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ORIGINAL RESEARCH

Association Between Metabolic Syndrome and Cardiac Autonomic Nervous Function and Cardiorespiratory Fitness in Older Adults: A Retrospective Observational Study with Propensity Score Overlap Weighting

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Background: Delayed heart rate recovery (HRR) after exercise, an indicator of cardiac autonomic nervous function (CANF), has been found to be associated with metabolic syndrome (MetS) in general populations. However, this relationship has not been extensively studied in older adults. The present study aimed to investigate the association between MetS and HRRs at 1, 2, 3 and 6 minutes after exercise and cardiorespiratory fitness (CRF) in Chinese dwelling older adults.

Methods: This retrospective, observational study consecutively enrolled participants aged 60 years or older who underwent physical examinations in Shenzhen District Yantian People's Hospital from September 2019 to July 2021. The participants were categorized into MetS and non-MetS groups according to the International Diabetes Federation criteria. Logistic regression analysis was applied to assess the association between MetS and CANF and CRF. Propensity score overlap weighting was used to adjust the covariates.

Results: A total of 987 eligible participants were included (mean age±SD, 66±4 years; male, 47.1%), of whom, 506 were diagnosed with MetS. MetS group showed significantly lower peak heart rate, HRR1-3, HRR6, peak metabolic equivalents, and peak oxygen consumption compared to the non-MetS group. Furthermore, peak systolic and diastolic blood pressures in the MetS group were significantly higher. Logistic regression analysis showed that MetS was significantly associated with HRR2, HRR3 (odds ratio [95% CI], 0.997 [0.995,0.999], both; P=0.009 and 0.005, respectively) and HRR6 (0.996 [0.994,0.998], P<0.001). The association between MetS and CRF was significant (0.98 [0.97,0.98], P<0.001).

Conclusion: Elderly Chinese with MetS tend to exhibit reduced CANF and lower CRF. It is recommended that they boost physical activity and closely monitor heart rate and blood pressure during exercise to mitigate exercise-related risks.

Keywords: aging population health, heart rate recovery, systolic blood pressure recovery, geriatric cardiology, autonomic regulation, fitness evaluation

Introduction

The trend of an aging population is escalating, with approximately 100 million elderly people over 60 years old in China, a number projected to surpass 400 million by 2050.[1] With age augments, the overall prevalence of metabolic syndrome

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(MetS) also increases.[2] MetS is characterized by a cluster of cardiovascular risk factors,[3] and individuals with MetS are more likely to experience adverse cardiovascular events.[4] This association may be related to cardiac autonomic dysfunction.[5–7] Clinically, the role of cardiac autonomic is reflected mainly in two indicators after exercise: heart rate recovery (HRR) and blood pressure recovery (BPR). If there is an impairment in cardiac autonomic, it may manifest as delayed recovery of heart rate and blood pressure after exercise termination.

Most studies on the relationship between MetS and HRR focused on the first two minutes after exercise termination.[5–9] These studies encompass diverse populations, including obese children,[5] young adults aged 18–30,[6] and non-obese adults.[8] However, research on the elderly Chinese population remains underexplored. Regarding the study of exercise BPR, most researches focus on the prediction of hypertensive response during exercise for mortality[10] or adverse cardiovascular events.[11] Only two studies have a study population consisting of patients with MetS.[8,12] However, they not only have inconsistent definitions of BPR but also do not limit the population to the elderly. Therefore, the relationship between MetS and BPR in the elderly remains to be investigated.

Cardiorespiratory fitness (CRF) refers to the body's ability to take up, transport, and utilize oxygen, and it is the fifth vital sign defined by the American Heart Association.[13] Previous studies on the relationship between CRF and MetS mostly believe that low CRF is significantly and independently associated with MetS.[14–17] However, only two studies focused on elderly populations,[14,18] whose data were obtained through simple tests, showing no relationship between CRF and MetS. This study is the first to obtain CRF data via cardiopulmonary exercise testing (CPET) in the elderly, exploring its correlation with MetS.

This retrospective observational study collects HRR, BPR, and CRF related data through CPET. This research investigates of the association between MetS and cardiac autonomic nervous function (CANF) and CRF among the elderly in Chinese communities, aiming to provide new evidence for the formulation of precise exercise prescriptions for elderly patients with MetS.

Materials and Methods

Study Design and Participants

This retrospective observational study focused on a community-dwelling elderly population who underwent health examinations in Shenzhen District Yantian People's Hospital, China, between September 2019 and July 2021. A total of 1067 individuals were screened. The inclusion criteria were: 1) Age 60 years or older; 2) Completion of a CRF test; 3) Signed informed consent. Exclusion criteria were: 1) Lack of complete routine health examination data; 2) Failure to meet CRF test criteria, defined as not meeting any of the following: respiratory exchange ratio (RER) ≥ 1.05, peak heart rate during exercise > 85% of maximum heart rate, perceived exertion ≥ 17; 3) Abnormal data.

