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IS THE MAXIMAL OXYGEN CONSUMPTION SINGLE BEST PREDICTOR OF SHUTTLE-RUN TEST?

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Abstract The aim of the present study was to evaluate the influence of aerobic, anaerobic and strength parameters of young basketball players on the indices of shuttle run test. A sample of 26 teenage basketball players (age 15.6±1.1 years; height 188.4±8.0 cm; weight 75.0±10.6 kg) performed a battery of five tests. For each subject, maximal oxygen consumption, maximal ventilatory equivalent for oxygen and ventilatory threshold were obtained during the shuttle-run and Conconi test protocol, using a portable gas analyzer. Relative mean anaerobic power was determined during Wingate test on a cycle ergometer. Leg power and absolute leg strength were measured using standing long jump and a leg strength test was performed on an isokinetic dynamometer. The results showed that predictors significantly foresee total distance on shuttle-run test (R^2 = 0.648) in young basketball players. In the predictors system maximal oxygen consumption had the greatest individual influence, followed by ventilatory equivalent for O_2 and leg power. Obtained results indicate that total distance covered on shuttle-run test could be improved through development of anaerobic capacity or leg power besides aerobic power and/or capacity.

Key words: shuttle-run, wingate test, VO_{2max}, basketball, regression

INTRODUCTION

It is widely recognized that the most valid physiological indicator of a subject's cardiovascular function and aerobic fitness is a laboratory determined maximal oxygen uptake (VO_2max). Such determination requires the use of sophisticated technical equipment and is quite expensive. As a consequence, exercise scientists developed several field tests for estimating VO_2max, both maximal or sub-maximal.

The most common field test for the prediction of VO_2max in team sports is the 20 m multistage fitness shuttle run test. Developed by Leger and Lambert [20], the test was modified by reducing the stages to one minute, in order to simulate a continuous incremental exercise to volitional exhaustion as well as to mimic sport-specific activity pattern of team sports [12, 19]. The test is widely used by sports scientists, coaches, and fitness advisors because it requires limited equipment, it is relatively easy to administer, and suitable for the assessment of large numbers of subjects. A major limitation of all field tests (including shuttle-run) is that they do not exclusively measure aerobic fitness. It is likely that during, or at the end of the test the athlete's anaerobic lactic system is providing the energy that enables the athlete to keep going. Therefore athletes with good anaerobic capacity are likely to post scores that slightly overestimate their aerobic fitness [14].

Moreover, the energy cost of changing direction (180^o in the case of the shuttle-run test) with decelerating and accelerating, seems to be increased as compared to continuous running in a straight line [14]. Athletes who are efficient in changing direction (e.g. by good use of the stretch reflex and good rate of eccentric force development) will be favored in this test compared with athletes who are inferior in changing direction [14]. Tall athletes and athletes with insufficient leg strength and power may be disadvantaged in this test, also.

A number of studies concerning shuttle run test have been conducted, and most of them investigated the validity of the test in prediction of maximal oxygen consumption. Great number of studies revealed high correlation ($r \geq 0.81$) between predicted VO_{2max} and VO_{2max} obtained during multistage treadmill test [19, 20, 21 27, 29, 32]. However, there are some studies which revealed low correlation coefficient between predicted and obtained results [8, 22, 33]. Moreover, some studies indicate importance of anaerobic component especially in the phases of decelerating, turning and accelerating and its influence on overall test results [13]. In addition, recent studies have shown that explosive-strength training improves endurance performance without concomitant increase in maximal oxygen consumption [26].

Thus, it could be hypothesized that leg power have some influence in shuttle run results, especially concerning relatively high eccentric-concentric contractions of the lower limb muscle in the final stages of the test. Therefore, the aim of the present study was to evaluate the influence of aerobic, anaerobic and strength parameters of young basketball players on the indices of shuttle run test.

MATERIAL AND METHODS

SUBJECTS

The study has been carried out on the sample of 26 young male basketball players (Ages = 15.6±1.1 years; BH = 188.4±8.0 cm; BM = 75.0±10.6 kg). All athletes attended training sessions regularly for at least three years. All athletes or their parents signed an informed consent form. Before testing each subject confirmed that he is non-smoker and that he does not take any medications that could affect the results. Because of the difficulties involved in ensuring compliance, no attempt was made to control the diet of the subjects (including alcohol consumption) as a control of the pre-testing condition of the subjects. We collected several parameters including relative maximal oxygen consumption and maximal ventilatory equivalent for O_2 during shuttle-run test, relative oxygen consumption at ventilatory threshold during Conconi test, relative mean power during Wingate test, vertical jump height and leg press indices. Within a 30 day period, all participants underwent three testing sessions.

