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An evaluation of the association between anthropometric measurements and cardiorespiratory fitness using the Forest Service Step and the Ruffier-Dickson test.

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An evaluation of the association between anthropometric measurements and cardiorespiratory fitness using the Forest Service Step and the Ruffier-Dickson test.

Abstract:

Background/Objective: Cardiorespiratory fitness (CRF) is an important component of general fitness and is quantified in terms of maximum oxygen consumption (VO_2max). The aims of this study were (1) to determine the association between anthropometric measurements and VO_2max using the Forest Service Step (FSS) test and the Ruffier-Dickson test and (2) to develop a model to assess the VO_2max from the FSS test.

Methods: A cross-sectional correlation study in which the participants performed both the FSS and the Ruffier-Dickson test was conducted using data previously collected. The sample was composed of 67 healthy participants aged between 19 and 39 years.

Results: The VO_2max values for these participants ranged between 35.15 and 67.32 $ml\cdot min^{-1}\cdot kg^{-1}$. Linear regression analysis showed a correlation ($p<0.01$) between measured VO_2max ($L\cdot min^{-1}$) and height (m), weight (kg), waist (cm) and BMI ((kg/m^2). The multiple linear regression analysis generated the following equation to predict VO_2max ($L\cdot min^{-1}$) from the FSS Test: 3.937 + 0.045(Weight) – 0.103(HR Post FSS) – 0.406(Sex). The adjusted R^2 for the model was 0.845 with an excellent agreement between the model and the classification of CRF according to the American Heart Association (ICC=0.958).

Conclusion: The FSS test can be used to estimate the CRF reliably and economically.

Keywords: Cardiorespiratory fitness, Step test, Anthropometric measurements, Maximal oxygen consumption

Introduction

Cardiorespiratory fitness (CRF) is an important component of fitness because it concerns the pulmonary system for the consumption of oxygen, the cardiovascular system for the transport of oxygen and waste products, and the muscular system for the utilization of oxygen [1]. CRF is quantified in terms of maximum oxygen consumption (VO_2max) as the cardiovascular system is responsible for the supply of oxygen to active muscles [2]. VO_2max is considered an indicator that reflects a person's capacity to maintain aerobic exercise and physiological adaptation indicator for different types of training [3]. The importance of VO_2max as a clinical vital sign and predictor of cardiovascular disease has been highlighted by the American Heart Association [4].

Maximal oxygen consumption can be measured directly by open-circuit spirometry in the laboratory, but this measurement requires specific technology. Measuring VO_2max by an incremental exercise test can be time-consuming and difficult to administer in large population groups [5]. Consequently, a number of testing methods have been devised to predict VO_2max indirectly from maximal or submaximal tests which can be conducted in non-laboratory environments. Step test are predictors of VO_2max specific to ascending and descending steps at a predetermined cadence [4,6–10], and the 3-minute squat test has been validated to estimate CRF in healthy individuals [11–15].

VO_2max is quantified in absolute ($L \cdot min^{-1}$) and relative ($ml \cdot min^{-1} \cdot kg^{-1}$) terms. The units of litres per minute ($L \cdot min^{-1}$) represent the absolute amount or total oxygen consumed in the organism per minute. The absolute VO_2max is generally used to calculate the total amount of aerobic energy or calories the body can generate. The units of millilitres of oxygen per kilogram per minute ($ml \cdot min^{-1} \cdot kg^{-1}$) represent the oxygen consumption required to move one kilogram of body weight per minute [16]. Most of the time VO_2max is expressed in relative units because a person's functional capacity depends on the displacement of their own body weight [17].

VO_2max is considered a strong predictor of heatlh, and provides measures of cardiorespiratory fitness and cardiovascular health and function [7,14,18,19]. The VO_2max is affected by genetic factors, physical training, gender, age, and body composition [20,21]. The appropriate percentages of these components are related to health, especially the percentage of fat and muscle, which are the tissues most sensitive to changes resulting from physical activity and diet [9]. An increase in body fat levels leads to a decrease in VO_2max in relative terms [22–24]. Additionally, anthropometric variables such as weight, height, Waist-Hip Ratio (WHR) and Body Mass Index (BMI) can become predictors of cardiovascular disease risk [25–29]. The values of BMI suggest a possible effect on cardiorespiratory function [30], and the WHR is one of several methods used to evaluate overweight and obesity, as well as to estimate the risks of cardiovascular disorders [31]. Similarly, the anthropometry of a person is related to cardiorespiratory function such as VO_2max, relative VO_2max, relative VO_2 at the ventilatory threshold level and heart rate [32,33].