CPET and Assessment

The procedure of performing CPET complied with the Exercise Standards for Testing and Training released by the American Heart Association (AHA) and is briefly described below.[19] All exercise testing was conducted with cycle ergometry (Ergometry ERG 911 Plus, Germany) with a ramp protocol. Expired gas, and/or ECG measurements were performed using the CARDIOVIT system (CS200, Schiller, Switzerland). Workloads were gradually increased at a minute rate of the value of the predicted maximal work rate divided by 8 to 12 based on the individual's activity habits, ensuring the duration of CPET was within 8–12 min.

During CPET, data reflecting CANF and CRF were obtained. HRR refers to the difference between the peak heart rate during exercise and the heart rate at a specific moment during the recovery period after exercise. The HRR1, HRR2, HRR3, and HRR6 represent the difference at 1, 2, 3, and 6 minutes after exercise termination, respectively. HRR1′, HRR2′, HRR3′, HRR6′, are the corresponding binary variables for HRR at this time points. Similarly, systolic blood pressure recovery (SBPR) is defined by the difference between the peak systolic blood pressure (SBP) during exercise and the SBP at a specific moment during the recovery period after exercise. Specifically, SBPR3 and SBPR6 denote the difference between peak SBP and SBP measured at 3 and 6 minutes post-exercise termination, respectively. In addition, this study utilized peak oxygen consumption (VO_2 max), peak metabolic equivalents (METs), and peak oxygen pulse obtained through CEPT as metrics to assess CRF.

MetS

The diagnosis of MetS follows the International Diabetes Federation criteria,[3] requiring the presence of central obesity (defined in China as a waist circumference >90 cm for men and >80 cm for women, or a body mass index >30 kg/m²). Additionally, individuals must have at least two of the following four risk factors: 1) Elevated triglycerides >1.7 mmol or receiving appropriate treatment; 2) Reduced HDL-C, <1.03 mmol for men or <1.29 mmol for women, or receiving appropriate treatment; 3) High blood pressure, with SBP >130 mmHg or diastolic blood pressure >85 mmHg, or a prior diagnosis of hypertension with appropriate treatment; 4) Elevated fasting blood glucose >5.6 mmol or a prior diagnosis of type 2 diabetes with appropriate treatment. Waist circumference was measured using a soft tape between the 12th rib and iliac crest. Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m^2). Fasting venous blood samples were collected to measure glucose, total cholesterol, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglycerides.

Data Collection

The characteristics of all participants (sex, age, body weight, waist circumference, body mass index), indicators for diagnosing MetS, CPET test data were extracted from the electronic medical system. All patients were codified and anonymized to protect the confidentiality of individual participants.

Statistical Analysis

Continuous variable normality was assessed using the Shapiro–Wilk test. Descriptive statistics presented means with standard deviations for quantitative data and counts (percentages, %) for categorical data. To ensure covariate balance and reduce the impact of extreme propensity scores on the model's predictions, a propensity score model with covariates was constructed utilizing the method of overlap weighting.[20] Standardized mean differences were used to measure the intergroup balance in covariates before and after propensity score overlap weighting, with a standardized mean difference less than 0.1 is considered adequate for balance.[21] The receiver operating characteristic curve was used to convert continuous variables to binary variables with the maximum Youden Index. Logistic regression was employed to explore the correlation between MetS and HRR, BPR, and CRF. E-value was applied to assess the unmeasured confounders. The E-value is a statistical measure used to quantify the minimum strength of association that an unmeasured confounding factor would need to have with exposure and outcome to explain away the observed association between exposure and outcome.[22] All statistical analyses in this study were conducted using R 4.2.2. A two-sided p-value < 0.05 was considered statistically significant.

Results

Sample Characterization

During the study period, a total of 1067 individuals in the community underwent health examinations. After applying inclusion and exclusion criteria, 987 individuals were ultimately included for analysis, as illustrated in Figure 1. The average age of the participants was 66 (standard deviation, 4) years, with males accounting for 47.2%. Among them, 506 individuals were diagnosed with MetS, constituting 51.3% of the total sample. Table 1 presents the description and comparison of general clinical data for participants with and without MetS before and after propensity score overlap weighting. In the MetS group, participants were predominantly female, and the proportion of individuals with a history of hypertension and those taking antihypertensive medications was relatively higher. After propensity score overlap weighting, there were no statistically significant differences in baseline levels and clinical characteristics between the two groups, indicating good comparability. Detailed information is provided in Table 1 and Figure 2.

