Accepted: 11 July 2017
DOI: 10.1002/ajim.22752

BRIEF REPORT

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study

BongKyoo Choi[1,2,3] | SangBaek Ko[1,4] | Stacey Kojaku[1]

[1] Center for Occupational and Environmental Health, University of California Irvine, Irvine, California
[2] Enviromental Health Sciences Graduate Program, University of California Irvine, Irvine, California
[3] Program in Public Health, University of California Irvine, Irvine, California
[4] Department of Preventive Medicine, Yonsei University Wonju College of Medicine, Wonju, South Korea

Correspondence
BongKyoo Choi, ScD, MPH. Center for Occupational and Environmental Health, University of California, Irvine. 100 Theory, Suite 100, Irvine, CA 92617.
E-mail: b.choi@uci.edu

Funding information
National Institute for Occupational Safety and Health, Grant number: 5R21OH009911-02

Background: Little is known about the associations of resting heart rate (RHR) and heart rate reserve (HRR) with metabolic syndrome (MetS) in firefighters.
Methods: For each of 288 professional firefighters, HRR was calculated as the difference between measured RHR and estimated maximum HR. For comparison, VO_2 max based on a treadmill test was included. MetS was defined according to the NCEP/ATP III criteria.
Results: The prevalence of MetS was 14.2%. The average of RHR was 61.5 beat/min. Only 5.8% of the firefighters had RHR of ≥80 beat/min. Between the firefighters in the lowest and highest quintiles, the prevalence ratios (95% confidence intervals) for MetS were 1.88 (0.71-4.94), 5.90 (1.74-20.02), and 8.03 (1.86-34.75) for RHR, HRR, and VO_2 max, respectively. Both HRR and VO_2 max, but not RHR, were significantly associated with MetS and its most component risk factors in middle-aged firefighters.
Conclusions: HRR, a simple cardiovascular fitness measure, was inversely associated with MetS among middle-aged professional firefighters.

KEYWORDS
cardiovascular fitness, maximum heart rate, VO_2 max

1 | INTRODUCTION

About 1.2 million firefighters in the United States (US) are at high risk for on-duty cardiovascular disease (CVD) mortality.[1–3] In 2015, about half of the 90 on-duty firefighter deaths were sudden cardiac deaths in US firefighters.[4] Metabolic syndrome (MetS)[5] has been defined as a clustering of three or more of the following cardiometabolic risk factors: central obesity, high blood pressure, high fasting blood glucose, high blood triglycerides, and low blood high-density lipoprotein cholesterol. MetS is a well-known risk factor for Type II diabetes, coronary heart disease, stroke, and total mortality.[6–11] Several component risk factors of MetS such as hypertension, dyslipidemia, and obesity were also identified as risk factors for on-duty cardiac deaths among US professional firefighters.[1,3] Thus, early detection and management of the risk for MetS are very important for prevention of CVD and cardiac deaths in firefighters, particularly from the viewpoint of the firefighter medical surveillance programs.

Some investigators[12,13] have reported that cardiorespiratory fitness (VO_2 max, maximum oxygen consumption) assessed based on treadmill exercise tests is inversely associated with MetS in professional firefighters. However, the assessment of VO_2 max is resource-demanding in terms of time, space, equipment, and personnel. Also, it is not always available to all firefighters across the nation in the United States. For instance, in a report on firefighter cardiac fatalities during the period of 1995-2004,[14] only 39% of US fire departments had a voluntary firefighter fitness program. By contrast, resting heart rate (RHR) and heart rate reserve (HRR) as other cardiovascular fitness indicators can be available at all clinical settings for firefighters due to their simplicity in assessment. RHR is one of the simplest routine measures at clinics. HRR can be also easily calculated by clinicians as the difference between measured RHR and estimated maximum HR using a standard age-adjusted formula.[15] However, few studies have investigated the utility of both RHR and HRR as prognostic factors of MetS in working populations, including professional firefighters.

The longitudinal association between RHR and MetS has been inconclusive in general populations[16–20] and working populations.[21,22] No studies have examined RHR in relation to MetS in professional firefighters who have better fitness than general populations.[23,24] In addition, despite some evidence for HRR as a risk factor for cardiovascular mortality,[25–27] little is known about the association between HRR and MetS in general or working populations. Furthermore, no studies have compared three cardiovascular fitness indicators (RHR, HRR, and VO_2 max) in terms of the association with MetS and its component risk factors in working populations.

The objective of this cross-sectional study was to investigate and compare the associations of RHR, HRR, and VO_2 max with MetS and its cardiometabolic component risk factors in a group of professional firefighters who participated in a work and obesity project.[28]

2 | METHODS

2.1 | Background-FORWARD study

The main purpose of the FORWARD study (2010-2013) was to identify occupational and behavioral risk factors for obesity in firefighters who work for a fire department in Southern California, USA.[28–30] The FORWARD study had strong support from both the fire department and a local union of the International Association of Fire Fighters (IAFF). The FORWARD study was approved by the Institutional Review Board (IRB) of the University of California, Irvine. Phase I of the study involved developing a firefighter-specific work and health questionnaire through four focus groups with 20 firefighters from January to April 2011.[29,30] Utilizing input from the focus groups, a firefighter-specific work and health questionnaire (called hereafter the FORWARD study questionnaire) was developed. Phase II of the study involved a cross-sectional survey using the FORWARD study questionnaire. All together 365 firefighters (356 males and 9 females) participated in the survey (participation rate, 84% of the 436 firefighters) when they visited a university clinic for their wellness and fitness (WEFIT) medical examinations between May 2011 and December 2012.