Therefore, the studies suggest there is a relationship between anthropometric variables and maximal oxygen consumption. This suggests it would be important to know which and to what extent are the exact variables that have more influence on oxygen consumption in a young population. Using two simple tests a predictive model can be carried out to obtain the VO_2max, employing the combination of easily measurable variables.

The objectives of this study are (1) to determine the association between anthropometric measurements and VO_2max using the Forest Service Step (FSS) test and the Ruffier-Dickson test and (2) to develop a model to assess the VO_2 max from the FSS test.

Methods

Study participants

A cross-sectional correlation study was conducted using data previously collected. The sample is composed of 67 healthy participants with a mean age of 22.8 ± 3.42, comprising 54 men and 13 women. Prior to any testing, participants carried out Rapid Assessment of Physical Activity (RAPA) questionnaire to measure the level of physical activity [34]. The results showed 6 (9%) participants were regular underactive (light activities), 13 (19,4%) were regular underactive, and 48 (71,6%) regular active. None of the participants were taking any medications and none of them had consumed alcohol or caffeine 24 hours before the test. The clinical measurements were conducted following signed informed consent, in accordance with Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on General Data Protection Regulation (GDPR). All the procedures used in this study followed the ethical principles for medical research involving human volunteers as stated in the Helsinki Declaration. The study was approved by the ethical committee of the Universidad Isabel I (UI1-PI040).

Anthropometric measurements

Height and weight were taken using a scale with an integrated stadiometer (Tanita, WB-3000, Japan) with sensitivities of 0.1 cm and 0.1 kg respectively. Participants were measured without shoes, wearing light clothes at the same time of day and in optimal temperature conditions. BMI was calculated and individuals classified using the standard World Health Organization's indicators for adults [35]**.** Waist and hip circumferences were measured in triplicate, with the mean being obtained with an inextensible tape measure with an accuracy of 0.1 cm. Waist circumference was measured over bare skin at the level of the umbilicus. Hip circumference was measured at the level of the maximum extension of the buttocks posteriorly in a horizontal plane. Waist-Hip Ratio (WHR) was calculated.

VO_2max assessment

Two tests were performed - the Forest Service Step (FSS) test, which evaluates relative aerobic capacity, and the Ruffier-Dickson (RD) test, which measures the cardiovascular adaptation to stress.

The FSS test was adjusted for sex, heart rate (HR), body weight and age to predict aerobic capacity [36]. The test consisted of walking up and down a step of 38 cm high for men and 33 cm high for women for 5 minutes. The rhythm was paced by a metronome at a rate of 90 beats per minute (22.5 cycles up and down the bench per minute). HR was measured for 15 seconds between the second 15 and 30 after the test was completed. Adjusted estimates of VO_2 max ($ml \cdot min^{-1} \cdot kg^{-1}$) and the age correction factors proposed by Sharkey [36] were used to perform the calculation of aerobic capacity. HR values obtained after the FSS test were adjusted for the weight of the participant. The VO_2 max values were adjusted according to age and sex. This protocol has been previously carried out by other researches [6,37–41]. Hansen et al. [8], validated the test to predict VO_2 max by comparing the results with a maximal ergospirometry test, with an assessment of cardiopulmonary parameters.