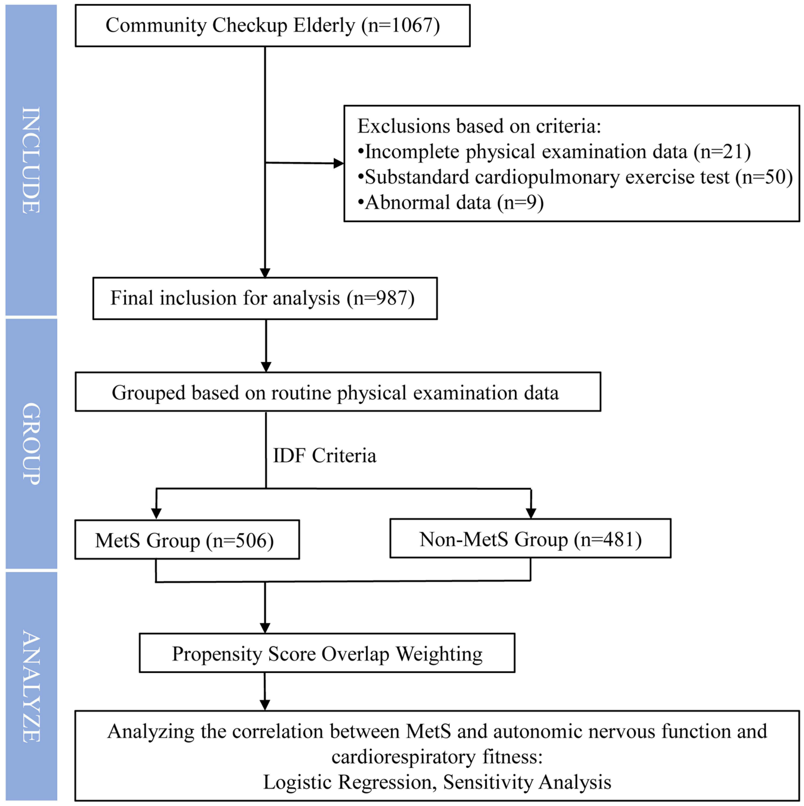

Figure 1 Sample flow chart.
Abbreviation: MetS, metabolic syndrome.

Intergroup Distribution of Diagnostic Factors for MetS

The intergroup distribution of diagnostic factors for MetS is presented in Table 2. As shown in the table, the MetS group exhibited significantly higher values for body mass index, waist circumference, triglycerides, blood pressure, and fasting blood glucose compared to the non-MetS group. Additionally, the HDL-C level in the MetS group was significantly lower than in the non-MetS group. Detailed data are provided in Table 2.

Table 1 Participant Characteristics Before and After Propensity Score Overlap Weighting (Quantitative Data, Mean ± SD; Count Data, n (%))

Variables	Before Weighting			After Weighting		
	MetS Group (N=506)	Non-MetS Group (N=481)	SMD*	MetS Group (N=233)	Non-MetS Group (N=233)	SMD*
Age (years)	66±4	66±4	0.056	66±4	66±4	<0.001
Gender						
Male	213 (42.1%)	253 (52.6%)	0.212	111 (47.6%)	111 (47.6%)	<0.001
Female	293 (57.9%)	228 (47.4%)	0.212	122 (52.4%)	122 (52.4%)	<0.001
LDL-C (mmol/L)	3.05±0.91	3.13±0.87	0.086	3.10±0.92	3.10±0.87	<0.001
Medical history						
Hypertension	145 (28.7%)	69 (14.3%)	0.354	46 (19.7%)	46 (19.7%)	<0.001
Diabetes	52 (10.3%)	28 (5.8%)	0.164	18 (7.7%)	18 (7.7%)	<0.001
CAD	11 (2.2%)	11 (2.3%)	0.008	5 (2.0%)	5 (2.0%)	<0.001
Hyperlipidemia	134 (26.5%)	105 (21.8%)	0.109	54 (23.4%)	54 (23.4%)	<0.001

(*Continued*)

Table 1 (Continued).

Variables	Before Weighting			After Weighting		
	MetS Group (N=506)	Non-MetS Group (N=481)	SMD*	MetS Group (N=233)	Non-MetS Group (N=233)	SMD*
Medication history						
Antihypertensive	128 (25.3%)	80 (16.6%)	0.214	47 (20.2%)	47 (20.2%)	<0.001
Antidiabetic	53 (10.5%)	31 (6.4%)	0.145	19 (8.2%)	19 (8.2%)	<0.001
Cholesterol-lowering	135 (26.7%)	106 (22.0%)	0.108	55 (23.6%)	55 (23.6%)	<0.001

Notes: Propensity score overlap weighting covariates: age, gender, low-density lipoprotein cholesterol, medical history, and medication history. *SMD <0.1 indicates no statistical difference between groups.
Abbreviations: CAD, Coronary artery disease; LDL-C, Low-density lipoprotein cholesterol; MetS, Metabolic syndrome; SD, Standard deviation; SMD, Standardized mean difference.

