Metabolically Healthy Obesity and Physical Fitness in Military Males in the CHIEF Study

Sheng-Huei Wang

National Defense Medical Center

Pei-Shou Chung

Hualien Armed Forces General Hospital

Yen-Po Lin

Taipei Tzu Chi Hospital

Kun-Zhe Tsai

Hualien Armed Forces General Hospital

Ssu-Chin Lin

Hualien Armed Forces General Hospital

Chia-Hao Fan

Hualien Armed Forces General Hospital

Yu-Kai Lin

National Defense Medical Center

Gen-Min Lin (✉ farmer507@yahoo.com.tw)

Department of Preventive Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL 60611, USA

Research Article

Keywords: cardiorespiratory fitness, metabolically healthy obesity, military males, muscle strength, physical activity

Posted Date: December 9th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-119378/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Version of Record: A version of this preprint was published at Scientific Reports on April 27th, 2021. See the published version at <https://doi.org/10.1038/s41598-021-88728-0>.

Abstract

The metabolically healthy obese (MHO) characterized by the absence of abdominal obesity have been reported to have superior cardiorespiratory fitness (CRF) than the metabolically unhealthy obese (MUO). However, this finding might be biased by the baseline sedentary behavior in the general population.

This study utilized 3,669 physically active military males aged 18-50 years in Taiwan. Obesity and metabolically unhealthy were respectively defined as body mass index ≥ 27.5 kg/m² and waist circumference ≥ 90 cm, specifically for Asian male adults. Four groups were accordingly classified as the metabolically healthy lean (MHL, n=2,607), metabolically unhealthy lean (MUL, n=234), MHO (n=208) and MUO (n=620). CRF was evaluated by time for a 3-kilometer run, and muscular strengths were separately assessed by numbers of push-up and sit-up within 2 minutes. Analysis of covariance was utilized to compare the difference in each exercise performance between groups adjusting for age, service specialty, smoking, alcohol intake, and physical activity.

The prevalence of metabolic syndrome in MUO, MHO, MUL and MHL was 45.3% 13.0%, 29.1% and 3.7%, respectively. The performance of CRF did not differ between MHO and MUO (895.3 $\pm$ 5.1 sec and 891.5 $\pm$ 3.1 sec, p=0.68) which were both inferior to MUL and MHL (877.5 $\pm$ 4.8 sec and 849.5 $\pm$ 1.4 sec, all p-values <0.05). The performance of muscular strengths evaluated by 2-minute push-ups did not differ between MUL and MUO (44.8 $\pm$ 0.2 and 45.2 $\pm$ 0.5, p=0.40) which were both less than MHO and MHL (48.1 $\pm$ 0.8 and 50.5 $\pm$ 0.2, all p-values <0.05). However, the performance of 2-minute sit-ups were only superior in MHL (48.0 $\pm$ 0.2) as compared with MUL, MHO and MUO (46.0 $\pm$ 0.5, 46.7 $\pm$ 0.5 and 46.2 $\pm$ 0.3, respectively, all p-values <0.05).

Our findings suggested that in a physically active male cohort, the MHO might have greater muscle strengths, but have similar CRF level compared with the MUO.

Introduction

The global prevalence of obesity has increased dramatically over the past few decades, which results in reduced individual life expectancy of more than 10 years and causes enormously social health burden.¹⁻³ Many guidelines for the diagnosis of obesity was according to body mass index (BMI), but BMI could not precisely estimate the percentage of body fat, location of fat accumulation, and the risk of future obesity associated comorbidities.⁴ Early to 1950s, Jean Vague observed that the obese with different body fat distribution may have different propensity for development of atherosclerosis or diabetes mellitus.⁵ Therefore, the concept of metabolically healthy obesity (MHO) and unhealthy obesity (MUO) has been established according to numerous observational and interventional studies after decades.

MUO is one obesity phenotype that 80–90 percent of obese individuals belong to this category, and MHO is another phenotype that the prevalence is 10–20 percent in obese individuals and higher in female gender and decreases with aging.^{6,7} The body fat disposition in MHO individuals accumulates mainly in the legs and subcutaneous tissues, while that of MUO individuals locates in ectopic regions including visceral tissues and the liver, resulting in abdominal obesity. These two obesity phenotypes are bidirectionally interchangeable by means of weight loss/gain measures, aging, hormone changes, and so on.⁸⁻¹⁰ The pathogenesis of MUO is related to adipose tissue dysfunction that chronic positive energy balance decreases subcutaneous adipose tissue expandability, leading to hepatic steatosis and body fat accumulation in visceral tissues.^{11,12} The adipose tissue dysfunction and ectopic fat accumulation cause generation of proinflammatory cytokines, disturbance of circulatory singling molecules, lipotoxicity and insulin resistance, which could transit the obesity phenotype from MHO to MUO.^{6,13} Several studies have reported that MUO individuals have higher risk of cardiometabolic diseases than MHO individuals.^{14,15}

With regard to a comparison of cardiorespiratory fitness (CRF) between MHO and MUO, disparities exist in prior studies. Two large cross-sectional studies conducted by Jae and Ortega reported that MHO individuals had better CRF than MUO individuals, whereas several small studies revealed no differences between the two obesity phenotypes.¹⁶⁻²⁰ A recent meta-analysis revealed that MHO individuals had higher CRF level compared to MUO individuals, while many studies recruited for analysis contained potential confounders such as different life styles, habits, and frequency of illicit behaviors which could not be well adjusted at baseline.²¹ Therefore, we conducted a cross-sectional study to investigate the association of CRF and muscle strengths with metabolically healthy and unhealthy lean and obesity in military personnel who lived in the same closed-system environment, and had similar physical activity in Taiwan.

