

**Original research article**

## **THE ANALYSIS OF TWO TESTS FOR THE EVALUATION OF MAXIMAL OXYGEN CONSUMPTION RATE**

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**Abstract.** *Our interest in this research was directed towards finding the answer to the question if the results for the evaluation of maximal aerobic power would be significantly different if they were measured by two different ergometers, and two different procedures which are used in the testing. The sample consisted of 64 young basketball players, 15-17 years old. The evaluation of the maximal oxygen consumption rate was determined by the Astrand evaluation test on bicycle ergometer and by the Von Döblen step test with a gym bench height of 30, 40, 50.8cm. Spearman's rank correlation coefficient and the Student's T-test were used as statistical procedures. The results indicate that the values of the maximal oxygen consumption rate of the participants measured by the Astrand test on a bicycle ergometer and the step test evaluated by the Von Döblen formulae are significantly different. 77% of the participants had a higher oxygen consumption rate on the step test. The differences can be explained by the fact that the physiological reaction of the body is different in comparison to work on a bicycle ergometer. The work on a gym bench in relation to a bicycle ergometer is different based on the engaged muscles and their mass, and because of that the load of the cardio vascular system is different. It means that the organism does not have the same physiological reaction to different types of load even when it is the same in terms of the size of the work.*

**Key words:** *aerobic ability, step test, bicycle ergometer, objectivity.*

### INTRODUCTION

The physical working capacity or physical fitness is the ability to adapt to mechanical work of different intensity, as well as the speed and the ability of recuperation (Đurđević, 1978). It can be said that the physical working capacity of an individual combines the re-

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sult of a coordinated effort of integration of different functions (Nikolić, 1995), and considering the importance of some determinants, the physical working capacity is now equated with aerobic power (de Vris, 1976; Đurđević, 1978). Aerobic power is the ability of an organism to create energy needed for physical work through the use of aerobic metabolic processes (Životić-Vanović, 1991). The measure of aerobic power, in fact, the best criterion for its evaluation is the maximal quantity of the consumed oxygen (Burke, 1976; Đurđević, 1981; Životić-Vanović, 1991), which represents the effect of cooperation between all the organs which participate in the intake and transport of oxygen to engaged tissues as well as the neurohumoral mechanism which coordinates their activity (Vojnarovska, 1978). The abilities of oxygen consumption are measured by aerobic power tests, during which work is done in pure aerobic conditions (Medved, 1987). Aerobic energy processes generate energy in the presence of oxygen – aerobic glycolysis (the metabolism of carbohydrates) and lipolysis (the metabolism of fats) (Heimer, Medved & Mišigoj, 1987). From the biochemical point of view it can be said that the maximal consumption of oxygen is reached by achieving the maximal power of ATP synthesis aerobically. Additional work can be done only in aerobic processes whose final product is lactic acid (Nikolić, 1995).

It is impossible to determine the general acceptable standard values of maximal oxygen consumption. Because of that, the level of aerobic value, on the basis of the value of maximal oxygen consumption is determined according to some of the qualifications, always separate for the sexes (Životić-Vanović, 1991). The classification of the American Health Association is frequently used (The American Heart Association, 1972) which is also accepted by the World Health Organization. However, it is considered that at rest, for normal adults the consumption of oxygen is  $0.25\text{--}0.35\text{ L}\cdot\text{min}^{-1}$ , or about  $4\text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  and that during physical work it progressively increases depending on the intensity of the physical load (Nikolić, 1995).

The ideas are the same (Astrand & Rodahl, 1977; Nikolić & Ilić, 1994; De Vris, 1976) that the consumption of oxygen during workout depends on the following factors: lung ventilation, the ability of blood cells to receive oxygen, minute heart volume, oxygen diffusion, artery-vein difference of oxygen in the blood, and that the limiting factor for adults is heart minute volume (Medved, 1987; Nikolić & Ilić, 1994), except during work at higher altitudes where partial oxygen pressure in atmospheric air can be smaller (Nikolić & Ilić, 1994).