Comparison of CPET Data Between Groups

Table 3 presents the relevant data obtained from CRF tests for the MetS and non-MetS groups. The table indicates that there were no intergroup differences in autonomic nervous system-related indicators such as resting heart rate, SBPR3, and SBPR6. However, statistically significant differences were observed between the two groups in peak heart rate, HRR1, HRR2, HRR3, HRR6, HRR1′, HRR2′, HRR3′, HRR6′, peak SBP, and peak diastolic blood pressure. Compared to the non-MetS group, the MetS group showed a significant decrease in peak heart rate, HRR1, HRR2, HRR3, and HRR6, along with a significant increase in peak blood pressure. The proportions of individuals meeting criteria such as HRR1′ < 18, HRR2′ < 22, HRR3′ < 37, and

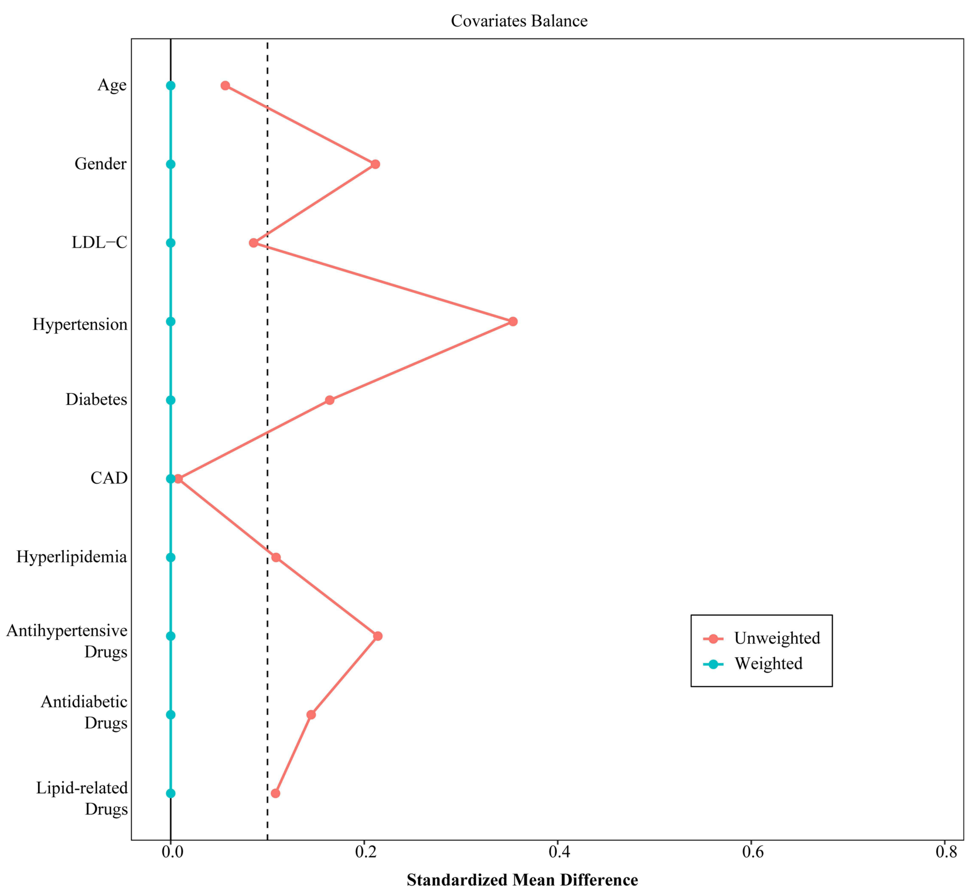

Figure 2 The Love plot evaluates the balance of covariates between the pre- and post-weighted metabolic syndrome and non-metabolic syndrome groups.
Abbreviations: CAD, Coronary artery disease; LDL-C, Low-density lipoprotein cholesterol.

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Table 2 Distribution and Comparison of Diagnostic Factors for MetS Between Groups. (Mean ± SD)

Variables	Overall (N=987)	MetS Group (N=506)	Non-MetS Group (N=481)	*P* value
BMI (kg/m^2)	24.2±3.1	25.7±2.6	22.6±2.8	<0.001
Waist circumference (cm)	87.3±9.3	92.4±7.3	82.0±8.1	<0.001
TG (mmol/L)	1.6±1.2	1.8±1.4	1.2±0.8	<0.001
HDL-C (mmol/L)	1.26±0.30	1.15±0.25	1.37±0.30	<0.001
SBP (mmHg)	133±16	137±15	129±16	<0.001
DBP (mmHg)	74±10	76±10	73±11	<0.001
FPG (mmol/L)	6.4±1.5	6.8±1.7	6.0±1.1	<0.001

Abbreviations: BMI, Body Mass Index; DBP, Diastolic Blood Pressure; FPG, Fasting Plasma Glucose; HDL-C, High-Density Lipoprotein Cholesterol; MetS, Metabolic Syndrome; SBP, Systolic Blood Pressure; SD, Standard Deviation; TG, Triglycerides.