2.2 | Firefighters for the current study (*N* = 288)

Among the 365 firefighters who participated in the FORWARD study survey, we excluded the firefighters who were rookies (having <1 year of employment at the fire department) ($N = 3$), who were taking medications for heart problems ($N = 7$) in consideration of their potential impact on RHR, and who did not have valid information on any of the five components of MetS ($N = 67$). Thus, 288 firefighters (281 males and 7 females) were included in the current study (Table 1). There were no significant (at the level of alpha = 0.01) differences in age, sex, education, race/ethnicity, waist circumference, systolic and diastolic blood pressure, central obesity, and RHR between the 288 firefighters and the 67 firefighters.

2.3 | Resting heart rate, heart rate reserve, and VO_2 max

Experienced clinical staff (nurses) at the university clinic measured RHR of each of the firefighter during their WEFIT medical examinations. The pulse rate of each firefighter was assessed for 10 s and then multiplied by six to get his/her RHR (beats per minute: bpm). The HRR of each firefighter was calculated by subtracting his/her measured RHR from his/her maximum heart rate estimated using the following equation: $205.8-(0.685 \times \text{age})$.[15] VO_2 max (mL/kg/min) of each firefighter was estimated based on the Gerkin treadmill test by an experienced exercise physiologist during WEFIT medical examinations. For comparative analyses, each of RHR, HRR, and VO_{2max} was grouped into quintiles. In addition, five groups of RHR with an interval of 10 bpm were used for analyses considering the threshold level of RHR (80-85 bpm) for defining a high RHR population [Palatini, 1998]: 40-49 bpm; 50-59 bpm; 60-69 bpm; 70-79 bpm; and ≥80 bpm. The information on RHR and HRR was available for all firefighters ($N = 288$). The information on VO_2 max was available for 270 firefighters (263 males and 7 females).

2.4 | Metabolic syndrome

The firefighters with MetS were defined as those who had three or more out of the following five CVD risk factors, as recommended by the modified US National Cholesterol Education Program/Adult Treatment Panel III (NCEP/ATP III)[5]: central obesity, high blood pressure (BP), high fasting blood glucose, high blood triglycerides (TG), and low blood high-density lipoprotein (HDL) cholesterol. Central obesity was defined as those who had waist circumference of >102 cm (40 inches) for men and >88 cm (35 inches) for women; high BP as systolic BP of ≥130 mmHg, diastolic BP of ≥85 mmHg, or on anti-hypertensive drug treatment; high fasting glucose ≥100 mg/dl or on drug treatment for elevated glucose; high TG ≥ 150 mg/dl or on drug treatment for elevated triglycerides; and low HDL cholesterol as HDL cholesterol <40 mg/dl for men and <50 mg/dl for women, or on drug treatment for ow HDL cholesterol.

Waist circumference and BP of the firefighters were assessed with experienced clinical staff at the clinic during WEFIT medical examinations using standard assessment protocols.[31,32] For example, firefighter BP was measured after a 5 min rest in a sitting position. It was measured twice with a time interval of 1 min and averaged for analysis. Firefighter blood tests for fasting serum lipid profiles (HDL cholesterol and triglycerides) and glucose were conducted in other local laboratories within 2 weeks before and after their WEFIT exams. The firefighters returned the laboratory results to the WEFIT clinic. The information on medications due to heart problems, hypertension, hyperlipidemia and diabetes mellitus, and on smoking or use of tobacco products was extracted from a clinical questionnaire that firefighters filled out at their WEFIT examinations.

2.5 | Other variables

Age, sex, race/ethnicity, education, job title (rank-and-file firefighters, firefighter apparatus engineers, engineers, firefighter captains, and firefighter chiefs), frequency of exercise (moderate or vigorous level of physical activity and more than 30 min) at fire station and during leisure-time, consumption of high-fiber fruits and vegetables, and

TABLE 1 Spearman correlations between resting heart rate (RHR), heart rate reserve (HRR), and VO_2 max among 288 firefighters

Variables	Number of firefighters	Mean (standard deviation)	Range	1	2	3
1. Age (years)	288	42.7 (8.9)	25-63			
2. RHR (beat/min)	288	61.5 (9.5)	40-92	0.168*		
3. HRR (beat/min)	288	115.0 (12.1)	76.8-143.6	−0.655**	−0.834**	
4. VO_2 max (mL/kg/min)	270	46.1 (7.1)	33-65	−0.548**	−0.442**	0.644**

*$P < 0.01$ and **$P < 0.001$

smoking or consumption of tobacco products were assessed with questions in the FORWARD survey questionnaire.

2.6 | Statistical analyses

The descriptive statistics of MetS and the three cardiovascular fitness indicators (RHR, HRR, and VO_2 max) were examined. The interrelationships of the fitness indicators with age were examined with Spearman correlation coefficients. The associations of the sociodemographic and health-related behavior variables with MetS, RHR, HRR, and VO_2 max were examined by Chi-square test. Due to the small sample size of female firefighters ($N = 8$), the associations of the three fitness indicators with MetS and its component risk factors were examined and compared only in male firefighters ($N = 281$) using gamma coefficients and Cox's proportional hazards models.[33] The analyses were replicated after stratification of the data by age (24-44 and 45-63 years old). As a sensitivity test, all of the above analyses were also replicated in male firefighters ($N = 266$) after excluding those who were taking anti-hypertensive medications ($N = 15$) considering the possibility of suppressed RHR by some popular anti-hypertensive medications such as beta-blockers and non-dihydropyridine calcium channel blockers.[34–36]

3 | RESULTS

3.1 | Descriptive statistics of MetS, RHR, HRR, and VO_2 max in firefighters in 288 firefighters

The prevalence of MetS (≥3 cardiometabolic risk factors) was 14.2% among the firefighters. About 45% of the firefighters did not have any component risk factors; 25% had one risk factor; and 16% had two risk factors of MetS. The prevalence of each component risk factor of MetS was 24.7% for central obesity; 19.4% for high BP; 18.1% for high fasting glucose; 23.6% for high TG, and 19.1% for low HDL cholesterol.