Methods

Study population

The whole data of this study was retrieved from the Cardiorespiratory Fitness and Hospitalization Events in Armed Forces (CHIEF) study in Taiwan.²² The protocol and design of the CHIEF study have been described in detail in prior studies.^{23–30} Briefly, this study included 4,080 military individuals, aged 18–50 years, who received the annual health examinations including a questionnaire survey for their habitual habits of tobacco smoking (current vs. former/never), alcohol intake (current vs. former/never) and physical activity evaluated by weekly exercise times (each time longer than 30 minutes) in the past half year (never or occasionally, 1–2 times and ≥ 3 times) in the Hualien-Armed Forces General Hospital, and performed at least one of the annual three exercise tests including 2-minute push-ups, 2-minute sit-ups and 3 kilometer run test at the Military Physical Training and Testing Center in 2014. As the sample of MHO in females defined as waist circumference < 80 cm and body mass index (BMI) ≥ 27.5 kg/m² was merely 8 cases, all female subjects ($n = 411$) were excluded for a small sample size which had insufficient power to be analyzed, and thus the male subjects ($n = 3,669$) were left for the following analyses.

Measurements

The body height and weight of every individual were measured in standing position, and the waist circumference was measured at the midline between the top of the iliac crest and the lowest palpable rib. The definition of BMI was body weight (kg) divided by square of body height (m²). Resting blood pressure was assessed over the right upper arm of each participant by an automated blood pressure monitor (FT-201, Parama-Tech Co. Ltd., Fukuoka, Japan). Over a 12-hour fasting, venous blood specimens were drawn from each individual to measure concentrations of fasting glucose, triglycerides, and cholesterol on an auto analyzer (AU640, Olympus, Kobe, Japan).

Metabolic and obese status classifications

For Asian male adults, obesity was defined as BMI ≥ 27.5 kg/m² based on the Taiwan's Department of Health guidelines.^{31,32} As abdominal obesity defined as waist circumference ≥ 90 cm is the major feature of metabolic syndrome, the cut-off point was utilized to determine the metabolically healthy or unhealthy status. Four groups were thereby classified into the metabolically healthy lean (MHL, $n = 2,607$), metabolically unhealthy lean (MUL, $n = 234$), MHO ($n = 208$) and MUO ($n = 620$).

Physical fitness tests

Time for a 3-kilometer run test of each participant was used for an evaluation of the level of CRF. The examinees ran 3-kilometer on a flat playground at the Military Physical Training and Testing Center in Hualien without bearing any burden. This running test was held uniformly outdoor at 04:00 PM, and the coefficient of the heat stroke risk formula had to be lower than 40 (the product of outdoor temperature on the Celsius scale and relative humidity (%) $\times 0.1$). In addition, muscular strengths of each participant were separately evaluated by numbers of push-ups and sit-ups within 2 minutes. The stopping point (2 minutes) in brief bursts of push-up and sit-up exercises was determined by the findings from other studies.^{33,34} These two anaerobic exercises performed on sponge pad were scored by computerized machines. In the push-up test, the examinees obtained score while his back in a line with head and buttocks returned to the initial set level at resting, detected by infrared sensors within 2 minutes. But the push-up test was discontinued immediately once the body excepting hands and toes touched down on the pad before the time ran out. In the sit-up test, the examinees' feet were both fixed by the anchors on sponge pad and their hands attached close to the ears. The examinees obtained score when their upper trunk bended forward and the elbows touched the artificial sensors on both thighs. The present study was approved by the Institutional Review Board of the Mennonite Christian Hospital (No. 16-05-008) in Taiwan and the written informed consents were obtained from all subjects. All methods were performed in accordance with the relevant guidelines and regulations

Statistical analysis

For the characteristics of each group, categorical variables were expressed as numbers (percentages) and compared by χ^2 test, and continuous variables were presented as mean $\pm$ standard deviation (SD) and compared by analysis of variance (ANOVA). Pearson's correlation coefficients were used to plot the correlation of BMI and waist circumference with each exercise performance. The difference in each exercise performance between groups was estimated with analysis of covariance (ANCOVA), and the results were presented as mean $\pm$ standard error (SE). Multiple linear regression analyses were used to determine the relationship of the four groups with each exercise performance. Furthermore, we used multiple logistic regressions to determine the odds ratio (OR) of the best 10%

performers and the worst 10% performers in each exercise for comparisons between groups. In model 1, age and service specialty were adjusted. In model 2, current tobacco smoking, current alcohol intake and physical acidity were adjusted in addition to the covariates in model 1. A 2- tailed value of $p < 0.05$ was considered significant. SPSS statistical software was used for the statistical analyses (IBM Corp. Released 2013. IBM SPSS statistics for windows, version 22.0. Armonk, NY: IBM Corp.).

Results

Baseline Group Characteristics

Table 1 reveals the characteristics of the four groups. Levels of blood pressure were higher in individuals with obesity, BMI $\geq 27.5 \text{ kg/m}^2$ (MUO and MHO > MUL and MHL) and individuals with abdominal obesity (MUO > MHO and MUL > MHL) than their counterparts. The prevalence of metabolic syndrome defined by an updated criteria of International Diabetes Federation³⁵ in MUO, MHO, MUL and MHL was 45.3% 13.0%, 29.1% and 3.7%, respectively. There were no differences in the prevalence of physical fitness frequency, current tobacco smoking and current alcohol consumption.

Table 1
Baseline Characteristics of the Study Population (n = 3,669).

