Patterns of cardiovascular and ventilatory response to maximal cardiopulmonary test in elite basketball players

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Key words: *exercise testing, basketball, oxygen uptake.*

Summary. *Objective. The aim of this study was to investigate patterns of cardiovascular and ventilatory response during cardiopulmonary exercise stress test and determine standard values of physical capacity during cardiopulmonary exercise stress tests for professional basketball players.*

Material and methods. Materials of the study were collected during a ramp exercise test of 33 professional athletes using an electronically braked bike ERGOLINE 9000. Power output and heart rate samples were collected. Ventilation and gas exchange indices were measured during the tests using VMAX229 metabolic card and Sensor Medics gas flow analyzer. Scattergrams of power, oxygen uptake, heart rate and pulmonary ventilation with 95% mean prediction intervals were presented. Data of European champions as example of successful conditioning were compared with other athletes.

Results. The typical values of oxygen uptake, power output, hear rate and pulmonary ventilation are presented. We found statistically significant correlations between heart rate, oxygen uptake and power output at anaerobic threshold. Statistically significant correlations between heart rate, oxygen uptake and power output disappeared at peak of exercise.

Conclusions. The data of incremental exercise tests gives valid information about physical capacity of basketball players. The collected data could become referential source for the sport and might be useful for monitoring and evaluating current and future players. European champions developed relative high peak oxygen consumption despite "early" anaerobic threshold. Other advantages of European champions during cardiopulmonary testing were not determined.

Introduction

All forms of physical activity increase the metabolic rate involving the oxygen transport system. The high metabolic demands observed during occupational activity of professional athletes highlight the need for tests to assess physical capacity regularly. Cardiopulmonary exercise stress testing (CPET) grants an objective measurement of peak physical capacity, and has become an important tool in clinical sports medicine. Physical capacity can be defined and evaluated in achieved workload or/and in aerobic capacity. The value of peak oxygen consumption standardized per kilogram of body weight is the main outcome of the maximal exercise test and rests in the fact that it accumulates elements of cardiac adaptations, and skeletal muscle, pulmonary, and vascular qualities (1–4). So normal values of oxygen consumption for healthy adults are well known (2, 4–6) but estimation of normal values is still actual for some stick-out groups with special features. If we recognize that professional athletes in the same sport discipline are a sample with some special feature because of typical activities and phenotypical requirements for this discipline, it could be reasonable estimate normal values for those people. Basketball is an activity characterized by intermittent exercise bouts of varying intensities and duration involving different body parts and numerous recovery periods (7, 8). Paucity of data regarding physical capacity of basketball players is available in literature (7–13). There are no well-established and well-accepted standardized testing profiles for basketball players (10). Maybe it is associated with low regard or with some uncertainty about the influence of aerobic capacity on performance in basketball. But which values

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might be recognized as normative references if level of investigated players and used methods are so different?

There are no described patterns in current literature regarding physical capacity of high-level male basketball. We suggest that investigation and description of physical capacity in current high-level male basketball are necessary for successful modeling and conditioning in future.

The aim of this article was to investigate patterns of cardiovascular and ventilatory response during standard cardiopulmonary exercise stress test and estimate typical values of physical capacity for professional basketball players.

Material and methods

Participants

All 33 investigated athletes were professional players with international experience (European Cups for clubs). Part of investigated players was members of national teams, two players were European champions 2003 in Stockholm; four players were members of Olympic Games in Sydney or Athens. High performance in sport is outcome of successful conditioning. We suggested that winning of European championship is really high performance. We separated European champions as example of successful conditioning for comparison with other athletes. Written informed consent for participation in this study was obtained from each athlete in accordance with the code of ethics. The cardiorespiratory exercise testing was part of biomedical examination before signing or extension of contract.

Design

Firstly the morphological indices of the participants were determined. Standing height was measured without shoes to the nearest 1.0 cm using a stadiometer model 220 (Seca, Hamburg, Germany). Body weight was measured to the nearest 0.1 kg using an electronic digital scale model 770 (Seca, Hamburg, Germany). Each subject was well rested before the test and had not done hard physical work during the preceding 24 hours. All tests were carried out under laboratory conditions complying with regulations of the American Thoracic Society (ATS) (6). Each subject performed the exercise test on an electrically braked cycle ergometer ERGOMETRICS 800 (Ergoline, Bitz, Germany). Power output was increased by 25 or 30 Watts (W) at every minute and pedaling cadence was kept constant at 60–70 revolutions per minute (rpm). The exercise tests were terminated upon exhaustion, or when the criteria established for test termination were met. Termination of the test was associated with the following criteria: respiratory exchange ratio being 1.10 or more, heart rate attaining a plateau with increasing workload; oxygen consumption attaining a plateau with increasing workload (2, 6, 10).