The means (±standard deviations) of RHR, HRR, and VO_2 max values were 61.5 bpm (±9.5 bpm), 115.0 bpm (±12.1 bpm), and 46.1 mL/kg/min (±7.1 mL/kg/min), respectively (Table 1). Sixteen of the firefighters (5.6%) had ≥80 bpm of RHR and five of the firefighters (1.4%) had ≥85 bpm of RHR. As expected, RHR was negatively correlated with HRR and VO_2 max values. VO_2 max was more strongly correlated with HRR than with RHR: Spearman coefficients, 0.644 ($P < 0.001$) and −0.442 ($P < 0.01$), respectively. Age was more strongly correlated with HRR and VO_2 max values than with RHR (Table 1).

3.2 | Associations of MetS, RHR, HRR, and VO_2 max with sociodemographic and health-related behavior variables in 288 firefighters

The prevalence of MetS was significantly higher in the older (45-63 years old) firefighters than in the younger (25-44 years old) firefighters: 24.8% versus 5.2%. It was also significantly higher in male firefighters, higher rank firefighters, firefighters who exercised two or more times per week at the fire station, and firefighters who consumed 5-6 servings of high-fiber fruits and vegetables per day (Table 2). RHR, HRR, and VO_2 max were all associated with age, job title, and exercise at work and during leisure time, although generally RHR had weaker associations compared to the other two measures. VO_2 max was also associated with the frequency of fruit and vegetable consumption.

3.3 | The univariate associations of RHR, HRR, and VO_2 max with MetS and component risk factors in 281 male firefighters

The firefighters in the highest quintile (Q5) had RHR of ≥69 bpm, while those in the lowest quintile (Q1) had RHR values of ≤53 bpm. The firefighters in the lowest and highest quintiles had HRR values of ≤105.4 bpm and ≥124.7 bpm, respectively. The firefighters in the lowest and highest quintiles had VO_2 max values of ≤39.4 and ≥53.2 mL/kg/min, respectively (Table 3). When the firefighters in the lowest and highest quintiles were compared, the prevalence ratios (PR (95% confidence interval (CI)) for MetS were 1.88 (0.71-4.94) for RHR, 5.90 (1.74-20.02) for HRR, and 8.03 (1.86-34.75) for VO_2 max (Table 3). There was no significant linear association between RHR and MetS: gamma coefficient (95%CI) 0.189 (−0.052, 0.426). By contrast, both HRR and VO_2 max were linearly and significantly associated with MetS: gamma coefficients (95%CIs) −0.501 (−0.681, −0.305) and −0.522 (−0.690, −0.330), respectively (Figure 1).

When RHR was tested as the five groups of 10 bpm intervals, the PR for MetS increased to 2.88 (0.53-15.70) between the lowest and highest RHR groups (≥80 bpm vs. 40-49 bpm). There was also a significant linear association between RHR and MetS: gamma coefficient (95%CI) 0.272 (0.023, 0.503) (Table 3 and Figure 2).

With regards to the associations with the component risk factors of MetS, all three cardiovascular fitness indicators were associated with high TG (Table 3). However, none of them were associated with high levels of fasting blood glucose. In addition, both HRR and VO_2 max were more strongly associated with the other three risk factors (central obesity, high BP, and low HDL cholesterol) than RHR (Table 3).

TABLE 2 Distributions of study variables and the prevalence of metabolic syndrome among the firefighters (*N* = 288)

Study variables	Category	Subcategory	Distribution of study variables	Mean values RHR (beats/min)	HRR (beats/min)	VO_2 max (mL/kg/min)	Metabolic syndrome
Sociodemographic	Age (years)	25-44	53.8	60.0***	121.4***	49.3***	5.2***
		45-63	46.2	63.4***	107.6***	42.3***	24.8***
	Sex	Men	97.6	61.6	114.9	46.1	14.6
		Women	2.4	59.7	118.8	47.1	0.0
	Race/Ethnicity	Non-Hispanic white	83.0	61.8	114.7	46.2	14.1
		Hispanic/Asian/others	17.0	60.5	116.5	46.3	14.6
	Education	Some college or high school	50.9	61.6	115.3	45.9	15.4
		College or graduate school	49.1	61.4	114.9	46.6	13.0
	Job title	Firefighters/engineers	68.4	61.0*	117.3***	47.2***	9.1***
		Captains/chiefs	31.6	62.6*	110.2***	43.6***	25.3***
Health-related behaviors	Exercise at work	≥2 days/week	87.2	61.0**	116.0***	46.8***	13.1*
		≤1 day/week	12.8	65.4**	109.0***	41.9***	22.2*
	Exercise during leisure time	≥2 days/week	75.4	61.0*	115.9**	47.0***	14.2
		≤1 day/week	24.6	63.4*	112.6**	43.8***	14.5
	High-fiber fruits/vegetable consumption	High (5-6 servings/d)	13.9	61.5	117.3	50.3***	5.1*
		Low (0-4 servings/d)	86.1	61.5	114.7	45.6***	15.7*
	Smoking or consumption of tobacco products	Yes	9.6	63.5	112.9	45.4	14.8
		No	90.4	61.3	115.4	46.3	14.2

*$P < 0.20$, **$P < 0.05$, and ***$P < 0.01$ at Chi-square test.

However, the prevalence of central obesity was significantly higher in the highest RHR (≥80 bpm) group than in the lowest RHR (40-49 bpm) group: PR (95%CI), 5.03 (1.05-24.22).

