Technologies of Effective Training Control in Amateur Triathlon
Non-Invasive Hemodynamic Measurements and Exercise Testing for Accurate Training Prescription

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Abstract: Although issues of training in professional triathlon are well highlighted and studied, the approach to supply, including medical-pedagogical aspects, still remains under debates in amateur triathlon. The intensity and volume of exercise loads in amateur triathlon tend to those in professional sports, whereas there is no consensus on efficient training strategy for active individuals engaged in amateur endurance sports. The objective of the study was to define the role of cardiovascular testing in training program design in amateur triathlon. Twenty-four healthy active male amateur triathletes aged 26-43 years participated in the study. Four trials of testing (hemodynamics and gas-exchange monitoring) were conducted to justify the amendments to training schedule. Based on significant differences of initial hemodynamic parameters (SV, SI, EDV, EDI) subjects were divided into 2 groups. Determining of the weak aspects of their functional state enabled to develop an efficient training schedule at the ongoing experiment stages. The obtained results of the final testing showed significant increase in VO_{2max}, maximal power (P_{max}) in cycling stress-test and LV volume characteristics in amateur triathletes.

1 INTRODUCTION

Triathlon is known as a multiple-stage competition. It involves three endurance disciplines: swimming, cycling, and running (O'Tool, 1995). Originated in the beginning of the 20th century, it started the Olympic history in 2002. In our days the International Triathlon Union (ITU) consolidates 119 national federations with more than 100 thousand of triathletes. But what is more interesting, social phenomena of triathlon popularity has non-sportive background: triathlon is a new form of reply to mid-life crisis. The explanation is quite easy: participating in triathlon is a great opportunity to change oneself and to become a legend. Nowadays middle-aged people come in amateur triathlon to find something challenging but available.

Although population of healthy individuals engaged in amateur sports gradually increases, there is quite a broad range of possible health issues that need to be considered. Considering that professional athletes are provided by high-quality assistance and medical-biological supply, aimed to minimize the possible medical risks (Corrado, 2005), amateurs' health and well-being are on their own responsibility. As their training intensity and volume almost come up to professional sport, hence it is critically important to prescribe trainings with reasonable accuracy.

Stated above enabled us to formulate the aim of the study – to estimate the efficiency of stage functional testing based on non-invasive hemodynamics measurements and exercise testing for accurate and correct training prescription.

2 ORGANIZATION AND METHODS

Subjects. Twenty-four healthy male amateur triathletes aged 26-43 (mean age 33.8±4.74 years, height – 181±5.66 cm, body mass – 80.8±8.86 kg) were recruited for the study. The participants of the study had no professional sports background. All subjects were free of cardiovascular or any other chronic disease. The investigation conforms to the principles of the Declaration of Helsinki of the World Medical Association. Athletes had been informed of the procedures, methods, benefits and possi-

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ble risks involved in the study before their written consent was obtained. The study was approved by the Ural Federal University Ethics Committee.

Research Design. Participants were divided into 2 groups according to initial functional state, evaluated by means of hemodynamic measurements. The experiment was carried out from December 2015 to August 2016 and included four consecutive trials of hemodynamics and gas-exchange measurements (Table 1). Testing schedule was based on training periods. All tests were conducted in the laboratory “Sports and health technologies” of the Institute of Physical education, sports and youth policy, UrFU.

Exercise Testing. All athletes underwent 12-lead ECG before exercise testing (ET). To evaluate aerobic capacity of athletes, the stress-system Schiller AG Cardiovit AT-104 (Schiller AG, Switzerland) was used. The maximal ramp cycling test protocol was applied in accordance with ACC/AHA 2002 guideline update for exercise testing (2006). VO_{2max} was determined by indirect calorimetry with the use of portable desktop metabolic system FitmatePro (COSMED, Italy). After a 1 min warm-up, subjects started at zero load, continuously increasing by 40 W per minute until exhaustion in order to determine HR_{max}, VO_{2max}, maximum attained load (P_{max}), VE_{max}, anaerobic threshold (AT). Heart rate monitoring was carried out with Garmin Forerunner 305 (Garmin, USA) during the test and immediate post-exercise period (5 minutes).

2.1 Hemodynamic Measurements

The hemodynamic monitor MARG 10-01 "MicroLux" (Chelyabinsk, Russia) is usually used in emergency and operation rooms. The device functioning is based on such noninvasive methods of hemodynamic monitoring as impedance cardiography and spectrophotometry, electrocardiogram monitoring (ECG), pulse oximetry monitoring, reography and central hemodynamics monitoring, blood pressure and temperature.

Measuring Methods. For the experiment a patient (athlete) was in supine position. Before recording all subjects were at rest in supine position during 10 minutes. All measured indicators of the central hemodynamics were automatically registered with 8 ECG electrodes by MicroLux software with beat-to-beat record.