Table 3 Comparisons of CPET Data Between Groups (Continuous Variables, mean±SD; Categorical Variables, n (%))

Variables	Overall (N=987)	MetS Group (N=506)	Non-MetS Group (N=481)	*P* value
Cardiac autonomic function				
Resting HR	75±11	75±11	74±11	0.125
Peak HR	133±18	131±17	135±18	<0.001
HRR1	22±13	21±14	23±12	0.009
HRR2	32±13	31±13	34±13	<0.001
HRR3	37±14	36±14	39±14	<0.001
HRR6	46±16	44±16	48±15	<0.001
HRR1′<18	341 (34.5)	200 (39.5)	141 (29.3)	0.007
HRR2′<22	171 (17.3)	107 (21.1)	64 (13.3)	0.001
HRR3′<37	494 (50.1)	287 (56.7)	207 (43.0)	<0.001
HRR6′<44	440 (44.6)	251 (49.6)	189 (39.3)	0.001
Peak SBP	198±24	202±23	193±23	<0.001
Peak DBP	93±14	94±14	92±14	0.004
SBPR3	47±21	47±22	48±19	0.768
SBPR6	63±20	63±21	63±19	0.789
CRF				
VO_2max	18.1±4.7	16.9±4.3	19.4±4.7	<0.001
Peak METs	5.2±1.3	4.8±1.2	5.5±1.4	<0.001
Peak Oxygen Pulse	8.7±2.7	8.9±2.9	8.6±2.5	0.109
Other indicators of CRF				
RER	1.15±0.13	1.15±0.12	1.16±0.13	0.081
RER>1.05	782 (79.2)	394 (77.9)	388 (80.7)	0.279
Achieving 85% of maximum HR	543 (55.0)	260 (51.4)	283 (58.8)	0.019

Abbreviations: CRF, Cardiorespiratory Fitness; HRR1/2/3/6, Heart Rate Recovery at 1/2/3/6 minute after exercise cessation; HRR1′/2′/3′/6′, Two-class variable converted with a threshold of 18/22/37/44 for heart rate recovery at 1/2/3/6 minute after exercise cessation; MetS, Metabolic Syndrome; METs, Peak Metabolic Equivalents; RER, Respiratory Exchange Ratio; SBPR3/6, Systolic Blood Pressure Recovery at 3/6 minutes after exercise cessation; SD, Standard Deviation; VO_2max, Peak Oxygen Consumption.

HRR6′ < 44 were significantly higher in the MetS group. Statistically significant differences were observed in VO2 max and peak METs between the two groups, while peak oxygen pulse showed no statistical difference. The criterion "reaching 85% of maximum heart rate" demonstrated statistically significant intergroup differences, while peak oxygen pulse and respiratory exchange ratio showed no statistical differences between the groups. Detailed data are provided in Table 3.

Figure 3a presents bar graphs illustrating the heart rate at different time points for the 2 groups. There is a statistically significant difference in peak heart rate between the two groups, with the Non-MetS group showing significantly higher