3.4 | The age-adjusted associations of RHR, HRR, and VO_2 max with MetS and component risk factors in 281 male firefighters

After stratification of the data into younger and older groups (Tables 4 and 5), the associations of HRR and VO_2 max with MetS substantially attenuated in the younger firefighters. In the younger firefighters, none of the three fitness indicators were significantly associated with MetS, although the prevalence of MetS was 4.78 times higher in the lowest VO_2 max group than in the highest VO_2 max group. Only a few younger firefighters had HRH values of ≥80 bpm (5/150, 3.3%), HRR values of ≤105.4 bpm (Q1 10/150, 6.6%), and VO_2 max values of ≤39.4 mL/kg/min (Q1 9/142, 6.3%) (Table 4).

However, in the older firefighters (45-64 years old), as in the univariate analyses, both HRR and VO_2 max were linearly associated with MetS: gamma coefficients (95%CIs), −0.320 (−0.580, −0.013) and −0.373 (−0.631, −0.075), respectively. There was a substantial difference in the prevalence of MetS between the lowest (Q1) and highest (Q5) groups of firefighters for HRR and VO_2 max: 35.4% and 23.1%, respectively (Table 5). A substantial proportion of the older firefighters had HRR values of ≤105.4 bpm (Q1 48/131, 36.6%) and VO_2 max values of ≤39.4 mL/kg/min (Q1 45/121, 37.2%) (Table 4). On the other hand, the linear association between RHR and MetS was not significant: gamma coefficient (95%CI) 0.138 (−0.147,

TABLE 3 The prevalence ratios (PRs) for metabolic syndrome (MetS) and its component risk factors by resting heart rate (RHR), heart rate reserve (HRR), and VO_2 max in 281 male firefighters

				MetS components: PR (%)				
Cardiovascular fitness indicator	**Five subgroups**	***N***	**MetS:PR (%)**	**Central obesity**	**High blood pressure**	**High fasting glucose**	**High triglycerides**	**Low HDL cholesterol**
RHR (beat/min): *N* = 281	Q1 (40-53)	52	1.00 (11.5)	1.00 (21.2)	1.00 (13.5)	1.00 (19.2)	1.00 (9.6)	1.00 (13.5)
	Q2 (54-58)	60	1.01 (11.7)	1.10 (23.3)	1.36 (18.3)	0.87 (16.7)	1.56 (15.0)	1.24 (16.7)
	Q3 (59-62)	53	1.15 (13.2)	1.16 (24.5)	1.12 (15.1)	0.88 (17.0)	2.55 (24.5)*	1.40 (18.9)
	Q4 (63-68)	56	1.24 (14.3)	1.10 (23.2)	1.59 (21.4)	0.93 (17.9)	3.16 (30.4)**	1.72 (23.2)
	Q5 (69-92)	60	1.88 (21.7)	1.58 (33.3)	2.23 (30.0)*	1.04 (20.0)	4.16 (40.0)***	1.86 (25.0)*
	Gamma coefficient		0.189*	0.132*	0.229**	0.022	0.412***	0.188*
RHR (beat/min): *N* = 281	40-49	23	1.00 (8.7)	1.00 (8.7)	1.00 (13.0)	1.00 (17.4)	1.00 (8.7)	1.00 (8.7)
	50-59	104	1.22 (10.6)	2.88 (25.0)*	1.18 (15.4)	1.11 (19.2)	1.88 (16.3)	1.99 (17.3)
	60-69	104	1.88 (16.3)	2.88 (25.0)*	1.70 (22.1)	0.89 (15.4)	3.21 (27.9)*	2.54 (22.1)
	70-79	34	2.37 (20.6)	3.38 (29.4)*	2.03 (26.5)	1.52 (26.5)	3.72 (32.4)*	2.71 (23.5)
	≥ 80	16	2.88 (25.0)	5.03 (43.8)**	2.40 (31.3)	0.72 (12.5)	6.47 (56.3**)	2.88 (25.0)
	Gamma coefficient		0.272**	0.198*	0.240**	0.005	0.405***	0.192*
HRR (beat/min): *N* = 281	Q5 (124.7-143.6)	57	1.00 (5.3)	1.00 (14.0)	1.00 (12.3)	1.00 (15.8)	1.00 (3.5)	1.00 (8.8)
	Q4 (118.5-124.6)	56	1.02 (5.4)	1.15 (16.1)	1.16 (14.3)	0.68 (10.7)	4.58 (16.1)*	1.22 (10.7)
	Q3 (113.1-118.4)	56	2.71 (14.3)	2.16 (30.4)	1.02 (12.5)	1.24 (19.6)	6.62 (23.2)**	2.65 (23.2)*
	Q2 (105.5-113.0)	54	3.17 (16.7)*	1.98 (27.8)*	1.66 (20.4)	1.06 (16.7)	8.97 (31.5)***	2.53 (22.2)*
	Q1 (76.8-105.4)	58	5.90 (31.0)***	2.70 (37.9)**	3.23 (39.7)***	1.75 (27.6)*	13.27 (46.6)***	3.73 (32.8)***
	Gamma coefficient		−0.501***	−0.315***	−0.381***	−0.201*	−0.543***	−0.377***
VO_2 max (ml/kg/min): *N* = 263	Q5 (53.2-64.9)	51	1.00 (3.9)	1.00 (7.8)	1.00 (9.8)	1.00 (17.6)	1.00 (5.9)	1.00 (3.9)
	Q4 (47.7-53.1)	54	1.42 (5.6)	1.18 (9.3)	0.76 (7.4)	0.42 (7.4)	1.89 (11.1)	2.36 (9.3)
	Q3 (43.5-47.6)	50	4.08 (16.0)	3.57 (28.0)**	1.63 (16.0)	0.91 (16.0)	3.74 (22.0)**	6.63 (26.0)**
	Q2 (39.5-43.4)	54	4.72 (18.5)*	4.72 (37.0)***	2.46 (24.1)*	1.36 (24.1)	5.67 (33.3)***	7.08 (27.8)***
	Q1 (32.6-39.4)	54	8.03 (31.5)**	4.96 (38.9)***	3.78 (37.0)***	1.36 (24.1)	8.19 (48.1)***	8.97 (35.2)***
	Gamma coefficient		−0.522***	−0.478***	−0.459***	−0.204*	−0.566***	−0.487***

Q1 to Q5: quintiles . *$P < 0.20$, **$P < 0.05$, and ***$P < 0.01$ of PRs or gamma coefficients.