Individual maximal aerobic power can be determined with high precision only by direct measure of maximal oxygen consumption. It implies the application of some laboratory tests of maximal load, with the use of adequate equipment and experts (Životić-Vanović, 1991). The application of such tests is very expensive, it requires laboratory conditions, calibration, electric power, expert stuff, and preliminary training and it is very risky especially for older and sick people (Đurđević, 1981; Medved, 1987; Životić-Vanović, 1991). A wish to surpass the problems caused the appearance of submaximal tests based on the fact that different physiological indicators change correctly with the increase of the intensity of the load to the maximum, on the basis of which it was possible to evaluate maximal oxygen consumption (Astrand & Ryhming, 1954; De Vris, 1976; Životić-Vanović, 1991).

With the appearance of new tests some old problems were eliminated, but new ones appeared. Different tests and instruments used for the same participants started giving significantly different results. One comparative study about working capacities was done

on different ergometers (a gym bench and a bicycle ergometer) at the Faculty of Medicine – Department for Physiology – Charles University in Czechoslovakia (Skranc, Havel & Bartak, 1970). Eighteen sedentary men were tested on three submaximal loads, one maximal on the bicycle ergometer and the gym bench step testing with more stair loads. The results showed that during the same oxygen consumption and heart frequencies the participants with lower loads on the step test achieved load 44% lower in comparison to the bicycle ergometer. With the increase in the load the differences became less at 16.5%. Yet, maximal oxygen consumption on the step test was by  $0.33\text{L}\cdot\text{min}^{-1}$ , i.e. 11% lower in relation to the values on the bicycle ergometer. Yoopat, Vanwonderghem & Louhevaara (2002) also obtained the same results, where twenty-year-old students indicated a difference of 15%. There were no differences in the case of the women. Skranc et al. (1970) explained this by the fact that different loads give different cardio respiratory and metabolic reactions. Depending on the kind of load, different groups of muscles are engaged. Numerous factors have influence on different loads, whether they are maximal or sub maximal (ventilation, oxygen diffusion, central and periphery circulation, heart minute volume). Because of that the speed of increase, the upper limit of heart frequency and maximal level of oxygen consumption differ, for example, during work which is done manually in relation to the work done by the legs.

Shepard proved this statement (1988) in his work “Muscle mass as a factor of limiting physical work”. As inspiration for this work he used a debate about how much heart minute volume is a limiting factor during strong physical work (the central factor), and how limited it is by the local blood stream or metabolic capacity of active muscles (the peripheral factor). Maximal loads were applied to 8 men and 8 women volunteers. Four types of ergometers were used which enabled work with two legs, one leg, one arm and the muscles of one arm and the shoulder. The results of maximal oxygen consumption were compared with the evaluated mass of active muscles. All six controlled aerobic variables were proportional to the active physical mass, and correlations were more significant when the oxygen consumption was closer to the maximal values. On the basis of these results, the authors think that arm work is limited by peripheral factors. One leg work is equally determined by central and peripheral factors. The work on a bicycle ergometer depends on the system for oxygen transport. These are the reasons why the values of maximal oxygen consumption on the bicycle ergometer were evaluated at 70% less than the values on a treadmill and it is considered a good recommendation of the International Biological Program to do similar measurements on a treadmill.

