linked to a number of dietary groups, particularly dairy, fruits, vegetables, nuts, seeds, and legumes [57]. One possible explanation is that the food mentioned above has more fiber and less energy overall, which can help reduce the total energy of daily dietary intake [58] and the antioxidant content of food, which helps to lessen systemic oxidative stress and fight free radicals. A further advantage of glucose could be its lower glycemic index [59]. The positive effects of exercise on body composition, such as increased skeletal muscle insulin sensitivity and decreased insulin resistance, may help explain the influences of physical activities [60].

Overall, the potential interaction between physical inactivity and unhealthy diet exerted an additive effect on increasing the risk of hypertension, T2D, HLDL-c and dyslipidemia than the single exposure. More attention should be paid to the population with both exposures. To encourage adult physical activities, many countries have devised practical and efficient public health interventions. One of the most important interventions to lower the quantity of insufficient physical activities is promoting physical activities by the media. Furthermore, dietary concerns related to sodium are a significant factor in determining hypertension blood pressure levels and total cardiovascular risk [61]. Strategies for reducing salt intake are a “best buy"—that is, the most cost-effective and feasible for implementation—for preventing NCDs [62].

Several highlights of this study should be considered. Firstly, our study is the first to evaluate, on an additive basis, the interactions between dietary habits and physical activities on cardiovascular risk variables in a community sample from Nanjing. Additive interactions possess a higher degree of direct relevance in disease prevention and risk prediction. We were able to estimate the additive interaction effect accurately due to the large and representative sample size. To confirm that the sample was representative of the area, a multistage random sampling procedure was adopted. Secondly, we employed standardized tools and procedures together with a structured questionnaire in accordance with the guidelines set forth by the Chinese Center for Disease Control and Prevention. Before, during, and after the study, the Nanjing Centers for Disease Control and Prevention put in place a stringent quality control process to guarantee the reliability and authenticity of the data. Thirdly, our analysis improved the reliability by considering known possible confounders. But there are also a lot of restrictions to take into account.

Limitations of this study should also be considered. First, determining causality was impossible due to the cross-sectional design. Second, selection bias may have occurred because participants altered their lifestyles after learning that their levels of metabolic risk variables were elevated. Third, even after adjusting for a few confounding factors, there may still be additional unaccounted confounders, including a family history of chronic disease. The prevalence of cardiovascular risk factors, health profiles, and dietary and physical exercise habits may vary throughout the survey year, which could lead to a misclassification bias; however, as our primary goal is to assess the interaction effect of dietary habits and physical activities on cardiovascular risk factors—rather than the prevalence of these factors—the conclusion of this study may not be greatly impacted. Therefore, the findings of this study provide valuable new information for addressing the issue of the additive interaction between dietary habits combined with physical activities and cardiovascular risk factors in various nations and locations, including China. To validate this additive interaction and clarify the underlying mechanism, more prospective cohort research is required, which will ultimately lead to better CVDs prevention measures.

5. Conclusions

In conclusion, the results of the cross-sectional study conducted among the people of Nanjing validated previous studies on the association of physical activities and dietary habits with cardiovascular risk factors. Moreover, this study also showed that an unhealthy diet and physical inactivity combined to provide an additive effect on T2D, hypertension, HLDL-c, and dyslipidemia, suggesting a higher risk than the total of these conditions, particularly HLDL-c. Preventive strategies aimed at reducing cardiometabolic risks such as hypertension, T2D, HLDL-c, and dyslipidemia are necessary for targeting physical inactivity and unhealthy diets.

Ethics statement

This study involves human participants and was approved by Ethics Committee: Nanjing Municipal Center for Disease Control and Prevention ID: PJ2017002. Participants gave informed consent to participate in the study before taking part.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Weiwei Wang: Writing – original draft, Visualization, Methodology, Investigation. **Hairong Zhou:** Visualization, Validation, Investigation, Data curation. **Shengxiang Qi:** Software, Investigation, Data curation. **Huafeng Yang:** Visualization, Methodology, Investigation. **Xin Hong:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28845.

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