INFLUENCE OF ANTHROPOMETRIC DIMENSIONS ON THE PREDICTION OF VO_2 MAX BY STEP-TEST

Goran Šekeljić, Milovan Stamatović, Danica Dzinović, Filip Kojić
Faculty of Teacher Training, University of Kragujevac, Serbia
Faculty of Teacher Training, University of Belgrade, Serbia
Faculty of Sport and Physical Education, University of Belgrade, Serbia
gsekeljic@sbb.rs; stamatovic@ucf,kg.ac.rs; danicadzinovic@uf.bg.ac.rs

Abstract: *Our interest in this paper is directed toward answering this question, whether the anthropometric characteristics affect the prediction of VO_2 max results obtained by step-test? The survey included 57 young athletes aged 15 to 17. The assessment of maximal oxygen consumption was determined by Astrand test on the treadmill and by step-test by von Döbeln on the stools 30cm high. The results were processed by comparative statistics methods: Spearman's correlation coefficient, Student's t-test and multiple regression analysis. The results indicate that the estimated values of maximum oxygen consumption of the respondents obtained by Astrand cycle ergometer test and the values obtained by step-test assessed by von Döbeln's formula are significantly different. The identified differences between the two tests were significantly correlated with body height, leg length, leg and body mass of the sample. Dependence among the described phenomena has been described by mathematical model, based on which it is possible to perform correction of the results of measurement and reduce the error estimates of VO_2 max by 5%.*

Keywords: *aerobic capacity, step-test, cycle ergometar, a corrective factor*

INTRODUCTION

The need to assess the aerobic capacity led to the appearance of Harvard step-test back to 1943, and to the appearance of the first ergometer test of functional ability (step-stools). Since then many new tests have been patented, which, in the meantime, have been modified many times in order to obtain reliable data.

It took decades of research in order to standardize the measurement conditions, acquire the necessary tests and psychometric properties. Over the years, the number of gaps have been removed and the assessment of the intensity of stress has included weight of subjects, it was evaluated the mechanical work that requires descent from the bench, the obtained values began to be expressed in $ml \times kg^{-1} \times min^{-1}$ as the true representative of the values of VO_2 max and technological advances made it possible to measure heart rate during labor and immediately in the first seconds of recovery.

The first respectable test was patented by Wilhelm von Döbeln, Irma Astrand and Arne Bergström (1967). Applying several submaximal and one maximal load on a cycle ergometer on the 84 subjects aged between 30 and 60, they noted regularities between the following:heart rate during maximal load and several submaximal loads, performed mechanical work expressed in kilopondmeter/min, body weight and age and in this way the mathematical model suitable to calculate VO_2max was defined based on heart rate measured immediately after the submaximal workload.

However, climbing the step-stool system requires a specific work that is not typical of other ergometers, such as treadmill or bicycle ergometar. Because of this specificity there is doubt that longitudinal anthropometric characteristics may affect the test results. Therefore Keen & Sloan (1958), using the protocol Harvard step-test, conducted research on two groups of healthy young men. The test was performed, recovery indices calculated according to the original procedure, but nothing pointed to the connection between the structure of the body, leg length, bi-iliac diameters or weight with the obtained results, although one of the conclusions was that the length of the leg could affect the results of step-test.

Ten years later Ariel (1969) tried to determine the impact of the angle between the part of the leg below the knee and the one above the knee, obtained by moving the height of the bench while the foot was raised on it, with index values of recovery obtained while performing the Harvard step test. For this purpose 30 students were subjected to tests at four different heights of stools. The authors concluded that the angle formed between the lower leg and the upper leg with height stools significantly affected the values of the recovery index, but not in a linear relationship with cardiorespiratory parameters/

Miyamura (1975) on a sample of 69 young Japanese between the ages of 13 and 14 performed a series of tests with stool heights of 22-30% of the length of each leg of the respondents. Based on the research results the authors conclude that there is no significant correlation with directly measured values, except in cases where the height of the stools were 25, 27 and 29% of body height, and even then they were very low r=0.351. After all, the authors believe that the results achieved in the step-test are influenced by many different factors such as aerobic capacity, anaerobic capacity, testing techniques, motivation, and duration of operation and structure of the body. On the other hand, the results suggest that within reasonable limits the results do not depend on the weight, height or leg length.