Gas exchange data were collected continuously using an automated breath by breath system VMAX229C (Sensormedics Corps., Yorba Linda, CA, USA). Calibration of the flow/volume sensor was achieved immediately before each test by manually pumping a 3-liter syringe through the flow meter at a rate similar to that achieved during the exercise test. Samples were formed for each 20 s interval for the evaluation of the lung ventilation indicators, heart activity and oxygen uptake. The anaerobic threshold was identified by the conventional criterion using the V-slope method (2, 4, 6). The data were analyzed using the MARQUETTE-CARDIOSYS 3.01d diagnostic algorithm. In all investigated subjects the following variables were sampled: oxygen uptake expressed per kilo of subject's weight at rest (VO_{2rest}), at anaerobic threshold (VO_{2AT}), at peak of exercise (VO_{2peak}), ratio between oxygen uptake at anaerobic threshold and at peak of exercise, work rate at anaerobic threshold (P_{AT}), work rate at peak of exercise (P_{peak}) and relative power expressed as peak of work rate per kilo of subject's weight (P_{rel}), heart rate at anaerobic threshold (HR_{AT}) heart rate at peak of exercise (HR_{peak}), pulmonary ventilation at anaerobic threshold (VE_{AT}), pulmonary ventilation at peak of exercise (VE_{peak}) and respiratory exchange ratio (RER) at peak of exercise.

Statistical analysis

Results are presented as the mean ± standard deviation of the mean (m±SD). Correlations between variables were calculated using Spearman rank test. Correlated variables were submitted to a forward regression analysis in order to assess linearity. Scattergrams with 95% mean prediction intervals were prepared to compare data of European champions with other athletes. Statistical significance was set at $p<0.05$.

Results

The physical characteristics of investigated players were as follows: age 24.73±3.83 years; height 197.64±9.74 cm; weight 96.17±12.31 kg; body mass index 24.55±1.85 kg/m². The cohort studied was comprised of 14 guards, 5 center players, and 14 forwards. Descriptive statistics of main parameters of cardiorespiratory stress testing are presented in Table 1.

Because not all variables showed normal distribution we used Spearman rank test to evaluate correlations between main stress testing parameters. The

Table 1. **Descriptive statistics of main parameters during cardiopulmonary exercise stress testing**

Variable	n	Minimum	Maximum	Mean	Std. Deviation	Median
P_{peak} (Watts)	33	270	450	341.48	44.97	349
P_{AT} (Watts)	33	101	300	178.33	40.46	177
VO_{2AT} (ml/kg/min)	33	15.6	40,8	24.47	4.86	24.2
VO_{2peak} (ml/kg/min)	33	35.6	66.3	48.92	7.83	47.7
VO_{2AT} /VO_{2peak}	33	38	66	50.25	7.28	48.6
VO_{2rest} (ml/kg/min)	33	1.6	6.6	4.68	1.02	4.7
P_{rel} (W/kg)	33	2.75	4.82	3.6	0.56	3.53
VE_{AT} (L/min)	33	33.4	83.4	54.6	12.49	54
VE_{peak} (L/min)	33	89	193.4	134.73	26.48	127.8
RER	33	1.03	1.41	1.2	0.09	1.18
HR_{AT} (bpm)	33	101	154	123.39	13.43	121
HR_{peak} (bpm)	33	141	194	171.03	13.17	172

results of Spearman rank test are available in Table 2.

Scatterplots with verification of linearity between most important variables of CPET are presented in Figures 1–6.

Discussion

Aerobic capacity of investigated professional athletes expressed in ml/min/kg is not developed extremely but values are comparable with upper limit of normative values for healthy adults (2, 4–7). Table 3 presents comparisons between our data and other studies regarding peak oxygen consumption in male basketball players.