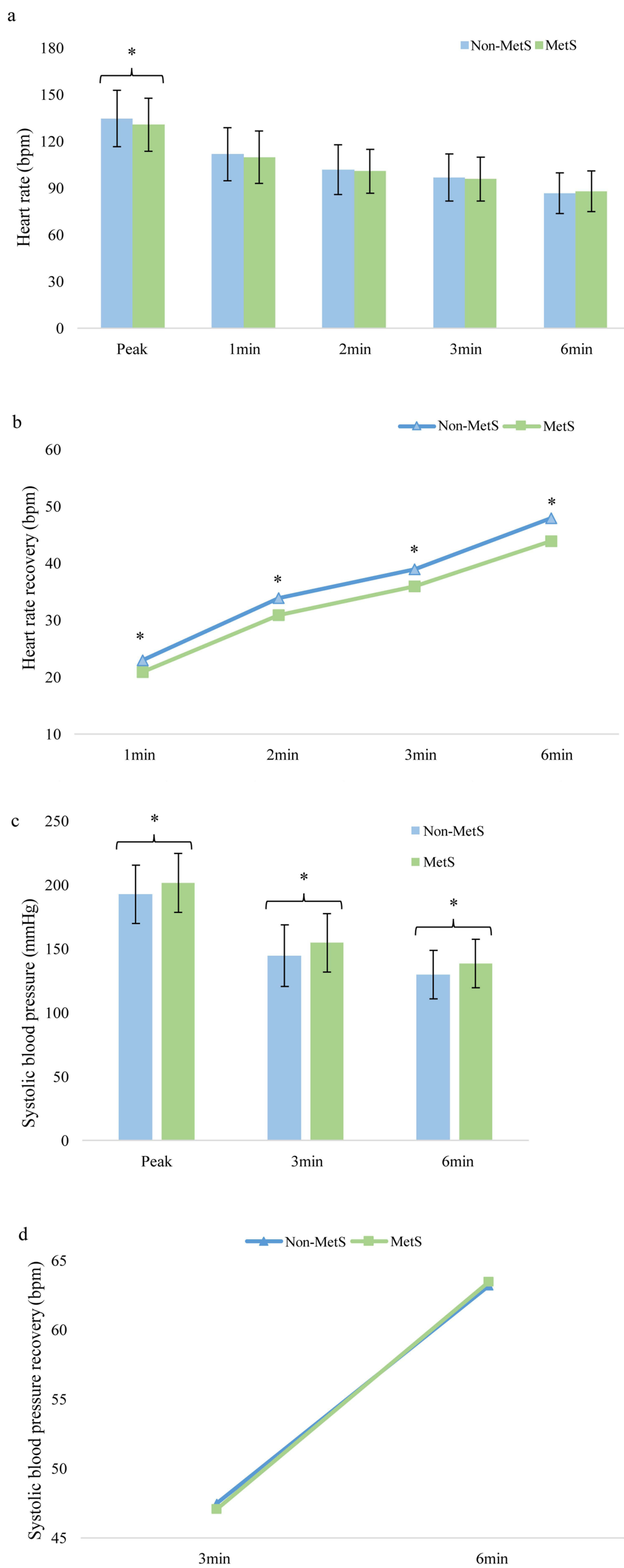

Figure 3 The (**a**) heart rate change plot, (**b**) heart rate recovery plot, (**c**) systolic blood pressure change plot, and (**d**) systolic blood pressure recovery plot between groups. * $p<0.05$.
Abbreviation: MetS, metabolic syndrome.

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peak heart rate than the MetS group. However, no intergroup differences were observed in heart rate at 1-, 2-, 3-, and 6-minutes post-exercise. Figure 3b depicts the change in HRR for both groups over time. As the post-exercise time increases, heart rate gradually recovers from peak to resting levels. There are intergroup differences in HRR at different time intervals, with the MetS group exhibiting a noticeable delay compared to the Non-MetS group. Figure 3c shows bar graphs of SBP at different time points for both groups. At various time points, the MetS group's SBP is significantly higher than that of the Non-MetS group. Figure 3d illustrates the change in SBP for both groups over time. PeakSBP during exercise and gradually decreases to resting levels as post-exercise time extends. There are no intergroup differences in BPR at 3- and 6-minutes post-exercise.

The Association Between MetS and CANF

Table 4 presents the results of logistic regression analysis for autonomic nervous function-related indicators and MetS before and after propensity score weighting. The logistic regression before weighting indicates that, except for resting heart rate, SBPR3, and SBPR6, which show no statistically significant correlation with MetS, other autonomic nervous function-related indicators are significantly associated with MetS. After propensity score weighting, peak heart rate, HRR2, HRR3, HRR6, HRR1′, HRR2′, HRR3′, HRR6′, peak SBP, and peak diastolic blood pressure remain significantly associated with MetS. However, BPR indicators remain unrelated to MetS after weighting, indicating a lack of association even after balancing the covariate effects. Detailed data are available in Table 4.

The Association Between MetS and CRF

Table 5 displays the results of logistic regression analysis for CRF-related indicators and MetS before and after propensity score weighting. The logistic regression before weighting reveals that, except for peak oxygen pulse, the other two CRF-related indicators are significantly associated with MetS. After propensity score weighting, VO_2 max, peak METs, and peak oxygen pulse all remain significantly associated with MetS. Detailed data can be found in Table 5.

Sensitivity Analysis

Table 6 presents the results of sensitivity analysis for the indicators of cardiac autonomic function and CRF significantly associated with MetS. The E-value is employed to gauge the impact of unknown confounding factors on the explored

Table 4 The Association Between MetS and CANF

Variables	Before Weighting			After Weighting		
	OR	95% CI	*P* Value	OR	95% CI	*P* value
Resting HR	1.00	[1.00,1.01]	0.119	1.00	[1.00,1.00]	0.177
Peak HR	0.997	[0.995,0.999]	<0.001	0.998	[0.996,0.999]	0.006
HRR1	0.997	[0.995,0.999]	0.010	0.998	[0.996,1.000]	0.078
HRR2	0.996	[0.994,0.998]	<0.001	0.997	[0.995,0.999]	0.009
HRR3	0.996	[0.994,0.998]	<0.001	0.997	[0.995,0.999]	0.005
HRR6	0.995	[0.993,0.997]	<0.001	0.996	[0.994,0.998]	<0.001
HRR1′	1.12	[1.05,1.19]	0.001	1.10	[1.03,1.17]	0.004
HRR2′	1.14	[1.05,1.24]	0.001	1.12	[1.03,1.22]	0.007
HRR3′	1.15	[1.08,1.22]	<0.001	1.12	[1.05,1.19]	0.001
HRR6′	1.11	[1.04,1.18]	0.001	1.11	[1.04,1.18]	0.001
Peak SBP	1.004	[1.003,1.005]	<0.001	1.004	[1.003,1.005]	<0.001
Peak DBP	1.003	[1.001,1.005]	0.005	1.003	[1.001,1.006]	0.003
SBPR3	1.00	[1.00,1.00]	0.796	1.00	[1.00,1.00]	0.193
SBPR6	1.00	[1.00,1.00]	0.787	1.00	[1.00,1.00]	0.920