Such a conclusion could be derived from energy consumption during mechanical work in which different muscle groups are engaged. It was the subject of the research of Goss (1989). The research examined 9 physically active men between the ages of 24 and 34. Maximal oxygen consumption was evaluated on a treadmill using the Bruce protocol, and the respiratory metabolic system was controlled by Rayfield's microprocessor for the analysis of the exhaled gas. Testing was done using a step test with a gym bench height of 34.6 cm and six levels of speeds of climbing and arm load. Arm work consisted of counter lateral movements in relation to leg movements with a load ranging from 0.91 to 1.82kg or without load. Pulse, oxygen consumption, ventilation, and respiratory exchange of gases were registered for five minutes during each load. The caloric equivalent for each liter of oxygen consumption was adapted into an energetic substrate by the change of the respiratory part. The results showed that metabolic consumption was higher in all cases when the rhythm of climbing was 30 cycles per minute in relation to the climbing

tempo with 20 cycles per minute. Besides, aerobic metabolism was from 4.5 to 8.4 ml·kg higher when the testing was followed by hand work with loads, when compared to work that was done without or with fewer loads. Energetic price calculated with caloric balance in those cases was higher by 18 or 21%.

The validity of a few selected laboratory and "field" tests on which aerobic ability is evaluated on the basis of distance for a given time, were the subject of investigation of the College for Health, Physical Culture and Recreation "Itaca", the University of New York – Burke (Burke, 1976). The sample consisted of 44 students from the same school. A significant correlation was found between maximal oxygen consumption presented in  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  and Cooper's twelve minute running test ( $r=0.90$ ), the 600-yard run ( $r=0.78$ ), the one-mile run ( $r=0.74$ ), the Balke test ( $r=0.77$ ), the all-out treadmill ( $r=0.74$ ), the Astrand Rhyming Test ( $r=0.62$ ), Harvard Step-Test ( $r=0.55$ ),  $\text{PWC}_{170}$  ( $r=0.58$ ) and the Progressive Pulse test ( $r=0.47$ ). By the use of the Multiple Stepwise regression analyses with maximal oxygen consumption presented in relative values ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) as a measure criterion, in repeated multi measurements the following coefficients were found: for submaximal tests ( $r=0.78$ ), for maximal tests ( $r=0.91$ ), for "field" tests ( $r=0.91$ ), for other laboratory tests ( $r=0.86$ ). The body weight and percentage evaluated of non-mass body weight have an insignificant influence on the correlation between maximal oxygen consumption presented in  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  and selected working tests.

In our country, similar research was done by the institute for medical research of the Military Medical Academy in Belgrade (Životić-Vanović, 1991). The results of the maximal oxygen consumption were compared in four different tests (Sharkey's step test, Bruce's treadmill test, Astrand's bicycle ergometer test and von Döblen's test). The results showed that the values of maximal oxygen consumption predicted by the results of pulse in recuperation after the bicycle ergometer test did not statistically differ from the directly measured values on a treadmill (Bruce protocol), and they correlated ( $r=0.689$ ;  $p<0.001$ ); statistically they were significantly higher from the predicted values of Astrand bicycle ergometer test by 16.9-19.4% and they correlated ( $r=0.703$ ;  $p<0.001$ ); statistically they were higher from the predicted ones on the bicycle ergometer by von Döblen by 11.4-15.5% and they correlated ( $r=0.696$ ;  $p<0.001$ ).

Specific sport training, which treats the same groups of muscles because of specific training procedure, thus developing specific muscle topographic structures characteristic for some sport disciplines, demands the use of specific ergometers during the evaluation of maximal oxygen consumption with the goal of getting valid information. It is unrealistic to expect a precise evaluation of  $\text{VO}_2$  max for rowers with the use of an ergometer which engages less trained muscles (Stamford, 1977). Considering these facts, laboratory determination of maximal oxygen consumption by the use of an ergometric test on a treadmill has a smaller value in the evaluation of the aerobic power of rowers than of long-distance athletes. The differences in the values of maximal oxygen consumption on the same sample of athletes, depending on laboratory or specific testing, can be huge. For skiers there were deviations of 3.1%, for cyclists 4.2%, for rowers 5.6%. However in some measures the deviations were even 14%, and always in favor of specific testing (Stromme, Inger & Meen, 1977).