Normal values of ratio AT/peak oxygen consump-

Table 2. **Correlation matrix of cardiopulmonary exercise stress testing-related variables**

		P_{peak}	P_{AT}	VO_{2AT}	VO_{2peak}	Ratio	VO_{2rest}	P_{rel}	VE_{AT}	VE_{peak}	HR_{AT}	HR_{peak}
P_{peak}	r	—										
	p	—										
P_{AT}	r	0.427	—									
	p	0.013	—									
VO_{2AT}	r	0.372	0.528	—								
	p	0.033	0.002	—								
VO_{2peak}	r	0.363	0.139	0.702	—							
	p	0.038	0.441	0.000	—							
Ratio	r	0.014	0.525	0.461	–0.230	—						
AT/peak	p	0.938	0.002	0.007	0.197	—						
VO_{2rest}	r	–0.036	–0.174	0.125	0.159	–0.029	—					
	p	0.844	0.332	0.490	0.378	0.872	—					
P_{rel}	r	0.554	0.121	0.583	0.576	0.054	0.218	—				
	p	0.001	0.502	0.000	0.000	0.765	0.223	—				
VE_{AT}	r	0.374	0.797	0.751	0.371	0.614	–0.041	0.234	—			
	p	0.032	0.000	0.000	0.034	0.000	0.820	0.190	—			
VE_{peak}	r	0.593	0.358	0.588	0.595	0.064	0.180	0.437	0.515	—		
	p	0.000	0.041	0.000	0.000	0.724	0.318	0.011	0.002	—		
HR_{AT}	r	0.276	0.629	0.515	0.249	0.392	–0.098	0.307	0.696	0.370	—	
	p	0.119	0.000	0.002	0.162	0.024	0.587	0.082	0.000	0.034	—	
HR_{peak}	r	0.343	–0.020	0.167	0.187	–0.059	0.046	0.314	–0.007	0.544	0.259	—
	p	0.051	0.912	0.354	0.298	0.746	0.799	0.075	0.969	0.001	0.146	—

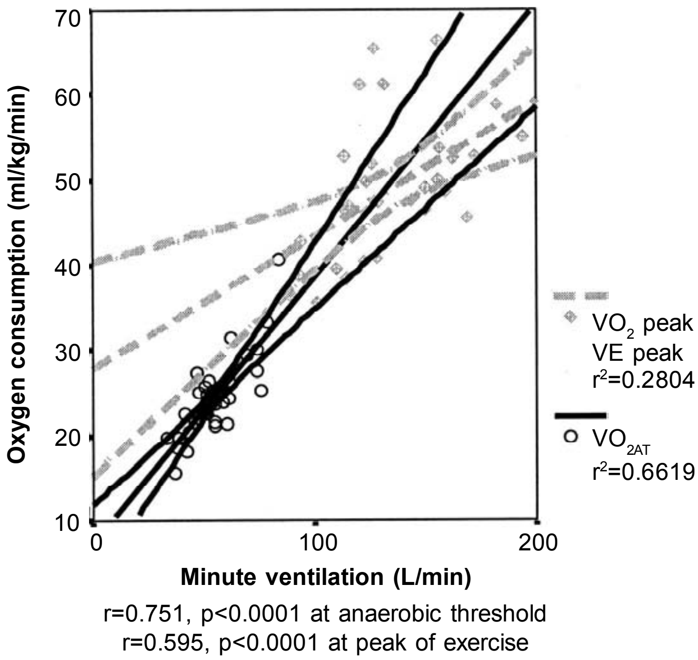

Fig. 1. **Correlations between pulmonary ventilation and oxygen consumption during cardiopulmonary exercise stress testing in professional players**

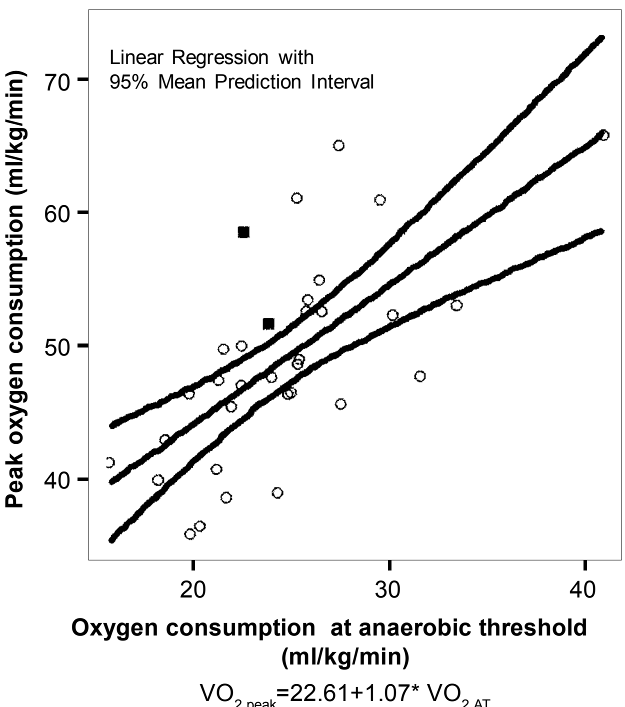

Fig. 2. **Scatterplot of oxygen consumption labeled by relative power (filled symbols represent values of European champions)**