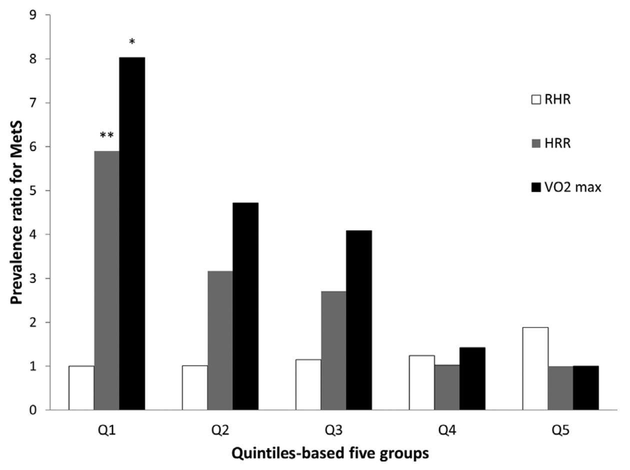

FIGURE 1 The prevalence ratios for metabolic syndrome (MetS) by resting heart rate (RHR), heart rate reserve (HRR), and VO2 max in 281 male firefighters. Q1 (the lowest) to Q5 (the highest): quintiles-based five groups. The reference group was Q1 for RHR and Q5 for HRR and VO2 max. *$P < 0.05$ and **$P < 0.01$

0.431). The linear association between RHR (based on 10 bpm intervals) and MetS was also not significant: gamma coefficient (95% CI) 0.184 (−0.118, 0.478), although the risk for MetS was 2.18 times higher in the highest RHR (≥80 bpm) group than in the lowest (40-49 bpm) RHR group.

As in the univariate analyses, all of the three indicators were linearly associated with high TG, but not with high levels of fasting blood glucose in both the younger and older firefighters. Also, VO_2 max was linearly associated with the other three risk factors (central obesity, high BP, and low HDL cholesterol) in both the younger and older firefighters (Tables 4 and 5). HRR was also linearly associated with the three risk factors, but largely limited to the older firefighters. RHR was not significantly associated with any of the three risk factors in either the younger or older firefighters.

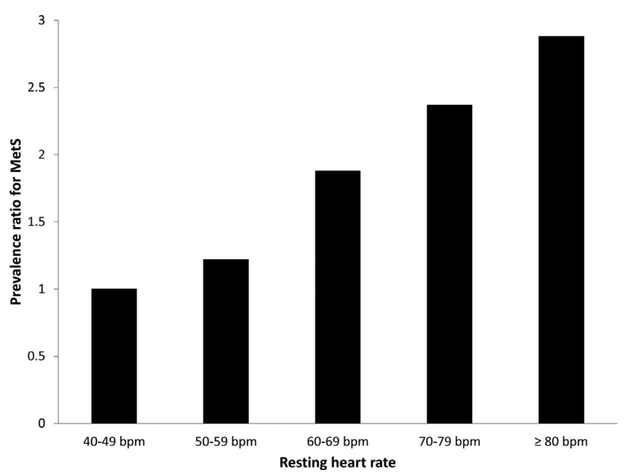

FIGURE 2 The prevalence ratios for metabolic syndrome (MetS) by resting heart rate (RHR) 10 bpm intervals in 281 male firefighters: the gamma coefficient, 0.274 ($P = 0.04$)

3.5 | sensitivity test without those who took anti-hypertensive medications in 261 male firefighters

The above results did not change much after those under treatment with anti-hypertensive medications were excluded from analyses. For instance, the prevalence of MetS slightly dropped to 11.5% (results not shown) The mean (±standard deviation) of RHR values was 61.2 bpm (±9.3 bpm) among the 261 male firefighters. The associations between RHR, HRR, and VO_2 max with MetS decreased to some extent. The univariate gamma coefficients (95%CIs) of RHR, HRR, and VO_2 max with MetS were 0.101 (−0.188, 0.380), −0.396 (−0.614, −0.152), and −0.428 (−0.647, −0.176), respectively. The gamma coefficient (95%CI) between RHR (based on 10 bpm intervals) and MetS was 0.175 (−0.120, 0.459).

4 | DISCUSSION

This is the first study to investigate and compare three cardiovascular fitness indicators (RHR, HRR, and VO_2 max) in relation to MetS and its component risk factors in working populations, including professional firefighters. RHR was not associated with MetS or most components risk factors in the firefighters. By contrast, both HRR and VO_2 max were inversely associated with MetS and most component risk factors, although for HRR, it was largely restricted to the older firefighters. Compared with RHR (based on quintiles), RHR (based on 10 bpm intervals) was more strongly associated with MetS, but the association became non-significant after adjustment for age. None of the three indicators were associated with high levels of fasting blood glucose. This study indicates that HRR (eg, ≤105 bpm) may have potential to be used as a simple clinical measure for predicting the risk for MetS and its component risk factors, particularly among middle-aged (45 to 63 years old) professional firefighters.