It is obvious that tests for the evaluation of maximal oxygen consumption should be adapted to specific sport disciplines so that the prediction of  $\text{VO}_2$  would be closer to the real values. That is why our interest is directed towards answering the question if the results for the evaluation of maximal aerobic power will be significantly different if they are achieved by two different ergometers (a bicycle ergometer and a gym step bench),

and two different procedures which are used during testing. Although there are two tests which evaluate the same ability, we believe that the results will be different because of the fact that during testing, muscle groups are not loaded in the same way, which can influence different cardio respiratory and metabolic reactions.

### THE METHOD

The research included a sample of 64 young basketball players 15-17 years old. We used four variables from the space of functional abilities (maximal oxygen consumption determined by the Astrand test on a bicycle ergometer, and maximal oxygen consumption determined by the von Döblen step test with the height of the gym bench of 30, 40 and 50.8cm. Measurement procedures were carried out following the original directions from the authors (Von Döblen, Astrand & Bergstrom, 1967). All of the data were processed by standard procedures of descriptive and comparative statistics. From the space of descriptive statistics the following were processed: distribution of frequencies, mean, standard deviation and variation coefficient. From the space of comparative statistics, Spearman's rank correlation coefficient and the Student T-test were used.

### THE RESULTS

On the basis of descriptive parameters (Table 1) it can be seen that the number of participants on the step test was declining with the increase in gym bench height.

**Table 1.** Maximal oxygen consumption of the participants represented in  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  measured by the Astrand test on a bicycle ergometer and the von Döblen step test with a bench height of 30cm, 40cm and 50.8cm.

	Mean	Min.	Max.	Std. Dev.	Cv	Count
Astrand	52.3	35.6	76.6	7.97	15.252	64
Döb.- 30	59.4	43.7	78.4	7.51	12.648	57
Döb.- 40	62.0	50.1	75.8	6.579	10.612	38
Döb.- 50.8	66.7	59.5	74.2	4.71	7.059	12

When the bench was 30cm high, 57 participants stood the test, while at a bench height of 50.8cm this number decreased to only 12 participant. It was expected because with the rise in bench height for each centimeter the level of the load significantly rises. It is obvious that testing with a bench height of 50.8cm could be stood only by the most capable participants which can be seen from the mean value of the group which succeeded in this and which is  $66.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ .

The relations between estimated aerobic abilities at different heights of the gym bench were evaluated by the T-test. Between the results measured at the heights of 30cm and 40cm there were no statistically significant differences ( $T=0.172$ ;  $p<0.8636$ ). At the same time a very high correlation was measured ( $r=0.97$ ). For the results of aerobic ability, measured at a height of the gym bench of 30cm and 50.8cm, the T-test did not show a statistically significant difference ( $T=0.400$ ;  $p<0.693$ ) with a slightly smaller correlation  $r=0.881$ . The results which were measured at gym bench heights of 40cm and 50.8cm

were not statistically significant (the T-test was 0.497;  $p < 0.6245$  and the correlation was  $r = 0.935$ ). The connection between the studied values of aerobic abilities at different heights of the gym step bench indicates the good metric characteristics of the test, its reliability and objectivity. It means that by the application of these tests, we can get confident information about the aerobic abilities of the participants on the basis of the measured heart rate frequency immediately after work.

The T-test was used to determine the relations between the results of the Von Döblen formulae with the values of the Astrand test. There were statistically significant differences between the results on the Astrand test ( $T = 4.334$ ,  $p < 0.001$ ) and the bench height of 30cm; ( $T = 4.064$ ,  $p < 0.001$ ) – with a bench height of 40cm ( $T = 3.543$ ,  $p < 0.0018$ ), for a bench height of 50.8cm. The highest correlation was between the Astrand test and the step test at a gym bench height of 30cm ( $r = 0.647$ ), while in two other cases, the level of correlation was lower for the bench height of 40cm ( $r = 0.487$ ) and for the bench height of 50.8cm ( $r = 0.392$ ). Because of that, it can be stated that the evaluated values of maximal oxygen consumption of the participants by means of the Astrand test on a bicycle ergometer and the values on the step test evaluated by the von Döblen formulae differ significantly and they are more prominent with the increase in load, which was proved in other studies (Astrand, 1954; Von Döblen et al., 1967; Životić-Vanović, 1991; Šekeljić, 1996).