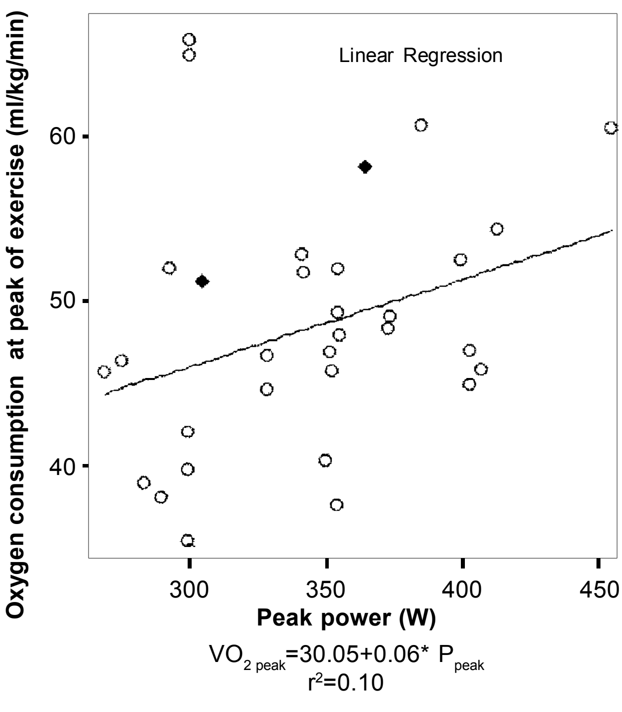

Fig. 3. **Relationship between power output and oxygen consumption at peak of exercise labeled with relative power (filled symbols represent European champions)**

tion are estimated 50–60% of peak oxygen consumption or >40% of predicted peak oxygen consumption (2, 4–6). Our data are in character with those reference values.

Despite VO_{2rest} did not correlate with any other variable of CPET, but mean value was higher than average for healthy adults. Higher energy expenditure at rest is accessory evidence of high level of investigated athletes (14).