Ruffier's test was used to measure short-term endurance and cardiac recovery capacity [42]. Resting HR was collected before starting the test (P1). The standing participant then performed 30 squats in 45 seconds, paced by a metronome. The back was straight, bending the knees to a 90-degree angle, with the arms extended straight forward. HR was recorded immediately after the squats (P2). A one-minute break was taken from sitting and HR was recorded again (P3). From the recording of the three HR measurements, the Ruffier Index (RI) and the Ruffier-Dickson Index (RDI) were respectively calculated as:

$$RI = \frac{\text{P1} + \text{P2} + \text{P3} - 200}{10} \qquad RDI = \frac{(\text{P2} - 70) + 2 \text{ x } (\text{P3} - \text{P1})}{10}$$

The RDI test performs a greater adjustment of the values and is aimed at assessment in the younger population. The Ruffier test has been used by several researchers [15,43–51] and has demonstrated a good test-retest reliability with intra-class coefficients of the HR features and RDI ranged from 0.66-0.86 [14].

Statistical analysis

All statistical analyses were performed using SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). Basic descriptive statistics (mean, standard deviation and min-max) were calculated. The relationship between anthropometric measures and VO_2max was examined using Spearman´s correlation analysis. A linear regression analysis was carried out to explain the relationship between anthropometric variables and VO_2max. Finally, a multiple linear regression analysis was performed to obtain a model to predict the VO_2max. The prediction model was built using stepwise forward multiple linear regressions. The models´ stability and performance were evaluated using adjusted R^2 and Kappa. A p value of <0.05 or <0.01 was considered to indicate the statistical significance on a case-by-case basis.

Results

A summary of the descriptive characteristics of the participants is shown in Table 1. The mean BMI of the participants was 23.2 (SD = 2.71), with a range of values from 18.5 to 31.1. Based upon the BMI classification, 53 participants were of normal weight, 13 overweight, and 1 obese. The mean values of VO_{2max} according to the FSS test were 3.55 (SD = 0.77), with a range of 1.38 to 5.21 $L \cdot min^{-1}$. The mean values of VO_{2max} according to the RDI test were 4.25 (SD = 0.48), with a range of 3.05 to 5.09 $L \cdot min^{-1}$. There was a significant (positive) correlation ($p<0.01$) between FSS results and BMI (kg/m^2) and waist (cm). Hip (cm) values were negatively correlated ($p<0.05$) with RDI results. FSS and RDI results were positively correlated ($p<0.01$) with weight (kg), height (m), and WHR (cm). The VO_2max values for these participants ranged between 35.15 and 67.32 $ml \cdot min^{-1} \cdot kg^{-1}$.

Please insert Table 1 near here

Figure 1 show the aerobic fitness rating from the predicted $V0_2max$ values adjusted for age according to the FSS. The waist values are displayed according to weight status. Within the normal BMI category, 32.8% of participants were classified in a good condition and 37.3% were in an excellent condition according to the aerobic fitness rating. Subjects classified as overweight were found to have a higher waist compared with those classified as normal weight.

Please insert Figure 1 near here

Figure 2 show the classification of the values obtained from $V0_2max$ of RDI. The results were very similar to those obtained for HSS. Within the normal BMI category, 34.3% were in a good condition and 23.9% were in a very good condition according to the RDI ranking.

Please insert Figure 2 near here

Figure 3 show regression statistics between measured VO_2max ($L \cdot min^{-1}$) and height (m), weight (kg), waist (cm) and BMI ((kg/m^2). Regression statistics between the VO_2max and height resulted in R^2 values of 0.27 (SE = 3.28), between VO_2max and weight the value was 0.40 (SE = 0.041), between VO_2max and waist was 0.22 (SE = 0.009), and between VO_2max and BMI was 0.14 (SE = 0.13).

Please insert Figure 3 near here

The results for the linear multiple regression model for predicting absolute VO_2max are shown in Table 2. The model was based on the FSS. Height, waist and BMI were not significant for the model. The adjusted R^2 for the 3 models were 0.394, 0.816, and 0.845 respectively, indicating that Model 3 explained the most variability in the VO_2max values. There was an excellent agreement between model 3 and the classification of CRF according to the American Heart Association (ICC=0.958). The final model derived from this analysis was:

$$VO_2max = 3.937 + 0.045 \times (\text{Weight}) - 0.103 \times (\text{HR Post FSS}) - 0.406 \times (\text{Sex})$$

in which weight is expressed in kilograms (kg), the HR Post FSS in beats per minute, and sex is coded as 1 for men and 2 for women.