Abbreviations: CANF, cardiac autonomic nervous function; CI, confidence interval; HRR1/2/3/6, Heart Rate Recovery at 1/2/3/6 minute after exercise cessation; HRR1′/2′/3′/6′, Two-class variable converted with a threshold of 18/22/37/44 for heart rate recovery at 1/2/3/6 minute after exercise cessation; OR, odds ratio; SBPR3/6, systolic blood pressure recovery at 3/6 minutes after exercise cessation.

Table 5 The Association Between MetS and CRF

Variables	Before Weighting			After Weighting		
	OR	95% CI	*P* value	OR	95% CI	*P* value
VO_2 max	0.97	[0.97,0.98]	<0.001	0.98	[0.97,0.98]	<0.001
Peak METs	0.91	[0.88,0.93]	<0.001	0.92	[0.89,0.94]	<0.001
Peak Oxygen Pulse	0.99	[0.98,1.00]	0.116	0.98	[0.97,0.99]	0.001

Abbreviations: CI, Confidence Interval; CRF, Cardiorespiratory Fitness; METs, Metabolic Equivalents; OR, Odds Ratio; VO_2max, Peak Oxygen Consumption.

Table 6 Sensitivity Analysis of the Association Between MetS and Cardiac Autonomic Function and CRF

Variables	HRR2	HRR3	HRR6	HRR1′	HRR2′	HRR3′	HRR6′	VO_2 max	Peak METs	Peak oxygen pulse
E-value	1.04	1.04	1.05	1.28	1.31	1.31	1.29	1.11	1.25	1.11
Lower limit	1.02	1.02	1.03	1.14	1.14	1.18	1.16	1.11	1.21	1.08

Abbreviations: HRR2/3/6, Heart Rate Recovery at 2/3/6 minute after exercise cessation; HRR1′/2′/3′/6′, Two-class variable converted with a threshold of 18/22/37/44 for heart rate recovery at 1/2/3/6 minute after exercise cessation; METs, Metabolic Equivalents VO_2max, Peak Oxygen Consumption.

correlations in this study. For example, considering peak METs, we observe an E-value of 1.25. This implies that if there exists an unknown confounding factor, its correlation with both MetS and peak METs must be at least 1.25 to fully explain the observed association between MetS and peak METs in this study.

Discussion

To our knowledge, this study is the first to explore the relationship between MetS and HRR and BPR in older adults, finding that older adults with MetS exhibit significantly delayed HRR after exercise. Additionally, it investigates the correlation between MetS and CRF, measured by CPET, in a Chinese community-dwelling elderly population for the first time, revealing a significant decrease in CRF among elderly Chinese patients with MetS.

Cardiac autonomic neuropathy refers to the imbalance between the sympathetic and parasympathetic nervous systems, characterized by overactivation of the sympathetic nervous system or abnormal activation of the parasympathetic nervous system.[23] Clinical indicators of cardiac autonomic neuropathy include elevated resting heart rate,[24] abnormal HRR, inability to achieve 85% of the maximum predicted heart rate during CPET[25] and heart rate variability.[26] The HRR thresholds after treadmill tests are 12 beats per minute within the first minute in upright position and 18 beats per minute in the supine position, with a 2-minute HRR of at least 22 beats.[27] One study had also examined the HRR at 3 minutes.[7]

This study used continuous HRR data at 1-, 2-, 3-, and 6-minutes post-exercise and converted these into binary variables based on the cutoff values obtained from the receiver operating characteristic curve to explore their association with MetS in the elderly. The results were consistent with findings from other age groups,[4,6,8] showing that patients with MetS exhibit delayed HRR post-exercise. The findings of this study show that the HRR at 1, 2, 3, and 6 minutes post-exercise are delayed in the MetS group, indicating that not only is the activation of the parasympathetic nervous system slow in elderly patients with MetS, but the withdrawal of the sympathetic nervous system is also delayed, resulting in a significant proportion (92.9%) of the elderly still not returning to their resting heart rate even after 6 minutes of rest following exercise.

Throughout exercise, increased sympathetic nervous system activity leads to a heightened oxygen demand in the muscles, causing an increase in cardiac output and a typical rise in SBP.[28] We found a significant correlation between MetS and peak blood pressure. Patients with MetS experienced a significantly higher peak blood pressure during exercise compared to those without MetS. This finding is consistent with the research by Tsioufis et al,[12] which indicated that hypertensive patients with MetS have a 2.3 times higher risk of hypertensive response during exercise than those without MetS.[12] In Tsioufis' study the BPR definition was a peak SBP of ≥210 mmHg in males and ≥190 mmHg in females.[29]

Additionally, another study showed a significant correlation between MetS and SBPR. In that study, BPR was represented by the ratio of SBP at the third minute after exercise termination to the peak SBP during exercise or SBP at the first minute after exercise termination.[8] Hence, the finding highlights a lack of a unified BPR indicator, necessitating further extensive research to explore this area.