Characteristics	MHL (n = 2,607)	MUL (n = 234)	MHO (n = 208)	MUO (n = 620)	p-value
Age	28.7 ± 5.9	30.3 ± 5.2	29.9 ± 5.6	31.5 ± 5.5	< 0.01
Specialty					
Army	1353 [51.9]	119 [50.9]	95 [45.7]	287 [46.3]	< 0.01
Navy	509 [19.5]	58 [24.8]	50 [24.0]	171 [27.6]	
Air force	745 [28.6]	57 [24.3]	63 [30.3]	162 [26.1]	
Body mass index, (kg/m ²)	23.4 ± 2.2	26.2 ± 1.2	28.6 ± 1.0	29.3 ± 1.2	< 0.01
(Minimum-Maximum)	(15.9–27.4)	(20.6–27.4)	(27.5–32.9)	(27.5–34.8)	
Waist circumference (cm)	79.7 ± 5.9	91.9 ± 2.0	86.5 ± 3.1	94.5 ± 3.6	< 0.01
(Minimum-Maximum)	(52.0–89.5)	(90.0–99.0)	(59.0–89.0)	(90.0–117.0)	
Waist to height ratio, WHtR	0.46 ± 0.05	0.52 ± 0.02	0.50 ± 0.08	0.55 ± 0.02	< 0.01
Systolic blood pressure, (mmHg)	116.5 ± 12.7	120.2 ± 11.0	122.6 ± 14.1	124.0 ± 13.1	< 0.01
Diastolic blood pressure, (mmHg)	69.4 ± 9.7	71.5 ± 10.0	73.0 ± 10.6	74.2 ± 10.6	< 0.01
Blood test					
Total cholesterol (mg/dL)	169.8 ± 32.2	183.0 ± 34.8	181.7 ± 34.7	188.0 ± 36.5	< 0.01
Serum triglyceride (mg/dL)	100.5 ± 84.3	138.0 ± 102.1	140.0 ± 91.7	159.1 ± 140.5	< 0.01
Fasting plasma glucose (mg/dL)	92.8 ± 11.6	94.3 ± 19.7	96.0 ± 16.6	96.0 ± 15.9	< 0.01
HDL-C (mg/dL)	49.3 ± 9.9	45.5 ± 9.1	44.8 ± 8.0	43.9 ± 8.7	< 0.01
LDL-C (mg/dL)	102.0 ± 28.2	113.0 ± 29.2	112.9 ± 31.6	117.5 ± 31.5	< 0.01
Metabolic syndrome	97 [3.7]	68 [29.1]	27 [13.0]	281 [45.3]	< 0.01
Current alcohol intake	1117 [42.8]	116 [49.6]	91 [43.8]	292 [47.1]	0.08
Current smoking	977 [38.1]	80 [34.8]	79 [38.7]	240 [39.1]	0.71
Physical activity					
Never or occasionally	561 [21.5]	42 [17.9]	41 [19.7]	125 [20.2]	0.74
1–2 times per week	970 [37.2]	98 [41.9]	76 [36.5]	234 [37.7]	
≥3 times per week	1076 [41.3]	94 [40.2]	91 [43.8]	261 [42.1]	
Continuous variables are expressed as mean ± standard deviation, and categorical variables as n [%]. HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol. MHL, metabolically healthy lean, defined as body mass index < 27.5 kg/m ² and waist circumference < 90 cm; MHO, metabolically healthy obesity defined as body mass index ≥ 27.5 kg/m ² and waist circumference < 90 cm; MUL, metabolically unhealthy lean defined as body mass index < 27.5 kg/m ² and waist circumference ≥ 90 cm; MUO, metabolically unhealthy obesity defined as body mass index ≥ 27.5 kg/m ² and waist circumference ≥ 90 cm.					

Pearson's correlation coefficients

Figure 1 displays the Pearson's correlation coefficients of waist circumference and BMI with the performance of each exercise. Both waist circumference and BMI were positively correlated with time for a 3-kilometer run ($r = 0.32$ and 0.29 , respectively) and inversely with numbers of 2-minute push-ups ($r = -0.26$ and -0.20 , respectively) and 2-minute sit-ups ($r = -0.18$ and -0.10 , respectively). All the associations were statistically significant ($p < 0.001$).

Group Mean Comparisons

Table 2 shows that the performance of CRF assessed by time for a 3-kilometer run test did not differ between MHO and MUO (895.3 ± 5.1 sec and 891.5 ± 3.1 sec, $p = 0.68$) which were both inferior to MUL and MHL (877.5 ± 4.8 sec and 849.5 ± 1.4 sec, all p -values < 0.05). The performance of muscular strengths evaluated by 2-minute push-ups did not differ between MUL and MUO (44.8 ± 0.2 and 45.2 ± 0.5 , $p = 0.40$) which were both lower than MHO and MHL (48.1 ± 0.8 and 50.5 ± 0.2 , all p -values < 0.05). On the contrary, the performance of 2-minute sit-ups were merely superior in MHL (48.0 ± 0.2) while compared with MUL, MHO and MUO (46.0 ± 0.5 , 46.7 ± 0.5 and 46.2 ± 0.3 , respectively, all p -values < 0.05).