Please insert Table 2 near here

Discussion

In this study, we showed that VO_2max can be related to anthropometric variables, including weight (R^2=0.40), height (R^2=0.27), waist (R^2=0.22) and BMI (R^2=0.14). The model was based on the FSS test. Height, waist and BMI were not significant predictors of VO_2max in our analysis. The model used as predictor variables weight, HR Post FSS test and sex, with an adjusted R^2 of 0.845. Our model can be used as an alternative to assess VO_2max as well as for comparing it with the other tests carried out.

Several studies have carried out a step-test protocol to predict VO_2max using predictive equations [7,15,50,52]. Some studies included sex as predictor variables in their model [12], age [53], body mass [10], and almost all studies included HR in bpm [54–57] and the recovery HR [41,58–61].

The results demonstrated weight as the main predictor variable of VO_2max. The study by Knight et al. [53], conducted with older adults, the variables used for the prediction of maximal oxygen uptake included the time to complete the stepping tests, weight, HR, age and sex. It has been suggested that weight may affect the accuracy of the prediction of CRF [10]. Hansen et al.[8] included as variables in the equation age, sex, height, BMI, step test HRmax and fitness index. For these authors, a single-stage fixed-rate step test is a valid instrument to estimate VO_2max in healthy adults. HR post FSS was a predictor variable included in the model: $VO_2max = (0.054 \times BMI) + (0.612 \times sex) + (3.359 \times Height) + (0.019 \times fitness\ index) – (0.012 \times HRmax) – (0.011 \times age) – 3.475$. Furthermore, Ibrahim & Nuhu [39] also develop a step test with a regression model for estimating maximal oxygen consumption (VO_2max). Data from the step test were analysed using multiple linear regressions to develop the regression equation: $VO_2max = 62.887 - (0.439 \times age) + (0.152 \times BMI) – (0.116 \times HR\ post\ exercise)$. McArdle et al. [62] first demonstrated the validity of the Queen's College step test to predict VO_2max. After completion of the step test, HR recovery was measured for 15s, from 5-20s post-test. This post-exercise HR was converted to beats/min and used to predict VO_2max using the following equation: VO_2max (mL kg-1 min-1) = 65.81 - (0.1847 × HR in beats/min). Santo & Golding [41], using the YMCA 3-minute Step Test to predicted VO_2max. The correlation coefficient was calculated between measured VO_2max and the 15s post-test HR. They also obtained a negative relationship between VO_2max measurements and HR Post FSS. Linear regression was used to develop the following prediction equations for VO_2max from these data: VO_2max = (-0.9675 ×

post-test HR 15 s) + 77.643. Others studies also include HR post-test: VO_2max = 65.81 - (0.1847 × HR in beats/min) [63], VO_2max = 71.97 - (0.776 × HR in beats/min) [54].

According to our results, using the Forest Service test, VO_2max was 3.55 ± 0.77 ($L \cdot min^{-1}$). The results using the linear regression equation were similar: VO_2max = 3.54 ± 0.71 ($L \cdot min^{-1}$). The measured VO_2max was 3.76 ± 0.58 ($L \cdot min^{-1}$) in men, and 2.65 ± 0.42 ($L \cdot min^{-1}$) in women. Likewise, a high agreement between measured and predicted VO_2max was confirmed by the high intraclass correlations (ICC=0.958). [8], in their predictive formula obtained a measure of VO_2max 3.2 ± 0.6 ($L \cdot min^{-1}$) in men and 1.9 ± 0.4 ($L \cdot min^{-1}$) in women. Prediction equations for individuals of different gender (males and females) and ages (between 18 and 75 years) were of equal or lower prediction accuracy. The results in [12] were similar, with 3.38 ± 0.61 ($L \cdot min^{-1}$) in men and 2.13 ± 0.57 ($L \cdot min^{-1}$) in women.

One of the limitations of the study was the relatively small sample size (n = 67). In addition, the participants were healthy young people and it was not possible to compare them with another control group. Our VO_2max estimation equation should be validated independently using a different population in future research. According to Hansen et al. [8] studies with a small sample size (< 100 participants) may be lacking for the estimation of VO_2max. Nevertheless, many studies have used a smaller sample than this study [12,39,53,63]. Another future question could be to check possible differences according to sex, as well as the interaction between sex and BMI. It could be confirmed if individuals with a higher BMI have a lower VO_2max.