4.1 | Comparison with previous studies

In the prevalence of MetS among professional firefighters, this study is similar to the previous studies from Arizona (US) and Germany[13,37]; namely, 14% versus 13-15%. However, one previous study[12] of the Mid-Western states, which are among the states with the highest average BMI in the United States,[38] reported a higher prevalence of MetS (28.3%) among professional firefighters. However, all of the above indicate that professional firefighters are better off than US adult general populations (prevalence of MetS 33%, over the period 2003-2016).[39]

As opposed to some previous longitudinal studies in male or male-dominated general and working populations,[16,20,21] there was no significant association between RHR and MetS in the professional firefighters after controlling for age. Two longitudinal studies[19,22] also failed to find a significant association between RHR and MetS in a male Japanese working population and a male Chinese general population, respectively. However, the result for RHR in the current study should be cautiously interpreted due to the following two reasons. First, the average RHR of the professional firefighters (61 bpm) in the current

TABLE 4 The prevalence ratios (PRs) for metabolic syndrome (MetS) and its component risk factors by resting heart rate (RHR), heart rate reserve (HRR), and VO_2 max in the younger (25-44 years old) male firefighters

Cardiovascular Fitness indicator	Five subgroups	*N*	MetS:PR (%)	MetS components: PR (%)				
				Central obesity	High blood pressure	High fasting glucose	High triglycerides	Low HDL cholesterol
RHR (beat/min): *N* = 150	Q1 (40-53)	35	1.00 (8.6)	1.00 (20.0)	1.00 (8.6)	1.00 (14.3)	1.00 (2.9)	1.00 (11.4)
	Q2 (54-58)	33	0.00 (0.0)	0.61 (12.1)	2.12 (18.2)	0.42 (6.1)	3.18 (9.1)	1.06 (12.1)
	Q3 (59-62)	34	0.69 (5.9)	0.88 (17.6)	1.03 (8.8)	1.03 (14.7)	7.21 (20.6)*	1.29 (14.7)
	Q4 (63-68)	24	0.97 (8.3)	0.83 (16.7)	1.94 (16.7)	0.58 (8.3)	5.83 (16.7)	1.46 (16.7)
	Q5 (69-92)	24	0.49 (4.2)	1.04 (20.8)	2.43 (20.8)	0.88 (12.5)	7.29 (20.8)*	0.37 (4.2)
	Gamma coefficient		−0.025	0.027	0.172	−0.019	0.391**	−0.058
RHR (beat/min): *N* = 150	40-49	15	1.00 (6.7)	1.00 (6.7)	1.00 (6.7)	1.00 (13.3)	1.00 (6.7)	1.00 (6.7)
	50-59	64	0.47 (3.1)	2.81 (18.8)	2.11 (14.1)	0.94 (12.5)	1.64 (10.9)	2.11 (14.1)
	60-69	51	1.18 (7.8)	2.65 (17.6)	2.06 (13.7)	0.59 (7.8)	2.65 (17.6)	2.06 (13.7)
	70-79	15	0.00 (0.0)	3.00 (20.0)	2.00 (13.3)	1.00 (13.3)	1.00 (6.7)	0.00 (0.0)
	≥ 80	5	3.00 (20.0)	3.00 (20.0)	6.00 (40.0)*	1.50 (20.0)	6.00 (40.0)*	3.00 (20.0)
	Gamma coefficient		0.166	0.113	0.169	-0.055	0.234	-0.052
HRR (beat/min): *N* = 150	Q5 (124.7-143.6)	53	1.00 (5.7)	1.00 (15.1)	1.00 (11.3)	1.00 (13.2)	1.00 (3.8)	1.00 (9.4)
	Q4 (118.5-124.6)	45	0.79 (4.4)	1.03 (15.6)	1.18 (13.3)	0.84 (11.1)	4.12 (15.6)*	1.18 (11.1)
	Q3 (113.1-118.4)	29	0.61 (3.4)	1.60 (24.1)	0.91 (10.3)	0.52 (11.8)	5.48 (20.7)**	2.19 (20.7)
	Q2 (105.5-113.0)	13	1.36 (7.7)	0.51 (7.7)	2.04 (23.1)	0.58 (7.7)	6.12 (23.1)**	0.82 (7.7)
	Q1 (76.8-105.4)	10	1.77 (10.0)	1.99 (30.0)	2.65 (30.0)*	1.51 (20.0)	5.30 (20.0)*	1.06 (10.0)
	Gamma coefficient		−0.051	−0.122	−0.203	0.077	−0.437***	−0.128
VO_2 max (mL/kg/min): *N* = 142	Q5 (53.2-64.9)	43	1.00 (2.3)	1.00 (7.0)	1.00 (7.0)	1.00 (14.0)	1.00 (7.0)	1.00 (4.7)
	Q4 (47.7-53.1)	42	3.07 (7.1)	1.37 (9.5)	1.37 (9.5)	0.34 (4.8)	1.37 (9.5)	1.54 (7.1)
	Q3 (43.5-47.6)	29	4.45 (10.3)*	3.46 (24.1)*	2.97 (20.7)*	0.74 (10.3)	1.48 (10.3)	5.19 (24.1)**
	Q2 (39.5-43.4)	19	0.00 (0.0)	5.28 (36.8)**	1.51 (10.5)	1.51 (21.1)	3.77 (26.3)*	4.53 (21.1)*
	Q1 (32.6-39.4)	9	4.78 (11.1)	4.78 (33.3)*	6.37 (44.4)**	0.80 (11.1)	7.96 (55.6)***	4.78 (22.2)*
	Gamma coefficient		−0.197	−0.512***	−0.390**	−0.065	−0.504***	−0.468***

Q1 to Q5: quintiles. **P* < 0.20, ***P* < 0.05, and ****P* < 0.01 of PRs or partial (age-adjusted) gamma coefficients.