Table 2
Differences in Each Exercise Performance between Various Metabolic and Obese Groups

	2-min push-ups (numbers)			2-min sit-ups (numbers)			3000-m running (seconds)		
	n	mean $\pm$ SE	p -value	n	mean $\pm$ SE	p -value	n	mean $\pm$ SE	p -value
Model 1									
MHL	2,592	50.5 ± 0.2	$< 0.01^1$	2,597	48.0 ± 0.2	$< 0.01^1$	2,432	849.8 ± 1.4	$< 0.01^1$
MUL	229	44.3 ± 0.8	$< 0.01^2$	231	46.1 ± 0.5	$< 0.01^2$	196	875.6 ± 4.9	$< 0.01^2$
MHO	207	48.0 ± 0.8	$< 0.01^3$	207	46.7 ± 0.5	0.02^3	176	895.3 ± 5.1	$< 0.01^3$
MUO	613	45.1 ± 0.5	$< 0.01^4$	616	46.2 ± 0.3	$< 0.01^4$	492	890.7 ± 3.1	$< 0.01^4$
			$< 0.01^5$			0.44^5			0.02^5
			0.50^6			0.84^6			0.02^6
			$< 0.01^7$			0.39^7			0.61^7
Model 2									
MHL	2,552	50.5 ± 0.2	$< 0.01^1$	2,558	48.0 ± 0.2	$< 0.01^1$	2,395	849.5 ± 1.4	$< 0.01^1$
MUL	225	44.2 ± 0.8	$< 0.01^2$	227	46.0 ± 0.5	$< 0.01^2$	193	877.5 ± 4.8	$< 0.01^2$
MHO	203	48.1 ± 0.8	$< 0.01^3$	203	46.7 ± 0.5	0.02^3	173	895.3 ± 5.1	$< 0.01^3$
MUO	607	45.2 ± 0.5	$< 0.01^4$	610	46.2 ± 0.3	$< 0.01^4$	486	891.5 ± 3.1	$< 0.01^4$
			$< 0.01^5$			0.36^5			0.06^5
			0.40^6			0.81^6			0.03^6
			$< 0.01^7$			0.35^7			0.68^7
¹ Overall p -value; ² MUL vs MHL; ³ MHO vs MHL; ⁴ MHO vs MHL; ⁵ MHO vs MUL; ⁶ MUO vs MUL; ⁷ MHO vs MUO. Mean $\pm$ SE (standard error) for each exercise performance estimated using analysis of covariance with adjustments for Model 1: age and specialty and Model 2: the covariates in Model 1, physical activity, current alcohol drinking and current tobacco smoking. MHL, metabolically healthy lean, defined as body mass index < 27.5 kg/m ² and waist circumference < 90 cm; MHO, metabolically healthy obesity defined as body mass index ≥ 27.5 kg/m ² and waist circumference < 90 cm; MUL, metabolically unhealthy lean defined as body mass index < 27.5 kg/m ² and waist circumference ≥ 90 cm; MUO, metabolically unhealthy obesity defined as body mass index ≥ 27.5 kg/m ² and waist circumference ≥ 90 cm.									

Multiple Linear Regression

Table 3 shows the results of multiple linear regressions of the performance of each exercise between groups. In general, the results were consistent with that presented in Table 2. The CRF level as evaluated by time for a 3-kilometer run was the best in MHL, subsequently followed by MUL, MHO and MUO. With regard to muscular strengths assessed by 2-minute push-ups, MHL remained the best and the following were changed to MHO, MUO and MUL. However, for muscular strengths assessed by 2-minute sit-ups, there were no differences between MHO, MUO and MUH, except that MHL was better than the others.

Table 3
Liner Regressions of MUL, MHO and MUO with Each Exercise Performance.

MUL					MHO				MUO			
	β value	95% CI	<i>p</i> - value	R ² , %	β value	95% CI	<i>p</i> - value	R ² , %	β value	95% CI	<i>p</i> - value	R ² , %
Model 1												
MHL												
2-min push-ups	-6.18	-7.71 – -4.65	< 0.01	3.9	-1.14	-1.93 – -0.34	< 0.01	1.8	-1.76	-2.10 – -1.43	< 0.01	5.3
2-min sit-ups	-1.91	-3.00 – -0.81	< 0.01	6.7	-0.63	-1.21 – -0.048	0.03	5.9	-0.62	-0.86 – -0.38	< 0.01	7.4
3000-m running	26.24	16.88 – 35.60	< 0.01	8.0	22.56	17.53 – 27.60	< 0.01	8.6	13.52	11.34 – 15.69	< 0.01	12.5
MUL												
2-min push-ups					3.82	1.34 – 6.30	< 0.01	3.1	0.35	-0.61 – 1.32	0.47	0.5
2-min sit-ups					0.55	-0.85 – 1.94	0.44	7.4	0.017	-0.53 – 0.56	0.95	7.3
3000-m running					18.67	1.11 – 36.23	0.03	2.2	7.42	0.80 – 14.05	0.02	5.0
MHO												
2-min push-ups									-3.17	-5.11 – -1.23	< 0.01	2.1
2-min sit-ups									-0.60	-1.77 – 0.58	0.31	5.9
3000-m running									-3.38	-18.23 – 11.47	0.65	2.1
Model 2												
MHL												
2-min push-ups	-6.32	-7.48 – -4.81	< 0.01	6.3	-1.16	-1.95 – -0.38	< 0.01	3.8	-1.76	-2.09 – -1.42	< 0.01	7.0
2-min sit-ups	-2.02	-3.09 – -0.94	< 0.01	10.0	-0.66	-1.23 – -0.088	0.02	9.2	-0.62	-0.85 – -0.38	< 0.01	10.3
3000-m running	27.93	18.77 – 37.09	< 0.01	12.3	22.85	17.92 – 27.78	< 0.01	12.5	13.86	11.73 – 16.00	< 0.01	15.8
MUL												
2-min push-ups					3.78	1.36 – 6.20	< 0.01	9.2	0.41	-0.55 – 1.36	0.40	2.5
2-min sit-ups					0.64	-0.74 – 2.01	0.36	11.7	0.06	-0.47 – 0.60	0.81	9.6
3000-m running					16.36	-0.78 – 33.49	0.06	8.3	7.06	0.52 – 13.59	0.03	8.2
MHO												
2-min push-ups									-3.10	-5.04 – -1.17	< 0.01	3.1
2-min sit-ups									-0.54	-1.71 – 0.62	0.35	8.2