Conclusions

This study has shown that the FSS test can be used to estimate the CRF reliably, economically and with accuracy. VO_2max is associated with the anthropometric measurements of height, weight, waist, and BMI. A general equation for the population can therefore be used to predict VO_2max since the prediction model had an excellent agreement, indicating that the VO_2max is dependent on weight, HR post FSS and sex.

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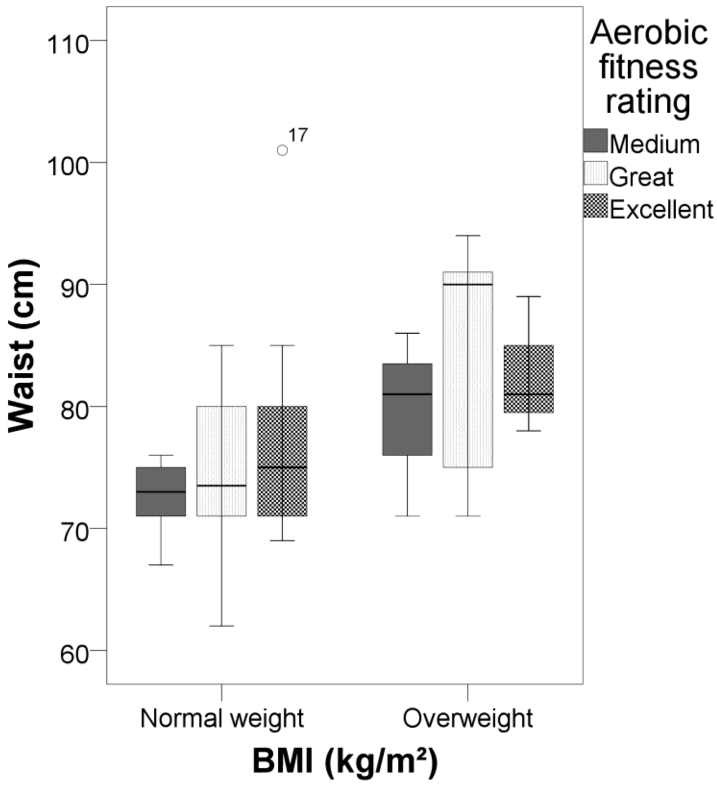

Figure 1. BMI/waist classification according to Aerobic Fitness Rating (FST).

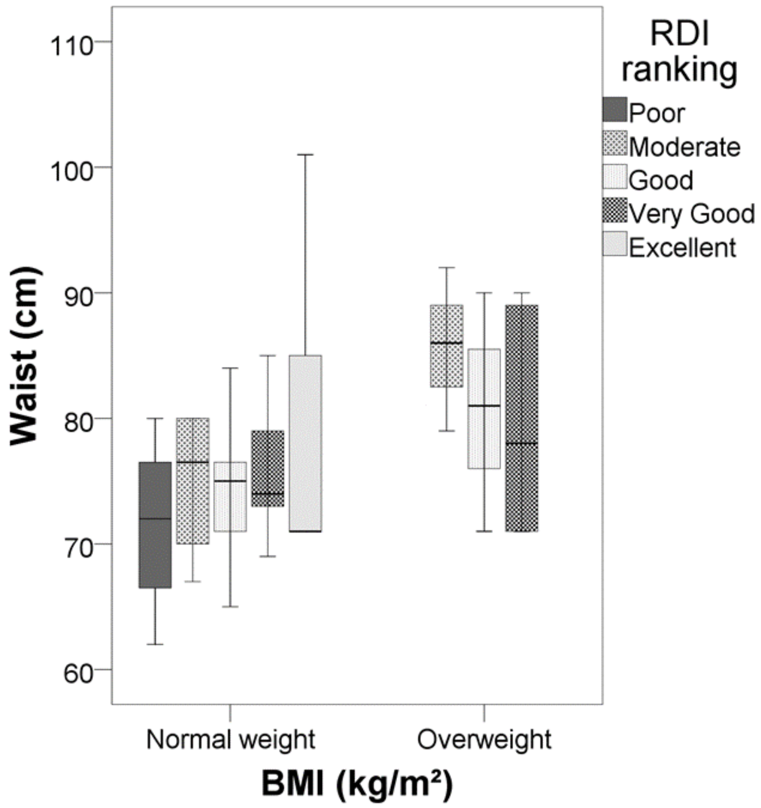

Figure 2. BMI/waist classification according to RDI Ranking.