This study demonstrates a significant and independent association between MetS and CRF in the elderly. However, these results contrast with two previous studies on elderly patients with MetS. The discrepancy may be attributed to the different methods of measuring CRF. One study by Chang et al[18] conducted in Taiwanese community-dwelling elderly used the number of steps taken in two minutes as an indicator of CRF, while another study by Câmara et al[14] in Brazilian community-dwelling elderly used the distance walked in six minutes as an indicator. Neither study observed a significant association between low CRF and MetS. In contrast, results from other studies involving other age groups utilizing data from CPET, more precise method, align with ours.[15,17,30]

Individuals with MetS exhibit reduced CRF due to several interconnected factors, with chronic low-grade inflammation being a significant contributor.[31] Chronic low-grade inflammation in individuals with MetS is characterized by elevated levels of markers,[32] including C-reactive protein, interleukin-6, and interleukin-18. These elevated markers not only impair CRF but may also contribute to insulin resistance and vascular dysfunction, compounding the adverse effects on CRF.[33] In terms of the diminished HRR observed among older individuals with MetS, the primary reason appears to be the imbalance in the autonomic nervous system activity, specifically between sympathetic and parasympathetic activity.[7,9] In MetS, heightened sympathetic activity and impaired parasympathetic reactivation[34] result in a delayed HRR following physical exertion. This dysfunction is associated with insulin resistance and other components of MetS, such as obesity and hypertension, which further compromise autonomic regulation during recovery periods after exercise.[35] Additionally, oxidative stress associated with MetS can exacerbate these autonomic imbalances, further contributing to a delayed recovery of heart rate.[31,36]

Exercise is widely recognized as an effective intervention for enhancing CRF. A substantial body of evidence demonstrates the benefits of exercise across various populations, including healthy individuals[37] and patients,[38] with elderly patients with MetS being no exception.[39] Moreover, some studies have reported that regular physical training can attenuate sympathetic nervous system activity and improve autonomic balance.[40,41] Consequently, structured exercise programs tailored for patients with MetS can not only enhance CRF but also regulate autonomic nervous system function, thereby contributing to improved clinical outcomes and prognosis.[42,43] For elderly patients with MetS, who commonly have a slower HRR following physical activity, it is essential to create a well-designed exercise regimen and closely track heart rate and blood pressure changes both during and after exercise to improve CRF and reduce exercise-related risks.

There are several limitations in this study. First, the data source is single, coming from one specific community, and the results may not be applicable to other populations, necessitating validation by multicenter samples. Second, this is an observational study, there are some unmeasured confounding factors that have not been adjusted for, such as participants' dietary habits. Although E-value evaluation shows that the possibility of unknown confounding factors fully explaining the observed associations is small, the impact of unmeasured confounding factors on the results cannot be completely ruled out. Third, as an observational study, this study is limited to exploring correlations and cannot determine the cause-and-effect relationships between MetS and the decrease in CRF and cardiac autonomic dysfunction.

Conclusion

In the Chinese community-dwelling elderly population, patients with MetS exhibit cardiac autonomic dysfunction and a significant decrease in CRF. It is suggested that elderly patients with MetS should enhance physical activity and closely monitor heart rate and blood pressure during exercise to reduce exercise-related risks.

Abbreviations

BMI, Body mass index; CANF, Cardiac Autonomic Nervous Function; CI, Confidence interval; CHD, Coronary heart disease; CPET, Cardiopulmonary exercise testing; DBP, Diastolic blood pressure; FPG, Fasting plasma glucose; HDL-C, High density lipoprotein cholesterol; HRR, Heart rate recovery; LDL-C, Low density lipoprotein cholesterol; MD, Mean difference; METs, Metabolic equivalents; MetS, Metabolic syndrome; OR, Odds ratio; RER, Respiratory exchange ratio; SBP, Systolic blood pressure; SBPR, Systolic blood pressure recovery; SD, Standard deviation; SMD, Standard mean difference; TG, Triglyceride; VO_2 max, Peak oxygen consumption.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was approved by the Medical Ethics Committee of Xiangya Hospital Central South University with the reference number [2024060651]. Procedures were conducted following the guidelines laid down in the Declaration of Helsinki and its amendments. Informed consent was waived due to the anonymous nature of the data, with subjects being unidentifiable prior to analysis, and in accordance with applicable regulations. Because this was a retrospective study using de-identified data, there was no provision for patient withdrawal or continuation.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The author(s) report no conflicts of interest in this work.

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