TABLE 5 The prevalence ratios (PRs) for metabolic syndrome (MetS) and its component risk factors by resting heart rate (RHR), heart rate reserve (HRR), and VO_2 max in the older (45-63 years old) male firefighters

				MetS components: PR (%)				
Cardiovascular fitness indicator	**Five subgroups**	**N**	**MetS:PR (%)**	**Central obesity**	**High blood pressure**	**High fasting glucose**	**High triglycerides**	**Low HDL cholesterol**
RHR (beat/min): *N* = 131	Q1 (40-53)	17	1.00 (17.6)	1.00 (23.5)	1.00 (23.5)	1.00 (29.4)	1.00 (23.5)	1.00 (17.6)
	Q2 (54-58)	27	1.47 (25.9)	1.57 (37.0)	0.79 (18.5)	1.01 (29.6)	0.94 (22.2)	1.26 (22.2)
	Q3 (59-62)	19	1.49 (26.3)	1.57 (36.8)	1.12 (26.3)	0.72 (21.1)	1.34 (31.6)	1.49 (26.3)
	Q4 (63-68)	32	1.06 (18.8)	1.20 (28.1)	1.06 (25.0)	0.85 (25.0)	1.73 (40.6)	1.59 (28.1)
	Q5 (69-92)	36	1.89 (36.4)	1.77 (41.7)	1.54 (36.1)	0.85 (25.0)	2.24 (52.8)*	2.20 (38.9)
	Gamma coefficient		0.138	0.113	0.199*	-0.060	0.360***	0.254*
RHR (beat/min): *N* = 131	40-49	8	1.00 (12.5)	1.00 (12.5)	1.00 (25.0)	1.00 (25.0)	1.00 (12.5)	1.00 (12.5)
	50-59	40	1.80 (22.5)	2.80 (35.0)	0.70 (17.5)	1.20 (30.0)	2.00 (25.0)	1.80 (22.5)
	60-69	53	1.96 (24.5)	2.57 (32.1)	1.21 (30.2)	0.91 (22.6)	3.02 (37.7)	2.42 (30.2)
	70-79	19	2.95 (36.8)	2.95 (36.8)	1.47 (36.8)	1.47 (36.8)	4.21 (41.7)*	3.37 (42.1)
	≥ 80	11	2.18 (27.3)	4.36 (54.5)*	1.09 (27.3)	0.36 (9.1)	5.09 (63.6)*	2.18 (27.3)
	Gamma coefficient		0.184	0.174	0.210*	−0.076	0.423***	0.229*
HRR (beat/min): *N* = 131	Q5 (124.7-143.6)	4	0.00 (0.0)	0.00 (0.0)	1.00 (25.0)	1.00 (50.0)	0.00 (0.0)	0.00 (0.0)
	Q4 (118.5-124.6)	11	1.00 (9.1)	1.00 (18.0)	0.73 (18.2)	0.18 (9.1)	1.00 (18.2)	1.00 (9.1)
	Q3 (113.1-118.4)	27	2.85 (25.9)	2.04 (37.0)	0.59 (14.8)	0.67 (33.3)	1.43 (25.9)	2.85 (25.9)
	Q2 (105.5-113.0)	41	2.15 (19.5)	1.88 (34.1)	0.78 (19.5)	0.39 (19.5)	1.88 (34.1)	2.95 (26.8)
	Q1 (76.8-105.4)	48	3.90 (35.4)*	2.18 (39.6)	1.67 (41.7)	0.58 (29.2)	2.87 (52.1)*	4.13 (37.5)*
	Gamma coefficient		−0.320**	−0.192*	−0.398***	−0.034	−0.435***	−0.325**
VO_2 max (mL/kg/min): *N* = 121	Q5 (53.2-64.9)	8	1.00 (12.5)	1.00 (12.5)	1.00 (25.0)	1.00 (37.5)	0.00 (0.0)	0.00 (0.0)
	Q4 (47.7-53.1)	12	0.00 (0.0)	0.67 (8.3)	0.00 (0.0)	0.44 (16.7)	1.00 (16.7)	1.00 (16.7)
	Q3 (43.5-47.6)	21	1.91 (23.8)	2.67 (33.3)	0.38 (9.5)	0.64 (23.8)	2.29 (38.1)	1.71 (28.6)
	Q2 (39.5-43.4)	35	2.29 (28.6)	2.97 (37.1)	1.26 (31.4)	0.69 (25.7)	2.23 (37.1)	1.89 (31.4)
	Q1 (32.6-39.4)	45	2.84 (35.6)	3.20 (40.0)	1.42 (35.6)	0.71 (26.7)	2.80 (46.7)*	2.27 (37.8)
	Gamma coefficient		−0.373**	−0.293**	−0.411***	−0.025	−0.355***	−0.318**

Q1 to Q5: quintile. *$P < 0.20$, **$P < 0.05$, and ***$P < 0.01$ of PRs or partial (age-adjusted) gamma coefficients.

study were substantially lower than those of US adult populations (71-73 bpm)[40] and a group of German professional firefighters (68 bpm).[37] As a result, only 5.8% of the firefighters had ≥80 bpm of RHR that could be regarded as a high RHR group in general populations.[41] Second, the PRs for MetS between the highest and lowest RHR groups (≥80 bpm vs. 40-49 bpm) were still greater than 2.1, even after controlling for age, although the differences did not reach the statistical significance of 0.05. This is largely consistent with the conclusion of a recent meta-analysis on the risk from 13 cross-sectional and cohort studies for MetS between the lowest and highest RHR groups[42]: the relative risk of MetS was 2.10 times greater in the highest RHR category than in the reference (lowest) RHR category. Thus, future studies with a larger sample of professional firefighters with greater statistical power are needed to clarify the association between RHR and MetS.

On the other hand, this is also the first study to show that HRR was associated with MetS and its component risk factors in general or working populations. Interestingly, despite the very high correlation between RHR and HRR (Spearman correlation, 0.83) among the professional firefighters, HRR was much more strongly associated with MetS and component risk factors than RHR. In a sense, this is consistent with previous studies[26,27] in which HRR was more predictive of CVD mortality, compared to RHR or maximum HR. However, the association between HRR and MetS in younger (25-44 years old) firefighters who constitute about 22% of total firefighter on-duty cardiac fatalities in the US[1] remains to be further tested in future studies.

