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ORIGINAL ARTICLE

Estimating Aerobic Capacity (VO_2-max) Using a Single-stage Step Test and Determining its Effective Factors

SATTAR HOSSEINI[1], MOHAMMAD REZA GHOTBI RAVANDI[2*], NARGES KHANJANI[3]

[1]MSc Student of Occupational Health Engineering, Department of Occupational Health Engineering, School of Health, Kerman University of Medical Sciences, Kerman, Iran;

[2]Associate Professor, Department of Occupational Health Engineering, School of Health, Kerman University of Medical Sciences, Kerman, Iran;

[3]Associate Professor, Research Center for Environmental Health Engineering, Kerman University of Medical Sciences, Kerman, Iran.

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ABSTRACT

Maximal Aerobic Capacity (VO_2-max) is an indicator of the preparedness of the cardiovascular and respiratory systems and a tool to estimate the physiological fitness of individuals for their work. This study aimed to measure the VO_2-max and Physical Work Capacity (PWC) of workers at a metal industry and the factors affecting it using a single-stage step test. This cross-sectional study was conducted on 60 workers in a metal industry in Tehran, in 2017. Data collection tools were a questionnaire including separate sections asking about demographic and anthropometric (height, weight, and BMI) characteristics. Quantitative variables were recorded after being measured. The Tuxworth and Shahnawaz method and step test were used in order to estimate VO_2-max and PWC. Data were analyzed using SPSS 22. The relative humidity of the place was 40% and local air pressure was 879 atmospheres. The average VO_2-maxand average maximum PWC of the study population were 3.13±0.283L/min and 15.65±1.41 kcal/min, respectively. There was a significant relationship between VO_2-maxusingsingle-stage step test and BMI (P=0.01), number of hours of exercise per week (P=0.009) and age (P=0.01). The step test is a rapid, easy and low-cost method to estimate physiological adaptation and PWC of individuals. Variables such asage, hours of exercise per week and BMI are effective on aerobic capacity.

KEYWORDS: *VO_2-max, Physical work capacity, Step test*

INTRODUCTION

Assigning jobs proportionate to individuals' physiological capacityhelps maintain workers' health, prevent their premature burnout, and increases their efficiency and production rate. Measurement of PWC is one of the important topics in ergonomics [1-2]. Today, the PWC can be determined using VO_2-max [1]. VO_2-max is an index for the maximum energy produced from the aerobic processes [3-4] and is an accepted criterion for measuring the functional limit of the cardio-respiratory system because it is closely correlated with cardiac output [5] often used as an index for this system's preparation [4].

VO_2-max is affected by factors such as the physical, psychological, environmental and physiological characteristics of the individual [6], and is lower in women compared to men. Exercise increases it; but aging [5, 6], weight gain [5], using diuretics like alcohol and caffeine [7], as well as insufficient fluid intake and increased sweating [8] reduce VO_2-max.

Corresponding author: M.R Ghotbi Tavandi
Email: *ghotbi@kmu.ac.ir*

VO_2-max is measured in two ways, directly and indirectly. Since it is difficult to use the direct method and it cannot be widely used, thus the indirect method was proposed [9].

Indirect methods include the use of the ergonomic bicycle, conveyor belt or the stairs [1, 6]. These methods are based on the relationship between heart rate and oxygen consumption. The main disadvantage of treadmills and ergonomic bicycles is that they have limitations for their use in field studies and out of the lab [10].

Single-stage step test is used widely and has become popular in estimating VO_2-max, because of its less complexity and unnecessary to use expensive equipment [11] as well as ease to use for high sample sizes [10-11].

Aside from the frequent use of VO_2-max in the medical, sports and rehabilitation fields, there is little research about this in industry. Among the range of industries available in the country, workers in the metal and steel industry, are exposed to noise [12] and a relatively unsafe working environment [13], and are involved in heavy physical work [14]; therefore, their physiological adaptation and concordance between the energy required for physical work and their strength is very important in these industries.

The present study estimated VO_2-max and PWC of workers in a metal industry and examined the demographic factors affecting VO_2-max.

MATERIALS AND METHODS

This descriptive and analytical cross-sectional study was conducted on volunteers working in a pipe and profiles producing industry, located in one of the industrial towns of Tehran Province, Iran, in 2017. The sample size was calculated to be at least 45, using the standard deviation of aerobic capacity (0.17) obtained from previous studies [15] and $n = \frac{z^2 \times (SD^2)}{d^2}$ formula with an acceptable error of 0.05 and a 95% confidence level. In order to increase accuracy, 60 workers were enrolled in the study.

The objectives of the research were explained to the participants and they were assured that their personal information would remain confidential. Informed consent was obtained from the subjects. The Ethics Committee of Kerman University of Medical Sciences, IR.KMU.REC.1394.737, approved this project.