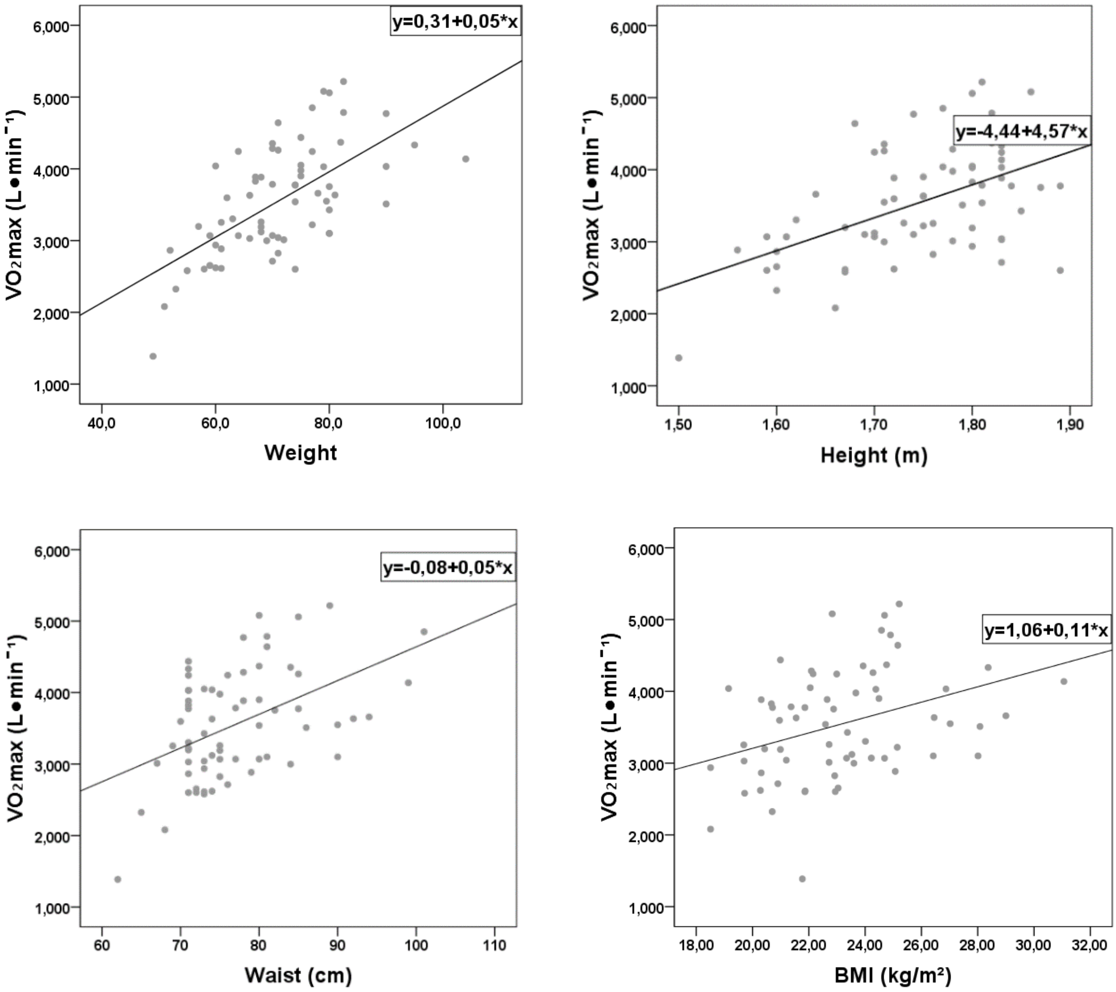

Figure 3. Regression line and equation between measured VO_2max and height, weight, waist, BMI from FSS.