The aim of the study of Shahnawaz (1978) was to evaluate the objectivity of the results with respect to the amount of steps and anthropometric characteristics of the respondents. The survey was conducted on ten men whose height ranged from 162 to 191cm. A total of 8 tests were conducted, one of which was at the height of 40cm, and in the other seven cases the height of the stool made 30 to 60% of the length of each leg of the respondents. For this purpose, useful and specially designed steep platform with sliding stool was used. The workload was standardized according to body weight of the subjects. The results showed that the height of the stool and the rhythm of climbing directly affect the measured values of maximal oxygen consumption. The lowest values of oxygen consumption were measured at a height bench that was 50% of the length of each leg of the respondents, and the highest value when the bench was 30% of that length. Within the range of climbing from 17 to 35 cycles per minute minimum oxygen consumption values were recorded with the speed of climbing from 20 to 25 cycles per minute. For this sample, the bench height of 40 cm is considered optimal for subjects with leg length between 75 and 85cm, while the standard height of 50.8cm most appropriate to the subjects with leg lengths over 90cm. The author concluded that the validity of each form of step-test increases if the height of the step is adapted to the lengths of the legs of the subjects compared to previously fixed values.

The research conducted by Francis and Kiuapepera (Cuipepper & Francis, 1988) was aimed at examining the possibilities of modifying step-test in relation to the biomechanical relationships arising from the anthropometric characteristics of the respondents. The study was conducted on thirty students at the University of Alabama, and a three-minute test consisted of a single-step climb on the stool at a pace of thirty times a minute. The stool height was adjusted to anthropometric characteristics of subjects in a manner that the foot was raised on the step-stool in the hip joint and the flexion of 73.3 degrees was achieved.Cardiac frequency of recovery was measured between the fifth and twentieth seconds. The correlation was identified between the value of the pulse in the recovery and directly measured values of maximal oxygen consumption on treadmill by Bryus protocol was r=0.70 with a standard error of ± $2.9 ml \times kg^{-1} \times min^{-1}$, which made an error of less than 7%. Retest showed high correlation r=0.86 when the heart ratewas measured by palpation of the carotid artery, and r=0.89 in the case where these values are measured by ECG.

This problem was also of interest to the Military Medical Academy research team that dealt with the problem of standardizing the step-test for the army (Životić-Vanović, 1991). The authors do not consider it necessary to take into account some of the other anthropometric characteristics except for body mass, because their impact on the adaptive response of the body on the work in a step-test assessed through mechanical efficiency has not been statistically changed significantly. The authors conclude that anthropometric quantities such as leg length, thigh and knee angles do not affect the size of the internal loads, because of the small size of their impact on the performed work.

Based on the previous research, it is clear that the size of the mechanical work of step-test is determined by the following: height stools, rate of climb and descent from the bench in a unit of time, the length of the duration of the performed work and the body mass of those who do the work (Nikolic & Ilic, 1994). However, it is unclear whether the amount of mechanical work performed can affect any of the anthropometrical characteristics (height, leg length, weight). Previous studies have not determined with any certainty the nature of these relationships and why the VO_2 max assessment carried out on different protocols differ so much. This study was undertaken in order to answer the question, whether it is possible to standardize an accurate and reliable test for the assessment of functional capacity of young athletes, with respect to their anthropometric differences?

METHOD

The research included 57 men aged 15 to 17. For the purpose of this research it was operated with 6 variables. Of these, 4 are of morphological area (body height, leg length, leg length and body mass), and two from the area of functional capacity (VO_2 max established by Astrand test on the treadmill, and VO_2 max test established by step-test according to von Döbeln at the height of the stool of 30 cm. Measurement procedures were performed according to the instructions of the original authors (Astrand, 1972; von Döbeln, 1967).

All data obtained in the survey were processed using standard procedures of descriptive and comparative statistics. From the area of descriptive statistics the following have been analyzed: frequency distribution, mean, standard deviation and coefficient of variation. From the area of comparative statistics the following have been used: X^2 test, Spearman's rank correlation coefficient, Student's t-test and multiple regression analysis.

RESULTS AND DISCUSSION

In order to facilitate the perception of the observed phenomena the sample that was chosen was non-homogeneous in terms of anthropometric variables, as indicated by the high value of the range (max-min) and coefficient of variation (Table 1). Thus, for example, analyzing the mass (AMAS) of the respondents it has been noted that the lightest respondent has a mass of 37, and the heaviest of 89kg.