Estimating aerobic capacity puts pressure on various body parts such as the cardiovascular, respiratory and musculoskeletal system. Therefore, in addition to consent, participants had to be free of cardiovascular, respiratory, musculoskeletal and neurological diseases. For this purpose, participants' medical records were reviewed and a medical emergency technician measured their blood pressure and heart rate. If the participant had a history of a disease or could not tolerate the aerobic capacity test, and we felt extra pressure on their cardio-respiratory system during VO_2-max measurement, we would stop the test and exclude the participant. All tests were carried out within two days and between 8 am and 2 pm while the volunteers were wearing light clothing [*Fig*.1].

Before the start of the study, environmental parameters were measured at the site. A questionnaire containing questions about age, marital status, educat l level, having a particular disease, smoking ercise, medication (any type) was used an ompleted by the researchers by asking the wo:

***Fig*.1.** A participant dressed in light clothing while performing the Tuxworth and Shahnawaz test

Estimating VO_2-max and PWC: VO_2-max was estimated using the step test and the Tuxworth and Shahnawaz method [16]. In this method, the height of the stairs is 40 cm for men. In this test, the participant has to go up and down the stair 25 cycles per minute for 5 min. After this, the heart rate was reported as at three different times, as follows: M1: number of heartbeats at 30-60 sec, M2: number of heartbeats at 90-120 sec and M3: number of heartbeats at 150-180 sec. Then, the index b was calculated by this formula:

$$Index\ b = \frac{(M_1 + M_2 + M_3) \times 2}{BW(kg)}$$

Then VO_2-maxwas calculated using the index *b*and the following formula:

Y= - 0.378(*Index b*) + 4.67,

In this formula, Y isVO_2-max (l/min).

Since the thermal value of using one liter of oxygen in the body is about 5 kcal; therefore,

the maximum energy exertion per minute can be calculated by multiplying VO_2-max by 5; and 33% of that is equal to the PWC (Kcal/min) or the maximum physical work capacity of a person for a period of 8 h without experiencing physiological stress, physical exhaustion or harm [1].

Measuring environmental parameters: Environmental parameters were measured using a conventional thermometer, whirling psychrometer and barometer, which respectively measured dry temperature, wet and dry spinning temperature and pressure. Relative humidity was estimated using the psychrometric chart [17].

Measuring height, weight, blood pressure, heart rate and body surface area: Participants' height and weight were measured by using a tape measure and a digital scale while wearing light clothing and no shoes or gloves. Body surface area (BSA) was determined using the DuBois Equation (11). In this formula, BSA, height, and weight are respectively in square meters, centimeters and kilograms.

$$BSA\ (m^2) = (Height)^{0.725} \times (BW)^{0.425} \times 0.007184$$

D) Heart rate was measured by using a PO 80-pulseoximeter (Bearer Co.) by the medical emergency technician.

Data Analysis: Data were analyzed by SPSS (ver. 22 Chicago, IL, USA) and *P*-values less than 0.05 were considered significant. As the VO_2-max variable did not have a normal distribution (Kolmogorov–Smirnov test $P<0.05$),the Kruskal-Wallis test was used to determine the difference between the average VO_2-max (l/min) among different age, weight, height, BMI, BSA and hours of exercise per week; groups.

RESULTS

In the experiment setting, the spinning wet and dry temperature, relative humidity and air pressure were 26 °C, 17 °C, 40% and 879 atmospheres. In Table 1 Some Characteristics of the participants are displayed. Also The mean, standard deviation, minimum and maximum of VO_2-max and PWC are displayed in Table 2 and 3**,** Mean, standard deviation, minimum and maximum of VO_2-max based on BMI, BSI, age, weight, height and hours of exercise among the participants are displayed.

Table 1. The Characteristics of the participants (n = 60)

Variable	Mean	SD	Min	Max
Age (yr)	31.7	4.94	22.00	42.00
Weight (kg)	76.16	1.28	52.00	98.00
Height (cm)	172.58	6.13	160.00	191.00
Work experience (yr)	4.15	3.11	0.00	14.00
Hours of exercise per week	1.56	2.9	0.00	14.00
BMI (kg/m^2)	25.49	3.49	19.00	33.71
BSA (m^2)	1.89	0.17	1.62	2.21
Smoking (cigarettes per day)	2.53	5.18	0	20
			Number(percent)	
Marital status	Single		4 (6.7)	
	Married		54 (93.3)	
Level of education	Under Diploma		26 (43.3)	
	Diploma		32 (51.7)	
	Undergraduate degree		3 (5)	

Table 2. Mean, standard deviation, minimum and maximum VO_2-max (n = 60)

Variable	Mean	SD	Min	Max
VO_2-max($L.min^{-1}$)	3.13	0.283	2.07	3.58
Corrected VO_2-max($Ml.kg\text{-}1.min^{-1}$)	41.92	5.5	31.87	53.74
Maximum energy exertion(Kcal / min)	15.65	1.41	10.37	17.91
PWC (Kcal / min)	5.16	0.46	3.42	5.91

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Table 3. Mean, standard deviation, minimum and maximum of VO_2-max based on BMI, BSI, age, weight, height and hours of exercise among the participants (n = 60)