	MUL	MHO	MUO		
3000-m running			-2.99	-17.67–11.69	0.68 4.8
Data are presented as β and 95% CI (confidence intervals) using Pearson's correlation coefficients for Model 1: age and service specialty adjustments; Model 2: the covariates in Model 1, physical activity, current alcohol drinking and current smoking adjustments. MHL, metabolically healthy lean, defined as body mass index < 27.5 kg/m ² and waist circumference < 90 cm; MHO, metabolically healthy obesity defined as body mass index $\geq$ 27.5 kg/m ² and waist circumference < 90 cm; MUL, metabolically unhealthy lean defined as body mass index < 27.5 kg/m ² and waist circumference $\geq$ 90 cm; MUO, metabolically unhealthy obesity defined as body mass index $\geq$ 27.5 kg/m ² and waist circumference $\geq$ 90 cm.					

Multiple Logistic Regression

Table 4 reveals comparisons of the possibility as the best 10% and worst 10% performers in each exercise test between groups. With regard to the 2-minute push-ups test, the MUO had significantly lower possibility to be the best 10% performer than the MHO group in model 1 and model 2 (odds ratios (OR) 95% confidence intervals: 0.39 (0.22–0.70) and 0.40 (0.22–0.71), respectively). Similarly, the MHO group had a significantly lower possibility than the MUL group to be the worst 10% performer in the 2-minute push-ups test in model 1 and model 2 (OR: 0.54 (0.33–0.89) and 0.51 (0.30–0.86), respectively), while that had a significantly higher possibility than the MUL group to be the worst 10% performer in 3000-meter run test in model 1 and model 2 (OR: 1.85 (1.08–3.17) and 1.80 (1.04–3.10), respectively). For each exercise test, the MHL group had the highest possibility as the best 10% performers and had the least possibility as the worst 10% performers as compared with the other three groups.

Table 4

Associations of Various Metabolic and Obese Groups with the Best 10% and the Worst 10% of Each Exercise Performance

	MUL			MHO			MUO			MHL	MUL	MHO
	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value	Ref.	Ref.	Ref.
Top 10% of performance level												
Model 1												
2-min push-ups $\geq$ 60 numbers	0.49	0.29–0.82	< 0.01	0.76	0.48–1.21	0.25	0.33	0.22–0.49	0.25	1.000		
2-min sit-ups $\geq$ 59 numbers	0.63	0.37–1.06	0.08	0.65	0.38–1.12	0.11	0.55	0.38–0.79	< 0.01	1.000		
3000-m running $\leq$ 783 seconds	1.12	0.79–1.59	0.52	1.19	0.83–1.71	0.33	1.52	1.22–1.88	< 0.01	1.000		
2-min push-ups $\geq$ 60 numbers				1.56	0.79–3.07	0.20	0.81	0.59–1.12	0.20		1.000	
2-min sit-ups $\geq$ 59 numbers				1.03	0.49–2.14	0.94	0.94	0.69–1.28	0.68		1.000	
3000-m running $\leq$ 783 seconds				1.08	0.67–1.75	0.75	1.14	0.94–1.38	0.18		1.000	
2-min push-ups $\geq$ 60 numbers							0.39	0.22–0.70	< 0.01			1.000
2-min sit-ups $\geq$ 59 numbers							0.83	0.44–1.57	0.57			1.000
3000-m running $\leq$ 783 seconds							1.17	0.79–1.74	0.43			1.000
Model 2												
2-min push-ups $\geq$ 60 numbers	0.46	0.27–0.78	< 0.01	0.79	0.47–1.19	0.22	0.32	0.22–0.48	0.25	1.000		
2-min sit-ups $\geq$ 59 numbers	0.60	0.35–1.01	0.05	0.63	0.37–1.09	0.10	0.55	0.38–0.79	< 0.01	1.000		
3000-m running $\leq$ 783 seconds	1.11	0.78–1.58	0.55	1.19	0.83–1.70	0.35	1.51	1.22–1.88	< 0.01	1.000		
2-min push-ups $\geq$ 60 numbers				1.58	0.79–3.16	0.19	0.82	0.60–1.13	0.22		1.000	

Data are presented as odds ratios (OR) and 95% CI (confidence intervals) using multiple logistic regression analysis for Model 1: age and service specialty adjustments; Model 2: the covariates in Model 1, physical activity, current alcohol drinking and current smoking adjustments. MHL, metabolically healthy lean; MHO, metabolically healthy obesity; MUL, metabolically unhealthy lean; MUO, metabolically unhealthy obesity.