Consistent with previous firefighter studies,[12,13] this study supported the association between VO_2 max and MetS. This study adds new information to the literature that among the three fitness indicators, VO_2 max is the best correlate with MetS and its component risk factors in professional firefighters. In addition, in contrast with the previous study,[12] this study suggests that the association between VO_2 max and MetS might be stronger in older firefighters than in younger firefighters.

Among the five component risk factors, only high levels of fasting glucose were not associated with any of the three fitness indicators in the firefighters. This is similar to the finding in the previous US studies[1,3] in which diabetes mellitus was not associated with firefighter cardiac deaths, while, as expected, other CVD risk factors (obesity, hypertension, and hyperlipidemia) were significant predictors for firefighter cardiac deaths. It may be partly related to the fact that US firefighter candidates with diabetes mellitus (treated with insulin or uncontrolled by oral medications) are screened out in their pre-employment medical examinations (National Fire Protection Agency (NFPA)® 1582).[23,43]

4.2 | Important implications for prevention of MetS and CVD among professional firefighters

Among the three cardiovascular fitness indicators, VO_2 max was the best in the associations with MetS and its component risk factors in professional firefighters. This supports the current standard on health-related fitness programs for firefighters (NFPA® 1583)[44] in which aerobic capacity (VO_2 max) is recommended as part of a firefighter fitness assessment.

In addition, this study suggests that, if confirmed in future studies, HRR can be utilized as a simple clinical measure for detecting and reducing the risk for future MetS among older (45-64 years old) firefighters, that is, who are at higher risk for MetS and on-duty cardiac death than younger (25-44 years old) firefighters. Its clinical utility will be greater in many US fire departments that do not have yet a firefighter fitness program,[14] including the assessment of VO_2 max. It should be emphasized that our measure of HRR is a simple subtraction of a measured RHR from an estimated maximum HR using a standard age-based formula,[15] a calculation which can easily be performed by all clinicians and firefighters across the nation. Our study indicates that HRR (105 bpm) as a rough practical cut-point may be used for predicting the risk for MetS among middle-aged professional firefighters. The firefighters in the lowest HRR quintile (≤105.4 bpm) in the current study were about six times more likely to have MetS, compared to those in the highest HRR group in the whole sample of firefighters. They were also about four times more likely to have MetS compared to those in the second highest HRR group in the older firefighters. In addition, they had substantially greater levels of central obesity, high blood pressure, high triglycerides, and low HDL cholesterol than those in the highest HRR group in the whole sample of firefighters and the older firefighters.

There were strong correlations between the frequency of exercise at work and during leisure time and three fitness indicators. This implies that firefighter stakeholders need to make more collective efforts to encourage their physically inactive members to be engaged in exercise on a regular basis. In our previous study,[45] firefighters with high perceived coworker support for exercise are more likely to exercise at work than those with low perceived coworker support for exercise.

5 | LIMITATIONS

This study has three limitations. First, as this study used a cross-sectional approach, we cannot tell the temporal relationship between the three cardiovascular fitness indicators and MetS in this study. Future firefighter cohort studies are needed to confirm the causal direction between the fitness indicators and MetS. Second, the sample size of this study is relatively small. In particular, the age-stratified analysis in this study was likely to be underpowered. For example, there were only a few firefighters in the highest HRR group (Q1) in the older firefighters. Thus, future studies with larger samples of professional firefighters are needed in particular for examining any age-related (25-44 years old vs. 45-64 years old) associations of cardiovascular fitness indicators with MetS in professional firefighters.

Third, firefighter RHR in the current study was estimated based on a one-time 10 s assessment of pulse palpation by experienced nurses at a university clinic. Thus, firefighter RHR in this study may have been over-or under-estimated to some extent. According to the previous studies,[46,47] there were, on average, 2.4-3.4 bpm differences in RHR between a shorter (10 or 15 s) assessment and a full 60 s assessment, due to human errors or natural instability of human heartbeats. However, we think that some errors in RHR assessment, if any, would be non-differential rather than differential by MetS and its component risk factors because experienced nurses were blind to the status of firefighters on MetS and its component risk factors at the clinic. Given the non-differential exposure misclassification, the association between RHR and MetS may have been underestimated in the current study. Nonetheless, for future RHR research, it is desirable to follow the current standard assessment protocol,[48] including at least two consecutive assessments of RHR for 30 s each. Fourth, our sample of the professional firefighters in the current study came from a fire department in Southern California that has had a good firefighter WEFIT program since 2004. Thus, our findings in the current study remain to be further tested and confirmed in future studies with more diverse samples of professional and voluntary firefighters in the United States and other countries.

ACKNOWLEDGMENTS

We express our sincere thanks to a fire department and a local union of the International Association of Fire Fighters (IAFF) in Southern California for their support and input in this study. The fire department and union had no decision-making role in the decision to publish study results or the content of the publication. This study was supported by the Centers for Disease Control and Prevention (CDC)/National Institute for Occupational Safety and Health (NIOSH) (Grant #, 5R21OH009911-02). This study was partially supported by the Gangwon Cardiovascular Health Research Institute, South Korea. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC/NIOSH or the Gangwon Cardiovascular Health Research Institute.

ETHICS APPROVAL AND INFORMED CONSENT

The protocol of this study was approved by the Institutional Review Board (IRB) of the University of California, Irvine. All firefighters in this study were fully informed of the study and signed written informed consent forms.

DISCLOSURE (AUTHORS)

The authors report no conflict of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Rodney Ehrlich declares that he has no conflict of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

ORCID

BongKyoo Choi http://orcid.org/0000-0002-7087-9378

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How to cite this article: Choi B, Ko S, Kojaku S. Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study. *Am J Ind Med*. 2017;60:900–910. https://doi.org/10.1002/ajim.22752