The testing of shuttle run and vertical jump was conducted in the “Lukovski“ basketball center in Novi Sad (Serbia). Conconi test was conducted in fitness center in Novi Sad on a motor-driven treadmill. The anaerobic capacity testing and maximal leg strength have been carried out in the Laboratory for functional diagnostics at the Faculty of Medicine at the University of Novi Sad. Warm-up before the test was performed according to Inbar et al. [18]. Shuttle run and Conconi test were monitored using portable ergospirometry device. Vertical jump test has been carried out three times, after the proper warm-up, and as a result the highest value has been taken. All subjects performed tests at the same time of the day.

Before testing each subject, calibration of apparatuses had been performed by the instruction of the manufacturer. Special care was taken to maintain similar environmental conditions in all three testing sessions. All measurements were obtained by the same three-man squad. Prior to data collection, subjects were familiarized with all assessment protocols. They were also advised to avoid stressful activities 24 h prior to the data collection. Tests were conducted in a random order, by the same investigators, and at the same time for each subject either between 9 and 12 a.m. or between 5 and 8 p.m.

PROCEDURE AND MEASUREMENTS

SHUTTLE-RUN TEST

The test was conducted by the instructions [6]. Briefly, players ran back and forth between two lines, spaced 20-m apart, in time with the “beep” sounds from a compact disc (20-m shuttle Run test CD, Loughborough University, UK). Each successful run of the 20-m distance was a completion of a shuttle. The “beep” sounded at a progressively increasing pace with every minute of the test and correspondingly the player had to increase running speed accordingly. The player was warned if he did not reach the end line in time once. The test was terminated when one 1) could not follow the set pace of the “beeps” for two successive shuttles, and/or 2) stopped voluntarily. Typically the scores in the shuttle run test are expressed as levels and shuttles, but these values are discontinuous and cannot be used in statistical analysis. The total distance covered (i.e. 20 m x number of completed shuttles) was therefore reported as the player's performance measure in the shuttle-run test. During the test , metabolic and ventilatory parameters were collected using portable gas-analyzer K4 b^2 (COSMED, S.r.l. Italy). Software processing of the data was done with the original program provided with the instrument.

Conconi Test

The subjects performed an incremental maximal exercise test with 200 m stages [7] on a motor-driven treadmill (Run race, Technogym, Italy), with 1.0% inclination. A "breath-by-breath" gas analysis system (Quark b^2, Cosmed, Italy) was used for respiratory gas exchange recording. Heart rate (HR) was monitored using a heart rate monitor (Polar Accurex, Polar Electro Oi, Finland). HR, metabolic gas and ventilatory parameters were averaged for every thirty seconds. The maximal exercise test was terminated at volitional fatigue of the subject.

The anaerobic threshold was estimated by the V-slope method, using a second disproportionate increase of the volume of carbon dioxide expired in relation to the volume of oxygen consumption (respiratory compensation point) [34].

Wingate Test

Each subject performed a 30-s test on an air-braked cycle ergometer. According to generally accepted recommendations for anaerobic performance testing, the sessions started with a standardized cycling warming up of 5-min. Two sprints lasting 3 seconds were included, performed at the end of the third and the fourth minute as coordinative preparation for the subsequent high-intensity workload. After a subsequent 10-min rest, the subjects were instructed to pedal as fast as possible for 30 seconds. A resistance was applied from the start of the test. Cycle ergometer was connected to computer with software for manipulation of the obtained results. Relative mean anaerobic power was calculated in watts per kilogram. After termination of the test, the subjects continues to pedal at low intensity for couple of minutes. During the tests double-toe stirrups and straps were used to tightly fix the feet to the pedals.