	MUL			MHO			MUO			MHL	MUL	MHO
2-min sit-ups ≥ 59 numbers				1.08	0.52–2.28	0.83	0.95	0.70–1.30	0.75		1.000	
3000-m running ≤ 783 seconds				1.09	0.67–1.78	0.72	1.12	0.92–1.36	0.25		1.000	
2-min push-ups ≥ 60 numbers							0.40	0.22–0.71	< 0.01			1.000
2-min sit-ups ≥ 59 numbers							0.83	0.44–1.57	0.57			1.000
3000-m running ≤ 783 seconds							1.15	0.77–1.71	0.50			1.000
Bottom 10% of performance level												
Model 1												
2-min push-ups ≤ 37 numbers	3.96	2.81–5.59	< 0.01	2.10	1.38–3.20	< 0.01	3.00	2.31–3.89	< 0.01	1.000		
2-min sit-ups ≤ 40 numbers	1.87	1.25–2.81	< 0.01	1.24	0.78–2.00	0.36	1.60	1.22–2.10	< 0.01	1.000		
3000-m running ≥ 934 seconds	1.93	1.25–2.97	< 0.01	3.56	2.42–5.23	< 0.01	2.92	2.22–3.83	< 0.01	1.000		
2-min push-ups ≤ 37 numbers				0.54	0.33–0.89	0.01	0.76	0.53–1.11	0.15		1.000	
2-min sit-ups ≤ 40 numbers				0.71	0.38–1.33	0.27	0.83	0.53–1.31	0.83		1.000	
3000-m running ≥ 934 seconds				1.85	1.08–3.17	0.02	1.50	0.95–2.37	0.08		1.000	
2-min push-ups ≤ 37 numbers							1.41	0.900–2.21	0.13			1.000
2-min sit-ups ≤ 40 numbers							1.23	0.73–2.05	0.43			1.000
3000-m running ≥ 934 seconds							0.84	0.56–1.28	0.41			1.000
Model 2												

Data are presented as odds ratios (OR) and 95% CI (confidence intervals) using multiple logistic regression analysis for Model 1: age and service specialty adjustments; Model 2: the covariates in Model 1, physical activity, current alcohol drinking and current smoking adjustments. MHL, metabolically healthy lean; MHO, metabolically healthy obesity; MUL, metabolically unhealthy lean; MUO, metabolically unhealthy obesity.

	MUL			MHO			MUO			MHL	MUL	MHO
2-min push-ups $\leq$ 37 numbers	4.17	2.95–5.91	< 0.01	2.13	1.39–3.25	< 0.01	3.02	2.32–3.92	< 0.01	1.000		
2-min sit-ups $\leq$ 40 numbers	1.93	1.28–2.91	< 0.01	1.28	0.79–2.06	0.31	1.62	1.23–2.12	< 0.01	1.000		
3000-m running $\geq$ 934 seconds	2.00	1.29–3.10	< 0.01	3.63	2.47–5.36	< 0.01	2.93	2.23–3.85	< 0.01	1.000		
2-min push-ups $\leq$ 37 numbers				0.51	0.30–0.86	0.01	0.74	0.51–1.07	0.11		1.000	
2-min sit-ups $\leq$ 40 numbers				0.71	0.37–1.33	0.28	0.81	0.50–1.29	0.36		1.000	
3000-m running $\geq$ 934 seconds				1.80	1.04–3.10	0.03	1.45	0.92–2.30	0.11		1.000	
2-min push-ups $\leq$ 37 numbers							1.41	0.90–2.22	0.13			1.000
2-min sit-ups $\leq$ 40 numbers							1.22	0.72–2.05	0.46			1.000
3000-m running $\geq$ 934 seconds							0.85	0.60–1.29	0.43			1.000
Data are presented as odds ratios (OR) and 95% CI (confidence intervals) using multiple logistic regression analysis for Model 1: age and service specialty adjustments; Model 2: the covariates in Model 1, physical activity, current alcohol drinking and current smoking adjustments. MHL, metabolically healthy lean; MHO, metabolically healthy obesity; MUL, metabolically unhealthy lean; MUO, metabolically unhealthy obesity.												

Discussion

We found some intriguing and important points in this cross-sectional study conducted in a well-controlled military environment. First, it is in accordance expectation that MHL individuals had the best CRF level and muscle strength among the four groups categorized according to BMI and waist circumference. Second, MHO individuals had greater muscle strength assessed by 2-minute push-ups than MUO individuals, while the CRF levels of the two groups were similar. Third, MHO individuals had greater muscle strength assessed by 2-minute push-ups but less CRF level assessed by time for a 3 kilometer run test than MUL individuals. The last two points were novel findings and have not been reported before.

Several studies reported MHO individuals had higher CRF level compared to MUO individuals, but the recruited individuals living with different lifestyles, habits and environments, which could not be well adjusted.^{21,36} However, this study uncovered that MHO and MUO individuals completed 3-kilometer run with similar time. This finding suggested that MUO individuals could achieve the same level of CRF as MHO individuals when performing the same type, frequency and strength of physical activity in the military bases. In addition, it has been well known that MHL individuals have the lowest risk to develop cardiovascular disease compared with other groups partly because of the best CRF level. Whether improving the CRF for MUO individuals by intensifying daily physical activities could decrease the risk of developing cardiometabolic comorbidities needs more evidence to be verified.

Our study demonstrated that MHO individuals might have greater muscular strength but not CRF level than MUL individuals. Some studies have reported that combined aerobic exercise (i.e. long-distance run) and anaerobic exercise (i.e. short-term push-ups) can reduce more abdominal subcutaneous adipose tissue than aerobic or anaerobic exercise alone.^{37,38} In addition, the reduction of liver and visceral fat amounts might not differ with regard to the intensity and dose of aerobic exercise which the participants received,³⁹

and an increase of skeletal muscle mass was observed only in those taking anaerobic (resistant) exercise.⁴⁰ It is possible that MHO individuals might frequently receive more combined aerobic and anaerobic exercise training than the MUO and MHL so that MUO individuals had greater muscular strength than their counterparts. By contrast, the greater CRF levels in MUL individuals than MHO and MUO individuals was probably due to their lower BMI levels.