Central hemodynamic indicators are presented in four groups: perfusion (stroke volume, cardiac output, stroke index, cardiac index), preload (end-diastolic volume, end-diastolic index), afterload (the index of total peripheral resistance, stroke index of total peripheral resistance), contractility and left ventricular activity (contractility index, ejection fraction; index of left ventricle activity, stroke index of left ventricle (LV) activity). To investigate the functional state of young athletes we chose the most informative for endurance athletes’ hemodynamic indicators and indices (Shishkina, 2013):

Heart rate (HR, bpm) is the most accessible and informative indicator of the development of athletes’ cardiovascular system; *stroke volume (SV, ml)* values should be a reference point in examining athletes in endurance sport; *stroke index (SI, ml/m^2)* is the ratio of stroke volume to body surface area; *end-diastolic volume (EDV, ml)* is the maximum amount of blood received in left ventricle at the end of diastole; *end-diastolic index (EDI, ml/m^2)* is the ratio of end-diastolic volume to the body surface area in square meters; *end diastolic volume* provides sufficient stroke volume and cardiac output and is the guarantor of good tolerance to high intensity load in training and competitive activities; *ejection fraction (EF, %)* changes from 57 to 65 and serves as an indicator of fitness level as well as the intensity of previous training process.

Hemodynamics is described by three general indicators: volemia, inotropy, vascular tone. The above-mentioned indicators are shown at the monitor as a percentage of normal values. The deviations of more than 25% are considered too high/low in healthy people.

2.2 Cardiovascular Monitoring during Exercise Test

Maximal cycling test is commonly used in assessment of physical fitness and aerobic capacity. It is quite informative, relatively safe and easy reproducible. Gas-exchange measurements during stress-test enabled to obtain important information on athletes’ aerobic capacity (Vilikus, 2012) and accurate values of metabolic changes under stress conditions.

The following parameters were simultaneously and continuously recorded during exercise testing: oxygen consumption (VO_2, ml/kg/min), heart rate (HR, bpm), systolic blood pressure (SBP, mm Hg), diastolic blood pressure (DBP, mmHg), cycling load(P, W), respiratory ventilation (VE, l/min).

Table 1: Experiment schedule design.

	December 2015	March 2016	June2016	August 2016
Hemodynamic monitoring	*	*	*	*
The training focus selection	*	*	*	
Exercise testing		*	*	*

Immediate post-exercise measurements of HR, SBP and DBP during 5 minutes of recovery period were recorded. The current values of all measured parameters were demonstrated on the metabolic analyzer screen and saved in the device memory for ongoing analysis.

VO_{2max} and P_{max} are the values of maximal oxygen uptake and attained load the athlete could reach. It characterizes an athlete's integral readiness. In stress-test HR_{max} is an indicator of the priority in the cardiovascular or muscle fitness: if HR_{max} is lower than 180 bpm, then there is cardiovascular priority. And there is a priority of the muscular system in "heart-muscle balance" if HR_{max} is higher than 200 bpm. VO_{2max}, P_{max} and HR_{max} allow us to determine the limiting factors of athlete's performance (Seluyanov, 2002). According to modern concepts in cyclical sports physical workability can be largely limited by either cardiorespiratory system or muscular system.

2.3 Statistical Analysis

The statistic software package "SPSS Statistics 17.0" (IBM) was used for statistical analysis. Mean value (M) and standard deviation (SD) for the used parameters were calculated, t-test was applied for comparative analysis. The level of significance was set at $P < 0.05$. Pearson and Spearmen correlations between measured parameters were calculated. Two-way ANOVA was applied to estimate the impact of particular hemodynamic indices on aerobic capacity and athletes' exercise performance.

3 RESULTS AND DISCUSSIONS

The descriptive analysis of hemodynamic data was performed to define the weak aspects of athletes' functional state (Table 2). Thus it was found, that:

i) values of measured parameters varied within a certain range; ii) mean values of volume parameters and cardiac indices were lower in reference to athletic norm.

Based on stated above data from the 1st stage of the proposed study, a group of triathletes was divided into two groups by the criteria of LV volume characteristics. It was supposed that the leading parameter in endurance sport was SV (Zakharova, 2015), as a volumetric indicator, also characterising LV contractility and heart functional reserve.

Table 2: Hemodynamic parameters at the first stage.

Hemodynamic indices	Athletic norm	M±SD (min-max)
HR at rest, bpm	50-55	62.0±5.95 (51-71)
SV, ml	120-150	113.0±15 (90-131)
SI, ml/m^2	>70	58.8 ±7.96 (50-73)
EDV, ml	>190	177±25.1 (144-210)
EDI, ml/m^2	>100	90.67±14.9 (65-115)
EF, %	≥60	63.0±2.04 (60-66)
Volemia, %	+21	-20-+21
Inotropy, %	> +35	16.36±13.1 (0-+50)
Vascular tone, %	< – 30	-15.41±12.6 (0- -43)

The 1st group (n=16) was distributed by athletes with SV < 115 ml, and the 2nd group (n=8) – with SV ≥ 115 ml, respectively. Table 3 demonstrates the results of comparative analysis of initial hemodynamic parameters in both groups and significant differences in selected parameters.