**Table 2.** The descriptive parameter of differences in the maximal oxygen consumption between the Astrand test on a bicycle ergometer and the step tests by the Döblen formulae.

	Mean	Min.	Max.	Std. Dev.	Cv	Count
Ast - Döb. 30cm	6.27	-3.9	22.8	6.513	103.876	57
Ast - Döb. 40cm	6.55	-4.5	23.5	7.023	107.228	38
Ast - Döb. 50.8cm	8.41	-2.4	17.2	6.3	74.931	12
Ast - Döb. %	14.2	0	46.914	12.19	85.842	57

From the 57 participants whose values of aerobic abilities were evaluated by the step test with a bench height of 30cm by the von Döblen formulae, 15% achieved somewhat smaller values in relation to the Astrand test, while 77% of the participants had higher values of VO<sub>2</sub> max (Table 2).

## DISCUSSION

In many sub-maximal tests for the evaluation of VO<sub>2</sub> max in which the bicycle ergometer and step test were applied, there were many different results (Wasserman, Hansen, Sue & Whipp, 1999; Fitchet, 1985). In the sub-maximal tests on the bicycle ergometer for the evaluation of VO<sub>2</sub> max, which were based on HR ranges, it is thought that evaluations of 10% under or above real values are acceptable (Kilborn, 1990). Other studies like the one of Louhevaara, Ilmarinen & Oja (1980) have found deviations which vary from 13% to 9% when VO<sub>2</sub> max is evaluated by sub-maximal tests in relation to directly measured values, which is in accordance with earlier studies by Astrand & Ryhming (1954) and Glassford, Baycroft, Sedwick & Macnab (1965). However, these differences can be significantly outside of the expected acceptable frame, which was shown in the work of Swain & Wright (1977), where the values were 28% when the

ACSM protocol was applied. In the research of Životić-Vanović (1991), the values of von Döblen were 7% higher than the values predicted by the Astrand method. Both these methods were significantly lower than the directly measured values. The von Döblen test had a deviation of 11%, while the Astrand test had a deviation of 17% to 19%.

The main reason of such deviations is great individual variation which is characteristic of all age groups (Kilborn, 1990; Wasserman et al., 1999). It is considered that a good confidence interval can be achieved if sub maximal load reaches high enough values, and they are 90%  $\text{VO}_2$  max values characteristic for that age group (Fletcher et al., 1998) or when evaluation is done by means of a linear regression equation (Louhevaara et al., 1980; Astrand & Rodahl, 1977).

The reasons why there are differences between the values of  $\text{VO}_2$  max in many tests on the bicycle ergometer and step test were analyzed in many studies (Wasserman et al., 1999; Noonan, & Dean, 2000). It is thought that the reasons for such results can be explained by the differences in individual body mass and the relation between fat and muscle tissue (Spiro, Juniper, Bowman & Edwards, 1977), i.e. different sensibilities for different types of physical activities and load (Glassford, Baycroft, Sedwick & Macnab, 1965). Different effects were analyzed by different testing procedures, such as the speed of moving pedals which varies from 50-80 turns in a minute (Swain & Wright, 1997), lengths of the test (Fairster et al., 1983), or the achieved level of load (Balagos, Lua & Pascual, 1996).

Deviations in the predicted values of maximal oxygen consumption which were measured in this study can be explained by the fact that physiological responses to work in the step test determine their characteristics in relation to work during riding on bicycle ergometer. Work on the step bench in relation to the bicycle ergometer is different because of the engaged muscles and their mass, and the reaction of the cardiovascular system. From a physiological point of view it is not justifiable to expect that different types of work, even when they have the same values, will give the same physiological response of an organism.