There were some strengths of this study. First, there were sufficient numbers of military males for analyses to detect the differences in the performance of aerobic and anaerobic exercise in the four classified groups. Second, the three kinds of exercise tests were performed in a strict manner, and the process was standardized. Third, all the military males lived in the same environment and received similar training which could minimize the potential confounders to bias the study results. On the other hand, our study existed some limitations. First, this study recruited only male individuals so that the results could not be extrapolated to female individuals. Second, the presence of selection bias could not be excluded, for the participation rate of the military individuals in this study is 66.5%. Third, we used 27.5 kg/m² and 90 cm as the cut-point of BMI and waist circumference, respectively, to generally classify the metabolic and obese status that are different from the MHO definition in many studies, although the MHO definition has not been unified worldwide. Finally, for the essence of cross-sectional study, the causality between the status of metabolic and obesity and exercise performance could not be clarified.

In conclusion, we found that MHO individuals had similar CRF level as MUO individuals, and had better muscle strength than the MUL. Furthermore, we uncovered that MHL individuals had the best CRF and muscle strength level among all the groups, highlighting the importance of transition to MHL status from metabolically unhealthy or obese status since young adults.

Abbreviations

CHIEF, the Cardiorespiratory Fitness and Hospitalization Events in Armed Forces study; CRF, cardiorespiratory fitness; MHL, metabolically healthy lean; MHO, metabolically healthy obesity; MUL, metabolically unhealthy lean; MUO, metabolically unhealthy obesity.

Declarations

Funding

This study was supported by the research grants from the Medical Affairs Bureau Ministry of National Defense (NO. MND-MAB-110-148).

Declaration of Competing Interest

None

Authors Contributions

Sheng-Huei Wang wrote the paper; Pei-Shou Chung collected the data, Yen-Po Lin, Ssu-Chin Lin, Chia-Hao Fan and Yu-Kai Lin made critical suggestions and revisions on the study; Kun-Zhe Tsai analyzed the data; Gen-Min Lin conceived, designed and corresponded to the study.

References

- 1 Blüher, M. Obesity: global epidemiology and pathogenesis. *Nat. Rev. Endocrinol.***15**, 288-298 (2019).
- 2 Fontaine, K. R., Redden, D. T., Wang, C., Westfall, A. O. & Allison, D. B. Years of Life Lost Due to Obesity. *JAMA***289**, 187-193 (2003).
- 3 Swinburn, B. A. *et al.* The global obesity pandemic: shaped by global drivers and local environments. *Lancet***378**, 804-814 (2011).
- 4 Neeland, I. J. *et al.* Visceral and ectopic fat, atherosclerosis, and cardiometabolic disease: a position statement. *Lancet. Diabetes. Endocrinol.***7**, 715-725 (2019).

- 5 Vague, J. The degree of masculine differentiation of obesities: a factor determining predisposition to diabetes, atherosclerosis, gout, and uric calculous disease. *Am. J. Clin. Nutr.***4**, 20-34 (1956).
- 6 Blüher, M. Metabolically Healthy Obesity. *Endocr. Rev.***41**, 405-420, (2020).
- 7 van Vliet-Ostaptchouk, J. V. *et al.* The prevalence of metabolic syndrome and metabolically healthy obesity in Europe: a collaborative analysis of ten large cohort studies. *BMC. endocr. disord.***14**, 9, (2014).
- 8 Kabat, G. C. *et al.* Metabolic phenotypes of obesity: frequency, correlates and change over time in a cohort of postmenopausal women. *Int. J. Obes. (London)***41**, 170-177 (2017).
- 9 Börnhorst, C. *et al.* Metabolic status in children and its transitions during childhood and adolescence—the IDEFICS/I.Family study. *Int. J. Epidemiol.***48**, 1673-1683 (2019).
- 10 Soriguer, F. *et al.* Metabolically healthy but obese, a matter of time? Findings from the prospective Pizarra study. *J. Clin. Endocrinol. Metab.***98**, 2318-2325 (2013).
- 11 Crewe, C., An, Y. A. & Scherer, P. E. The ominous triad of adipose tissue dysfunction: inflammation, fibrosis, and impaired angiogenesis. *J. Clin. Invest.***127**, 74-82 (2017).
- 12 Tan, C. Y. & Vidal-Puig, A. Adipose tissue expandability: the metabolic problems of obesity may arise from the inability to become more obese. *Biochem. Soc. Trans.***36**, 935-940 (2008).
- 13 Ghaben, A. L. & Scherer, P. E. Adipogenesis and metabolic health. *Nat. Rev. Mol. Cell Biol.***20**, 242-258 (2019).
- 14 Eckel, N. *et al.* Transition from metabolic healthy to unhealthy phenotypes and association with cardiovascular disease risk across BMI categories in 90 257 women (the Nurses' Health Study): 30 year follow-up from a prospective cohort study. *Lancet. Diabetes. Endocrinol.***6**, 714-724 (2018).
- 15 Blüher, M. Obesity: The myth of innocent obesity. *Nat. Rev. Endocrinol.***9**, 691-692 (2017).
- 16 Jae, S. Y., Franklin, B., Choi, Y. H. & Fernhall, B. Metabolically Healthy Obesity and Carotid Intima-Media Thickness: Effects of Cardiorespiratory Fitness. *Mayo. Clin. Proc.***90**, 1217-1224 (2015).
- 17 Ortega, F. B. *et al.* The intriguing metabolically healthy but obese phenotype: cardiovascular prognosis and role of fitness. *Eur. Heart. J.***34**, 389-397 (2012).
- 18 Cadenas-Sanchez, C. *et al.* Prevalence of Metabolically Healthy but Overweight/Obese Phenotype and Its Association With Sedentary Time, Physical Activity, and Fitness. *J. Adolesc. Health.***61**, 107-114 (2017).
- 19 Dobson, R. *et al.* Metabolically healthy and unhealthy obesity: differential effects on myocardial function according to metabolic syndrome, rather than obesity. *Int. J. Obes. (London)***40**, 153-161 (2016).
- 20 Wiklund, P. K. *et al.* Serum metabolic profiles in overweight and obese women with and without metabolic syndrome. *Diabetol. Metab. Syndr.* **6**, 40 (2014).
- 21 Ortega, F. B. *et al.* Role of Physical Activity and Fitness in the Characterization and Prognosis of the Metabolically Healthy Obesity Phenotype: A Systematic Review and Meta-analysis. *Prog. Cardiovasc. Dis.* **61**, 190-205 (2018).
- 22 Lin, G. M. *et al.* Rationale and design of the cardiorespiratory fitness and hospitalization events in armed forces study in Eastern Taiwan. *World. J. Cardiol.* **8**, 464-471 (2016).
- 23 Chen, K. W. *et al.* Sex-Specific Association between Metabolic Abnormalities and Elevated Alanine Aminotransferase Levels in a Military Cohort: The CHIEF Study. *Int. J. Environ. Res. Public. Health.***15**, (2018).
- 24 Chao, W. H., Su, F. Y., Lin, F., Yu, Y. S. & Lin, G. M. Association of electrocardiographic left and right ventricular hypertrophy with physical fitness of military males: The CHIEF study. *Eur. J. Sport. Sci.***19**, 1214-1220 (2019).