The range between the lightest and the heaviest is 52kg. When it comes to body height (AVIS) is the shortest respondent in the sample was 149.5cm high while the tallest had a height of 204.5cm, this making the range of 55 cm. Similar descriptive characteristics have been observed in the length of the legs (ADNG), and the length of the lower leg (ADP), which is quite expected due to the fact that these anthropometric variables are characterized by high correlation with body height (Medved 1987).

Tablel 1. Descriptive parameters are related to the mass of the respondents (AMAS), body height of respondents (AVIS), the length of the legs of the respondents (AND), the length of the lower leg of the respondents (ADP).

	Mean	Min	Max	Std. Dev	Coef. Var.	Count
AMAS	64.18	37.5	89	11.373	17.72	57
AVIS	178.2	149.5	204.5	11.677	6.554	57
ADNG	95.6	79	108.5	6.493	6.789	57
ADP	45.43	37	52	3.17	6.977	57

Descriptive parameters of VO_2 max are shown in Table 2. It is notable that the sample is characterized by very high values of maximum oxygen consumption as the average value of VO_2 max amounted to 52. 256 ml×kg^{-1}×min^{-1}, classified according to Morehouse (1972).
Table 2. Maximum oxygen consumptions of the respondents expressed in ml×kg^{-1}×min^{-1} measured by Astrand test on the treadmill and step-test by von Döbeln on the stools 30cm high.

	Mean	Min.	Max.	Std. Dev	Coef. Var.	Count
Astrand	52.3	35.6	76.6	7.97	15.252	57
Döb.- 30	59.4	43.7	78.4	7.51	12.648	57

Descriptive parameters of the actual difference between Astrand and step-test (Table 3) indicate that the subjects on cycle ergometer on average achieved 6.27ml×kg^{-1}×min^{-1} (14%) higher score on the step test than on the cycle ergometer .
Table 3. Descriptive parameters of the difference in VO_2 max achieved on the treadmill and step-test (values are expressed in ml×kg^{-1}×min^{-1}).

Mean	Std. Dev	Std. Error	Variance	Coef. Var.	Count
6.27	6.513	.863	42.422	103.876	57
Minimum	Maximum:	Range:	Sum:	Sum Squared	Missing:
-0.9	22.8	26.7	357.4	4616.6	0

Realized differences were statistically significant ($t=4.334$, $p<0.001$), which confirms our expectation that the estimated values of maximum oxygen consumption obtained on the treadmill and step-test differ significantly, which is confirmatory and in relation to some other research (Wasserman et al., 1999; Fitchett, 1985; Šekeljic et al., 2012).

For submaximal tests estimates that are 10% above or below the true value are acceptable (Kilby, 1990). However, the differences may be significantly beyond the acceptable framework, to which the works and Swain and Wright indicate (Swain & Wright, 1977), where the values were 28% and 26% in the work of Greiwe et al. (1995). In the study of Životić-Vanović (1991) the obtained values on the step-test the according to von Döbeln formula were 11% lower, and on bicycle ergometer using Astrand's method 17 to 19% lower than the directly measured values .

These differences occur because of several reasons. One of the reasons is great individual variations typical of all age groups (Kilby, 1990; Wasserman et al., 1999; Noonan & Dean, 2000). Balgos et al. (Balgos, et al., 1996) think that achieved load level affecst the outcome of the test, and that the results are more reliable if submaximal load reaches 90% of VO_2 max (Fletcher et al., 1998).

Different cardiovascular responses may be caused by different methods in testing, such as the speed of pedaling that in certain protocols varies from 50-80 rpm (Swain and Wright, 1997), or the duration of the test (Fairster et al., 1983).

Variations can also be explained by the fact that the physiological response to the work achieved by different ergometers need not be the same. Work on the step stool compared to bicycle ergometar, even when it is of equal sizes, varies in relation to the involved muscles and their masses, and can cause different reactions of cardiovascular system (Wasserman et al., 1999; Noonan & Dean, 2000; Šekeljic, 1996).

Despite the fact that the causes of variability may be numerous based on Spearman 's correlation coefficient ,statistically significant correlation has been found between the actual difference in tests and anthropometric characteristics of the respondents (Table 4). A weak but statistically significant inverse correlation of stochastic nature has been determined, suggesting that the actual differences in the results between the tests are not affected only by independent variables (anthropometric variables), but also by a number of other factors which have not been identified.