Table 1. Descriptive characteristics of study participants (N = 67)

Variable	Mean ± SD or %	Min	Max	± SE	ƿ1	ƿ2
Sex					-0.565**	-0.685**
Age (y)	22.8 ± 3.42	19	39	0.41	0.215	-0.208
Weight (kg)	71.1 ± 10.73	49	104	1.31	0.626**	0.391**
Height (m)	1.74 ± 0.08	1.50	1.89	0.01	0.450**	0.390**
BMI (kg/m^2)	23.2 ± 2.71	18.51	31.06	0.33	0.399**	0.113
Weight Status						
Normal weight (18.5 ≤ BMI < 25) N=53	79.1%					
Overweight (25 ≤ BMI < 30) N=13	19.4%					
Obese (BMI ≥ 30) N=1	1.5%					
Waist (cm)	77.0 ± 7.71	62	101	0.94	0.406**	0.207
Hip (cm)	89.4 ± 7.26	78	110	0.88	0.123	-0.259*
WHR (cm)	0.86 ± 0.07	0.68	1.09	0.009	0.338**	0.414**
HR FSS (beats / 15 seconds)	30.13 ± 4.71	21	40	0.57	-0.551**	
VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$) FSS	50.21 ± 8.11	35.15	67.32	0.99		
VO_{2max} ($L \cdot min^{-1}$) FSS	3.55 ± 0.77	1.38	5.21	0.09		
Aerobic fitness rating						
Medium (N =10)	14.9%					
Great (N=29)	43.3%					
Excellent (N=28)	41.8%					
P1 HR (beats / min^{-1})	76.03 ± 16.73	48	124	2.04		-0.155
P2 HR (beats / min^{-1})	110.70 ± 18.52	72	168	2.26		0.062
P3 HR (beats / min^{-1})	80.85 ± 19.04	48	144	2.32		-0.319**
Ruffier Index (RI)	6.79 ± 4.96	0	18.8	0.6		-0.124
VO_{2max} ($L \cdot min^{-1}$) RDI	4.25 ± 0.48	3.05	5.09	0.05		
RDI ranking						
Poor (N=6)	9%					
Moderate (N=7)	10.4%					
Good (N=26)	38.8%					
Very Good (N=21)	31.3%					
Excellent (N=7)	10.4%					

(FSS = Forest Service Step; WHR = Waist-Hip Ratio; BMI = Body mass index; SE = standard error of mean; SD = Standard deviation; HR = Heart Rate; RDI = Ruffier-Dickson Index; HR = Heart Rate; ƿ1 = Spearman's correlation coefficient of VO_{2max} ($L \cdot min^{-1}$) FSS; ƿ2 = Spearman's correlation coefficient of VO_{2max} ($L \cdot min^{-1}$) RDI; ***p*<0.01; **p*<0.05)

Table 2. Multiple linear regression model for predictive absolute VO2max.

	B	SE	t	*P*	R	Adj. R^2	R^2 change	F change	ICC
Model 1	0.309	0.495	0.624	0.535	0.635	0.394	0.403	43.928	0.727
Intercept	0.046	0.007	6.628	0.000					
Weight	2.980	0.349	8.540	0.000					
Model 2	0.054	0.004	13.923	0.000	0.907	0.816	0.419	150.326	0.938
Intercept	-0.107	0.009	-12.261	0.000					
Weight	3.937	0.417	9.430	0.000					
HR Post FSS	0.045	0.004	10.563	0.000					
Model 3	-0.103	0.008	-12.644	0.000	0.923	0.845	0.030	12.805	0.958
Intercept	-0.406	0.113	-3.578	0.001					
Weight	0.309	0.495	0.624	0.535					
HR Post FSS	0.046	0.007	6.628	0.000					
Sex	2.980	0.349	8.540	0.000					

(SE = Standard Error; HR Post FSS = Heart Rate Post Forest Service Step; ICC= Intra-class Correlation Coefficient)