- 25 Tsai, K. Z. *et al.* Association between mild anemia and physical fitness in a military male cohort: The CHIEF study. *Sci. Rep.***9**, 11165 (2019).
- 26 Chung, P. S., Tsai, K. Z., Lin, Y. P., Lin, Y. K. & Lin, G. M. Association between Leukocyte Counts and Physical Fitness in Male Military Members: The CHIEF Study. *Sci. Rep.***10**, 6082 (2020).
- 27 Su, F. Y., Wang, S. H., Lu, H. H. & Lin, G. M. Association of Tobacco Smoking with Physical Fitness of Military Males in Taiwan: The CHIEF Study. *Can. Respir. J.* **2020**, 5968189 (2020).
- 28 Lin, G. M. *et al.* Machine Learning Based Suicide Ideation Prediction for Military Personnel. *IEEE. J. Biomed. Health. Inform.* **24**, 1907-1916 (2020).
- 29 Lin, G. M. & Lu, H. H. A 12-Lead ECG-Based System With Physiological Parameters and Machine Learning to Identify Right Ventricular Hypertrophy in Young Adults. *IEEE. J. Transl. Eng. Health. Med.* **8**, 1900510 (2020).
- 30 Lin, G. M. & Liu, K. An Electrocardiographic System With Anthropometrics via Machine Learning to Screen Left Ventricular Hypertrophy among Young Adults. *IEEE. J. Transl. Eng. Health. Med.***8**, 1800111 (2020).
- 31 Lin, G. M., Li, Y. H., Lin, C. L., Wang, J. H. & Han, C. L. Relation of body mass index to mortality among Asian patients with obstructive coronary artery disease during a 10-year follow-up: a report from the ET-CHD registry. *Int. J. Cardiol.***168**, 616-620 (2013).
- 32 Lin, G. M., Li, Y. H., Lai, C. P., Lin, C. L. & Wang, J. H. The obesity-mortality paradox in elderly patients with angiographic coronary artery disease: a report from the ET-CHD registry. *Acta. Cardiol.***70**, 479-486 (2015).
- 33 Spurway, N. C. Aerobic exercise, anaerobic exercise and the lactate threshold. *Br. Med. Bull.***48**, 569-591 (1992).
- 34 Hoad, N. A. & Clay, D. N. Smoking impairs the response to a physical training regime: a study of officer cadets. *J. R. Army. Med. Corps.***138**, 115-117 (1992).
- 35 Grundy, S. M. *et al.* Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation.***112**, 2735-2752 (2005).
- 36 Ortega, F. B. *et al.* The intriguing metabolically healthy but obese phenotype: cardiovascular prognosis and role of fitness. *Eur. Heart. J.***34**, 389-397 (2013).
- 37 Sigal, R. J. *et al.* Effects of aerobic training, resistance training, or both on percentage body fat and cardiometabolic risk markers in obese adolescents: the healthy eating aerobic and resistance training in youth randomized clinical trial. *JAMA. Pediatr.***168**, 1006-1014 (2014).
- 38 Alberga, A. S. *et al.* Effects of aerobic and resistance training on abdominal fat, apolipoproteins and high-sensitivity C-reactive protein in adolescents with obesity: the HEARTY randomized clinical trial. *Int J Obes (London)***39**, 1494-1500 (2015).
- 39 Keating, S. E. *et al.* Effect of aerobic exercise training dose on liver fat and visceral adiposity. *J Hepatol.***63**, 174-182 (2015).
- 40 Yan, J. *et al.* Effect of 12-Month Resistance Training on Changes in Abdominal Adipose Tissue and Metabolic Variables in Patients with Prediabetes: A Randomized Controlled Trial. *J. Diabetes. Res.* **2019**, 8469739 (2019).

Figures

Figure 1

reveals the Pearson's correlation coefficients of time for a 3-kilometer run, repetitive numbers of 2-minute push-ups and 2-minute sit-ups with body mass index and waist circumference, respectively.