Table 4. Spearman correlation coefficient at a significance level of α=0:05 between some anthropometric variables and differences in VO_2 maxobtained between Astrand and von Döbeln's test.

anthropometric variables	The correlation coefficient
AMAS (masa)	.367 gr. vred. - .362
AVIS (visina)	.387
ADNG (duž. noge)	.413
ADP (duž. potkole.)	.357

Interestingly, the survey results were in line with our expectations. The paradox is that the shortest respondents with the lowest body mass achieved significantly better results in the step-test than on the treadmill. This unexpected result could be explained by the fact that the values of heart rate during labor, among other things, depend on the involved muscle. If on the same load greater muscle mass is involved, heart rate will be lower, stable condition will be set up sooner, and the work will be carried out under aerobic conditions. On the other hand, the same work with less muscle mass may partially activate the anaerobic mode, resulting in lower efficiency and increased heart rate. Therefore, for example, in the case of the same load heart rate is higher when arms are involved than legs. In our experiment, in case of both ergometers (step stools and bike) work is carried out by legs. However, it is possible that work on cycle, due to the characteristic position of the respondent during the test, causes performing of the work exclusively using legs, which is the reason why the patients with lower muscle mass experience anaerobic mechanisms of energy release, which causes greater heart rate and substantially lower estimated values of VO_2 max than the real ones.

Studies of Miller et al. (Miller et al, 1993) show that anthropometrically dominant individuals generally have a higher absolute value of muscle force due to greater muscle mass and a higher contractile potential. This fact probably contains solutions to the paradox. Namely, Dopsaj et al. (2011), Kljajic et al. (2012) while exploring the muscle force during the grip of the hand, concluded that women show a greater endurance in this motoric task, despite the fact that men with whom they were compared were capable of realizing greater absolute force. Lower absolute force also includes lower energy demand and reduced need for oxygen. Therefore, the authors believe that people with lower absolute muscle realize physical work that requires endurance with greater energy efficiency. The mechanism is based on the phenomenon that such persons have a higher coefficient of respiratory exchange during submaximal exercise.

The results of this study indicate that respondents in the step-test achieve greater values in relation to VO_2max assessment carried out on the treadmill. Deviations are on average 6.27ml$\times$kg$^{-1}\times$min^{-1}, which amounts to 14%, and depending on the height and weight of respondents deviations range from -0.1 to 22.8% (Table 3). Taking into account the correlation of anthropometric factors and differences in the maximum oxygen consumption, using a statistical regression analysis a mathematical model that describes these relationships was obtained. With regard to body mass (BM) and body height (TV) mathematical model (MM) can be represented by the following formula.

MM = 0.019 x TM(kg) + 0.0257 x TV(cm)

The mathematical model describes how the error in estimating VO_2 max in step-test increases with increasing the height and weight of subjects. If this information is taken into account it is possible to correct the results obtained and reduce the error estimates VO_2max by 5%.

The importance of this work for functional diagnostics is that earlier research has been confirmed (Francis & Cuipepper, 1988; Shahnawaz, 1978), which suggest that the anthropometric characteristics may affect the psychometric properties of some tests for assessing VO_2 max. Unlike other work in this field, the dependence between the described phenomena has been described by a mathematical model, based on which it is possible to perform correction of the measurement results and reduce the error estimates by 5%. The results can be used for further research in the field of anthropometry, sport, medical rehabilitation, special education, and related areas.

A limitation of this study is the lack of data on maximal oxygen uptake, which is achieved by measuring in the laboratory, by the application of some of the tests of maximum physical exertion. According to Životić-Vanović (1991), in order to predict maximum oxygen consumption to be based on the pulse-step test to predict maximal oxygen consumption, pulse values and oxygen consumption must be known with the increase of standardized load to the maximum possible. Otherwise, despite the fact that the coefficients of correlatios can be very high and repeatedly confirmed, the results can not be generalized and may apply only for the test persons, regardless of the sample size.

CONCLUSIONS

The results obtained in this study suggest that body height and weight affect the actual differences in the assessment of VO_2 max obtained by the step-test and cycle ergometer. Dependence between phenomena has been described by mathematical model, based on which it is possible to perform correction of the results and minimize the error estimate VO_2 max by 5%.

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