Standing Long Jump

The athlete stands behind a line marked on the ground with feet slightly apart. A two foot take-off and landing is used, with swinging of the arms and bending of the knees to provide forward drive. The subject attempts to jump as far as possible with landing on single or both feet. Falling or stepping backward after the landing will result in measurement to that point of contact rather than where the feet first touched the ground. Three attempts are allowed. The best attempt is used as the test result.

Leg Strength

Leg strength testing on the isokinetic dynamometer (Weba Sport Dyno 2000, Germany) has been carried out in the Laboratory for functional diagnostics at the Faculty of Medicine at the University of Novi Sad. Subject starts to extend the legs as fast as he can while sitting on the seat, with feet tightly fixed and legs bent in knee and hip. After three control attempts, the next five legs extension attempts as the velocity of 40cm/s have been recorded. The best result was taken as a parameter of leg strength. In the case the subject has a subjective feeling of not giving his maximum effort, the same procedure is repeated after 15 minutes of rest.

Statistical Analysis

Means and standard deviations were calculated by methods of descriptive statistics. Multiple regression model analysis has been used to determine predictor system influence on the criterion variable. The level of significance was set at $p < 0.05$.

Results

The results of the present study are shown in Table 1 and Table 2. Table 1 represents the mean values and standard deviation of selected variables while Table 2 represents the multiple regression model results in the selected variables system.

Table 1. Mean values (Mean) and standard deviation (SD) of selected variables

Variable	Mean	SD
Shuttle run distance (m)	1656.9	269.9
VO_{2max} (ml/kg/min)	53.8	5.5
Ventilatory threshold (ml/kg/min)	46.3	6.1
Mean Power (W/kg)	6.3	1.0
Standing Long jump (m)	2.3	0.2
VE/VO_2	35.9	3.8
Leg strength (kg/m)	154.7	31.7

Table 2. Multiple correlation, determination coefficient, predictor significance level, individual predictor influence on the criterion in the predictive variables system and the significance level

Variable	Beta	t	Sig.t
VO_2max	0.480	3.272	**0.004**
Ventilatory threshold	-0.057	-0.313	0.757
Mean Power	0.127	0.764	0.454
Standing Long jump	0.385	2.230	**0.038**
VE/VO_2	0.422	2.371	**0.028**
Leg strength	0.058	0.312	0.759
R = .805	R^2 = .648	F = 5.842	Sig. F= 0.001

Abbreviations: Beta – standardized Beta coefficient, Sig. t – t-level significance, t – t value, R – Multiple correlation, R^2 – coefficient of determination, F – F value, Sig. F - level significance

Table 2 includes multiple regression analysis results of predictive variables system and their influence on total distance covered on shuttle run test. The predictive variable system consisted of maximal oxygen consumption and ventilatory equivalent for oxygen obtained directly during shuttle run test, ventilatory threshold, absolute leg strength, standing long jump and relative mean anaerobic power. The multiple correlation coefficient shows that the system of predictors correlates with the criteria 0.805. The coefficient of determination (R^2) is 0.648 and is significant at the significance level 0.001. It could be concluded that predictor system of variables predicts total distance on shuttle run test by about 65%. This means that about 35% of variance is independent of predictors and that this portion of shuttle run result is dependent of some other characteristics (i.e. motivation, agility, somatotype).

While analyzing Table 2 the system of predictors the maximal oxygen consumption has individually greatest influence on the criteria (statistically significant on the level 0.004). Next strong variables are ventilatory equivalent for oxygen and leg power, with significance level of 0.028 and 0.038, respectively. In addition, variables of leg strength, ventilatory threshold and relative mean power are not statistically significant.

Discussion

The shuttle run test is performance indicator of aerobic fitness in weight bearing sports which requires many changes of directions [14]. The test is widely used as VO_{2max} predictor, despite some conflicting results from different studies about validity of the test, when comparing to the gold standard measurement in the laboratory [22, 33]. In order to validate the use of shuttle run test for the determination of maximal oxygen consumption, it would be prudent to examine the influence of some parameters of physical fitness on the total distance covered during the shuttle run test (though the total distance is the parameter by which maximal oxygen consumption is computed).

The present study showed that maximal oxygen consumption has the greatest influence on the shuttle run test results. Relative VO_{2max} has proved to be the single most important factor in predicting distance running success in heterogeneous groups of athletes [28]. Considering that shuttle run can be recognized as prolonged activity and that the sample was non-homogenous in maximal oxygen consumption (53.8 ± 5.5 ml/kg/min), the obtained results are in line with the previous statement.