Variable		VO_2-max (l.min-1)				*P*-value*
		Mean	SD	Max	Min	
BMI groups(kg/m^2)	Thin (<18.5)	----	----	-----	-----	0.01
	Normal (18.5-24.9)	3.22	0.26	2.72	3.61	
	Overweight(25.29.9)	3.07	0.24	2.49	3.64	
	Obese (≥30)	2.96	0.22	2.64	3.23	
Smoking Status	Smoker	3.08	0.27	2.49	3.51	0.5
	Non-smoker	3.14	0.26	2.64	3.61	
BSI group (m^2)	1.55-1.77	2.96	0.29	2.55	3.61	0.1
	1.78-2	3.17	0.24	2.49	3.54	
	2.01-2.23	3.28	0.18	2.88	3.58	
Weight groups (kg)	<60	2.80	0.19	2.45	3.08	0.4
	60-70	2.96	0.36	2.77	3.33	
	71-80	3.19	0.18	2.84	3.56	
	>80	3.29	0.14	3.02	3.58	
height groups (m)	<170	3.04	0.31	2.49	3.54	0.4
	170-180	3.15	0.23	2.64	3.58	
	>180	3.35	0.21	3.11	3.61	
Age groups (yr)	22-26.9	3.31	0.28	2.75	3.61	0.01
	27-31.9	3.20	0.21	2.64	3.54	
	32-36.9	3.025	0.26	2.49	3.38	
	37-42	3.021	0.28	2.79	3.64	
Hours of exercise per week	0-4.99	3.09	0.26	2.49	3.61	0.009
	5-9.99	3.32	0.16	3.12	3.47	
	10-15	3.49	0.07	3.43	3.58	

Kruskal-Wallis test*

The Kruskal– Wallis test, did not show a significant difference for VO_2-max between smokers and non-smokers (*P*=0.5), and different weight (*P*=0.4), height (*P*=0.408) and BSA groups (*P*=0.1) (Table 4). However, the average VO_2-max decreased as age increased. The Kruskal - Wallis test showed that the average VO_2-max was significantly different in different age groups (*P*=0.011). The Mann-Whitney-U test also revealed that the average VO_2-max was significantly different in the first (22-26.9 yr) and third groups (32-36.9 yr) (*P*=0.01), and second and third groups (*P*=0.007).

In BMI classified according to WHO definition, among the three BMI groups, the maximum VO_2-max was observed in the group with normal BMI (Table 4). The Mann-Whitney test also revealed that there was a significant difference between normal and overweight groups (*P*=0.001) and normal and obese groups (*P*=0.013) in terms of average VO_2-max. This means that individuals with normal BMI have higher VO_2-max than other groups and are in better conditions in terms of the cardio-respiratory status.

The Kruskal-Wallis test showed that the median VO_2-max is significantly different in different groups in terms of hours of exercise per week (*P*=0.009). The Mann-Whitney test also revealed that there was a statistically significant difference between the first group (0-4.99 h per week) and the third group (10-15 h/w) in terms of VO_2-max (*P*=0.004).

DISCUSSION

The present study was conducted on 60 young men with an average age of 31.7 yr, average height of 172.58 cm and average BMI of 25.49kg/m^2;working in a metal industry.

The averageVO_2-max and average maximum PWC in the studied population was 3.13±0.283l/min and 15.65±1.41kcal/min, respectively. This finding is somewhat different from the results, which studied labor populations and estimated aerobic capacity, attributed to the individual characteristics of individuals [16].

Overall, 105 Iranian male workers in three age categories of 20-29, 30-39 and 40-49 were studied and estimatedVO_2-max in these age groups as 3.45±0.34, 2.73±0.29 and 2.33±0.29l/min, respectively, which is similar to the 20-29 age group of the present study and the difference is probably related to the effect of age on VO_2-max[2].

Overall, 500 male workers were studied in different factories in the city of Shiraz using anergometricbicycle, according to the Åstrand protocol. VO_2-max was 2.69±0.263which is slightly different from the present study, and it is likely due to a large number of workers in various industries and the average age of individuals who participated in their study. However, the significant relationship found between VO_2-max and age, BMI and the number of hours of exercise per week are consistent with the present study [6].

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Our results showed that the average VO_2-maxwassignificantly different in subjects who did weekly exercise and persons who did not weekly exercise, which confirms the results of studies [2, 7, 18]. In addition, VO2-max was not significantly related to age, though it decreased in age groups above 40 yr. which is not consistent with the current study whichVO_2-max decreased with increase in age (19). In the present study, there was no significant relationship between the average VO_2-max and variables such as weight, body surface are and height. However, significant correlations between mean VO_2-max, height, weight, and BSA that was inconsistent with the results of the present study (9). However, both studies found a significant relationship between VO_2-max and age.

CONCLUSION

Among the indirect means of assessing VO_2-max, the single stage step test is an easy and low-cost method that can provide a rough estimate of physiological adaptation and PWC of workers in a few minutes. There is a significant relation between VO_2-max and age, BMI and hours of exercise per week. Therefore, these factors can affect PWC as well. However, weight, height, and BSA had no impact on VO_2-max. VO_2-max can help assign duties to workers according to their physical and physiological capacity, and improve work efficiency and keep workers healthy as well.

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