Developed maximal power output of investigated

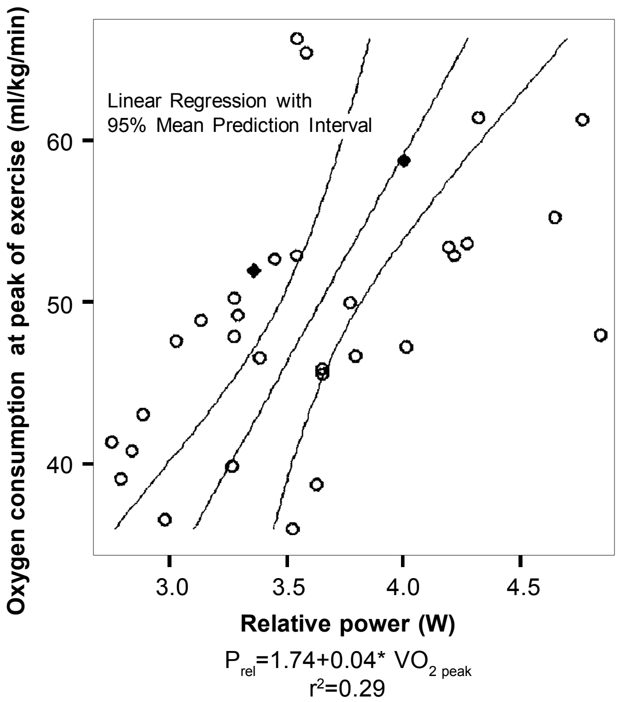

***Fig. 4.* Relationship between relative power and oxygen consumption (filled symbols represent European champions)**

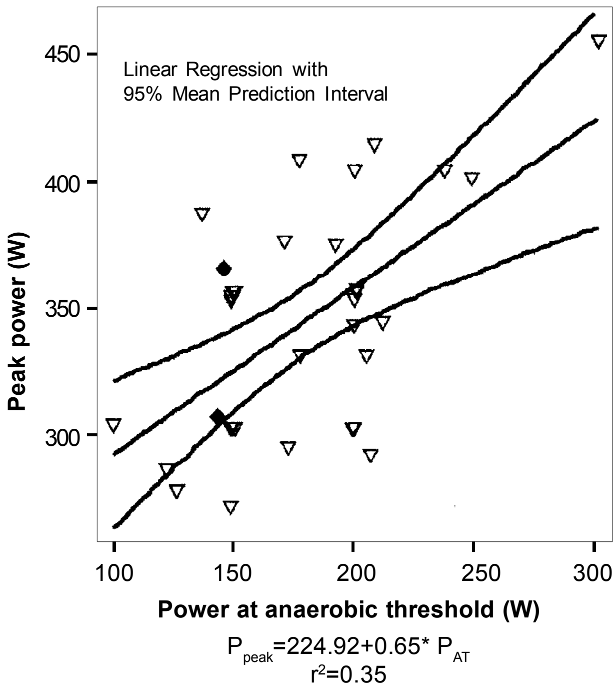

***Fig. 5.* Scatterplot of power output labeled by peak oxygen consumption (filled symbols represent values of European champions)**

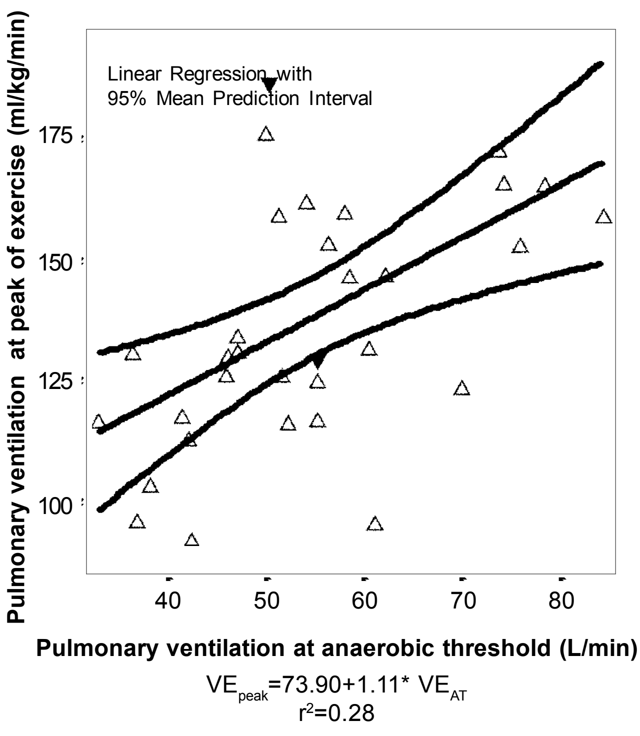

***Fig. 6.* Scatterplot of pulmonary ventilation labeled by peak oxygen consumption (filled symbols represent values of European champions)**

athletes was similar as described in sources (11) and (12) but those comparisons have limitations because different increments were used (15).

There was a very broad interval of HR_{peak} values during CPET for basketball players. We suggested that broad interval of HR_{peak} values was associated with termination reasons. Part of investigated subjects finished testing due to fatigue of leg muscles, but their cardiovascular adaptation was not marginal.

It is difficult to compare pulmonary ventilation at peak of exercise because we did not find any sources regarding pulmonary ventilation values in basketball. But we can conclude that pulmonary ventilation was not a reason to terminate testing for any investigated subject.

As work physiology canons have described, oxygen consumption and heart rate increase linearly with exercise intensity (1, 3). It could be consequent to find linear correlations between those parameters and define linear regressions for investigated subjects.

There were significant correlations between HR and other main variables of cardiovascular stress tests at anaerobic threshold as showed in Table 2. At peak of exercise we cannot confirm similar correlations.

Possible explanation of this pattern might be disappearing of linear response in the final stages of stress testing. In general, we can confirm linearity of rela-

Table 3. **Peak oxygen consumption in male basketball players**

Source	n	Value (ml/min/kg)	Remarks
Crisafulli et al. 2002, (9)	n=8	45.3±8.2	Italian C2 league players, field test using portable gas analyser
Hoffman, 2003, (8)	n=?	42–59	n. d. a.
Apostolidis et al. 2003, (12)	n=13	51.7±4.8	members of junior's national team, treadmill ergometry using breath-by-breath system
Pipe, 2003, (13)	n=?	50–55	n. d. a.
Laplaud et al. 2004, (11)	n=8	44.1±6.5	members of French professional club, cycle ergometry using breath-by-breath system

n. d. a. – no details available.

tions between main parameters of oxygen transporting system below anaerobic threshold.