However, study results revealed that ventilatory equivalent for oxygen and standing long jump have statistically significant influence on total distance during the test. Moreover, the influence of this parameters were almost just as strong as the influence of maximal oxygen consumption (0.422 and 0.385 in comparison with 0.480 for VE/VO_2, Standing Long jump and VO_{2max}, respectively). Ventilatory equivalent for oxygen can be considered as the measure of anaerobic capacity. This parameter is often used as the predictor of ventilatory threshold which marks the onset of hyperventilation during incremental exercise [34]. Most common explanation for hyperventilation is the inability to maintain a blood pH. During increases in workload, the rate of lactate production eventually exceeds the maximal combined capacity of eliminating and buffering mechanism and a ph decline in the blood become unavoidable. Although this assumption was proposed by Wasserman et al. [4, 34] it has been questioned by Farell and Ivy [11].

According to the results of the later study, authors suggest that VE/VO_2 occurs at similar work rate regardless of whether blood pH or lactate was increasing or decreasing. Farell and Ivy [11] suggest that the increase in VE/VO_2 is closely associated with the metabolic rate of active musculature. However, most recent study [25] for the first time directly demonstrated that exercise-induced lactate acidosis is causally involved in the hyperventilation that starts at ventilatory threshold. In addition, the authors stated that acidosis is not the only stimulus for the given phenomena. Consequently, if acidosis is the main reason for the rise in VE/VO_2 parameter, it could be hypothesized that maximal values of the parameter could also be associated with maximal acidosis and consequently anaerobic capacity.

The second parameter that could be considered as the measure of anaerobic capacity, relative mean power, has no significant influence on the criterion variable. The Wingate test is considered the most common test of anaerobic fitness. However, several questions arise concerning muscle and activity pattern specificity and accessibility of the test to basketball players [16]. Although the test was originally designed to measure lower-body anaerobic power and capacity, according to the authors [3, 18], mean power reflects local endurance of leg muscles and their ability to sustain extremely high-power. Influence of anaerobic capacities of athletes in distance running is well-documented by research [5, 17].

Several investigators showed that anaerobic characteristics can differentiate well-trained endurance athletes according to their distance running performance [17, 23]. In addition, it has been shown [10] that time to exhaustion at minimal intensity at which VO_{2max} occurs, was positively correlated with maximal oxygen deficit. Authors stated that during the test the energy is mainly provided by aerobic metabolism while anaerobic processes provide a supplement. But, anaerobic capacity is a limiting factor in such activities since exhaustion of the anaerobic capacity leads to the termination of the test, due to inability of aerobic processes to provide enough energy for the given intensity. In addition, authors stated that subjects with higher anaerobic capacity are able to exercise for the longer time than subjects with poor anaerobic capacity during an incremental test on treadmill. Considering that shuttle run is also an incremental test it could be hypothesized that this statement is valid for this study.

Standing long jump is the third parameter that has statistically significant influence on the criterion variable in the present study. This parameter can be considered as the indicator of explosive strength (power). Aziz et al. [2] used another parameter of the explosive strength (vertical jump) and found significant relationship between shuttle run test results and lower limb power. In addition, Paavolainen et al. [26] showed that explosive strength training improves distance running performance by improving muscle power and running economy. It could be hypothesized, that in the case of shuttle run test, influence of leg power could be also beneficial in the improvement of stretch-shortening cycle, especially in the final stages of the test (e.g. moment of changing direction).

CONCLUSION

In conclusion, ventilatory threshold and absolute leg strength have no significant influence to criterion variable (total distance at shuttle-run test). Ventilatory threshold measurements were found to better predict endurance performance than VO_{2max} [1, 9, 24, 30, 31] while absolute strength may lead to improved endurance performance [15, 23]. The present study did not appear to support those results.

PRACTICAL APPLICATION

The present study shows that total distance covered at shuttle-run test is not VO_{2max} - only dependent. The practical application of this statement is that one must be cautious when interpreting shuttle run test improvement or decline as a consequence of the training regimen. Several tests should be provided, including anaerobic capacity and leg power test procedures, in order to make better assessment on obtained shuttle run test results.

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