In the end it is necessary to indicate that for the precise evaluation of the objectivity of these two sub-maximal tests which were presented in this work it was necessary to compare them with the data about maximal oxygen consumption measured in the laboratory by the application of some of the tests of maximal physical load, which was not done in this research, which is one of the limiting factors of this study. Another limiting factor of this study is the small sample because of which the results cannot be generalized.

Besides this shortcoming, it is necessary to say that the results in this work show significant differences in the results which would be measured if the testing of  $\text{VO}_2$  max were done with two different ergometers. We can recommend step gym bench as an ergometer for the evaluation of the aerobic ability in the case of basketball players because work which is done on this ergometer is closer to specific basketball movements in comparison to movements which are done on the bicycle ergometer.

## CONCLUSION

The results measured on the step test with a bench height of 30, 40, 50.8cm, by which the prediction was made of the maximal oxygen consumption using the von Döblen formulae, indicate that there is a linear dependence between heart frequency and the step test load. The connection between the evaluated values  $\text{VO}_2$  max of different heights of the gym bench indicates the good reliability and objectivity of the applied test. It means that

by the application of these tests, we can get objective information about the aerobic abilities of the participants.

By the use of the T-test significant statistical differences were determined between the results of step test by using the von Döblen formulae with the values of the Astrand test on the bicycle ergometer. It can be explained by the fact that except different levels of load and intensity of work and types of movements or movement characteristic for certain ergometers, there can be different cardio respiratory and metabolic reactions. Depending on the type of movement, different groups of muscles are engaged in different ways. Because of that the speed of the increase, the upper limit of heart frequency, and with it the prediction of the maximal level of oxygen consumption often differ during different movements which are provoked by the test load. The step test experiment is based on climbing the gym bench, while the Astrand test movements were similar to those performed while riding a bicycle. Specific sport training which because of specific training procedure treats the same muscle groups and by doing this develops specific muscle topographic structures characteristic for certain sport disciplines, requires the use of specific ergometers during the evaluation of maximal oxygen consumption in order to obtain valid results. Thus, the ergometer muscle groups and movements which are characteristic for a certain sport will be engaged.

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## ANALIZA DVA TESTA ZA PROCENU MAKSIMALNE POTROŠNJE KISEONIKA

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*Naše interesovanje u ovom radu usmereno je ka odgovoru na pitanje, da li će rezultati za procenu maksimalne aerobne moći biti značajno različiti ukoliko su dobijeni pomoću dva različita ergometra, i dva različita postupka koja se koriste u testiranju? Istraživanjem su obuhvaćena 64 mlada košarkaša starosti od 15 do 17 godina. Procena maksimalnog utroška kiseonika ustanovljena je Astrandovim testom na biciklergometru, i step-testom po fon Debelnu na visinama klupice od 30, 40 i 50.8cm. Od statističkih procedura upotrebljen je Spirmanov koeficijent korelacije ranga i Studentov T-test. Rezultati istraživanja ukazuju da se procenjene vrednosti maksimalnog kiseoničkog utroška ispitanika dobijene Astrandovim testom na biciklergometru i vrednosti dobijene na step-testu procenjene po von Döbeln-ovoj formuli značajno razlikuju. Kod 77% ispitanika procenjena je veća maksimalna kiseonička potrošnja step-testom. Razlike se mogu objasniti činjenicom da je fiziološki odgovor organizma na rad u step-testu drugačiji u odnosu na rad pri vožnji biciklergometra. Rad na step klupici u odnosu na bicikl ergometar, razlikuje se u odnosu na angažovane mišiće i njihove mase, pa je i opterećenje kardiovaskularnog sistema drugačije. To znači da organizam ne daje isti fiziološki odgovor na različite vrste opterećenja čak i kada je ujednačen po veličini obavljenog rada.*

**Ključne reči:** *aerobna sposobnost, step-test, biciklergometar, objektivnost.*