Linear regression of VO_{2AT}-VO_{2peak} for elite basketball players could be described as proposed in Fig. 2 but successful participation in male basketball requires some special features. As it is showed in Fig. 2, European champions were able to develop relative high (if compare with other investigated subjects) VO_{2peak} despite "early" anaerobic threshold.

As it is showed in Fig. 3 linear regression VO_{2peak}-P_{peak} is not valid (r^2=0.25) despite the fact that weak correlation was statistically significant. This fact is in accordance with conclusion of K. Wasserman and colleagues that estimation of oxygen uptake from work rate during exercise is potentially inaccurate (2). In contrast, the relative power correlated significantly with many most important variables of CPET (it is presented in Table 2). It seems that relationship between oxygen uptake and work rate is expressed more precise using relative power. We succeeded to describe linear regression VO_{2peak}-P_{rel} as it is showed in Figure 4.

How could we evaluate CPET results of European champions? In general, those people do not have any significant advantage in physical capacity. Interesting detail is a relatively high peak oxygen consumption despite early anaerobic threshold. Maybe it is indirect evidence of better tolerability for anaerobic loads? The cardiorespiratory and muscle metabolic capacities are prime actors on the performance scene but as data of European champions showed, direct conjunction between results of laboratory testing and performance in basketball is not so good tangible.

In conclusion, an investigation of physical capacity in adequate homogenous group of athletes could be expendable as standard values for elite basketball players. Further research is necessary to elucidate relations between physiological properties and performance in basketball.

Conclusions

An investigation of physical capacity in adequate homogenous group of athletes could be expendable as standard values and might be useful for monitoring and evaluating current and future players.

We cannot determine some advantages of European champions during cardiopulmonary testing except developed relative high peak oxygen consumption despite early anaerobic threshold.

Širdies ir kraujagyslių bei kvėpavimo sistemų atsako į maksimalaus krūvio mėginius modeliai vertinant profesionalių krepšininkų pajėgumą

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Raktažodžiai: ergometrija, krepšinis, deguonies pernaša.

Santrauka. Nėra visuotinai priimto ir standartizuoto tyrimų komplekso krepšininkų fiziniam pajėgumui įvertinti, todėl nėra ir krepšininkų fizinio pajėgumo normos.

Tyrimo tikslas. Nustatyti fizinio pajėgumo norminius dydžius profesionaliems krepšininkams maksimalios ergometrijos pagalba.

Medžiaga ir metodai. Tyrime dalyvavo 33 atletai profesionalai, kuriems atlikta veloergometrija nuosekliai didinant krūvį iki maksimalaus toleruojamo. Deguonies pernašos funkcijos tirtos diagnostine sistema VMAX229 su „Sensor Medics" dujų srauto analizatoriumi. Sudarytos deguonies sunaudojimo, širdies susitraukimų dažnio, minutinės ventiliacijos, išvystomos galios anaerobinio slenksčio ir maksimalaus toleruojamo krūvio metu. Galios, deguonies sunaudojimo, minutinės ventiliacijos ir širdies susitraukimų dažnio skaterogramose su 95 proc. pasikliautinojo vidurkio predikcijos intervalais atskirai, kaip sėkmingo žaidybinių savybių ugdymo pavyzdžiai, pažymėti dviejų 2003 m. Europos vyrų krepšinio čempionato nugalėtojų duomenys.

Rezultatai. Pateikti šios sporto šakos sportininkams būdingi deguonies sunaudojimo, širdies susitraukimų dažnio, minutinės ventiliacijos, išvystomos galios rodikliai. Nustatytos tiesinės priklausomybės tarp minėtų rodiklių anaerobinio slenksčio metu, tačiau maksimalaus krūvio metu tokios priklausomybės neišlieka.

Išvados. Tyrimo duomenys galėtų būti kaip norminiai dydžiai šios sporto šakos atstovų atrankai bei sveikatos stebėsenai. Nepaisant „ankstyvojo" anaerobinio slenksčio, Europos čempionai išsiskyrė santykinai dideliu maksimaliu deguonies sunaudojimu. Jokių kitų Europos čempionų pranašumų krūvio testų metu aptikti nepavyko.

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