Table 3: Comparative analysis (t-test) of hemodynamic parameters in groups at the first stage.

Hemodynamic indices	M±SD	
	1st group	2nd group
HR at rest, bpm	62.33±4.76	61.67±7.4
SV, ml	100.33±9.3	125.5±5.5**
SI, ml/m^2	54.4±4.34	65.67 ±6.3**
EDV, ml	157.3±15.7	197.2±13.7**
EDI, ml/m^2	85.67±7.53	95.67±19.28
EF, %	62.83±1.9	63.17±2.32
Volemia, %	5+16.7	6+10.95
Inotropy, %	6.67±15.01	20±15.81
Vascular tone, %	-8.3±8.16	-22±12.77*

*- statistical significance at $P < 0.05$, ** - $P < 0.01$.

Before the 1st stage testing trainer's concept of week training was designed around 2 intensive workouts per week of 5 or 6 training days. On Wednesday triathletes usually had repeated short sprints on track training accompanied with building whole body and core stability by holistic explosive power training. Sunday training was long and took place principally on highly broken country.

After the primary testing and measurement analysis several corrections were offered for the first group training program design. The training process of the athletes with low heart volume indicators was supposed to be low intensive (HR=120±10). Sport walking, cycling, skiing on flat terrain, stationary bicycle training were recommended for low intensive endurance training in order to increase heart volumetric parameters. The objective of the trainings was to improve dimensional characteristics of the heart and cardiovascular adaptation to physical loads. The idea is that while HR is 120±10 bpm the stroke volume tends to its maximum and provides LV with better diastolic filling.

Based on the obtained data and defined weaknesses of participants the training focus selection was made: the 1st group was prescribed low intensity training. The training strategy of the 2nd group was a combination of short intervals at high-intensity trainings and statodynamic low intensive strength workouts (Seluyanov, 2002), high volume trainings were excluded.

The second stage of the study included hemodynamic measurements, exercise performance evaluation and amendments to the training strategy as the results of functional state evaluation demonstrated no significant changes in major parameters in both groups. 2.5 months of amateur athletes efforts were without results.

The conducted further correlative analysis enabled us to estimate the relations between hemodynamic parameters and exercise performance. It was found that VO_{2max} correlated with $HR_{at\ rest}$ (r=-0,48; P < 0.01), SV (r=0.578; P < 0.01), SI (r=0.56; P < 0.01), EDV (r=0.56; P < 0.01), as well as with P_{max} (r=0.676; p<0.01). Positive correlations between volume indices and aerobic capacity may serve as a proof of better cardiovascular adaptation to exercise loads and effectiveness of heart function in athletes with the increased LV volume and contractility.

Impact of P_{max} on both the exercise performance and cardiac functional state indices was estimated by factor analysis results. It was found that factor P_{max} had significant impact on variables VO_{2max} (P < 0.001) and EDV (P < 0.001).

Thus, it was found out that specific strength development and, hereafter muscular endurance improvement may significantly influence on VO_{2max}, i.e. on performance endurance in amateur triathletes (Cormie, 2011; Caleb, 2015).

The training guidelines for the next training period of triathletes (March-May) was rather different. The second group for maximal power production enhancement were subjected strength training for hypertrophy (7-12 reps at 60-80 percent of 1 RM, three sets per exercise, 2 session per week, 3 weeks). Aerobic middle- and low-volume trainings with triathlon – specific activities were used to maintain the technique, improve movement pattern and keep the aerobic capacity.

In April and May there was high-volume training for metabolic adaptations, movement efficiency and nerve system tolerance to enduring work. The power training component was presented by HIIT overall strength exercises, mainly with plyometric nature. Ballistic and TRX training were included for core stability and psychomotor training as a great stimulus for improving maximal power in complex triathlon movements.

For the 1st group athletes low intensive strength training (Seluyanov, 2002; Shishkina, 2013) aimed on hypertrophy of slow-twitch muscles was used instead of intensive strength one. The main idea of exercises performance is doing them slowly without leg (arm, back) extension feeling "fire" in muscles thus organizing specific state for hypertrophy in slow-twitch motor units.

The aerobic and strength components in April and May were the same as in the 2nd group but there was the task to limit HR, not exceeding 180 bmp during workouts.

In June-August there were more high-intensity training in both groups. A short-term period of high-intensity interval training (2 per week) consisting of repeated exercise bouts performed close to or well above the maximal oxygen uptake intensity, interspersed with low-intensity triathlon activities.

Also thanks to participation in triathlon and other competitions amount of prolonged submaximal exercise and moderate and long periods of training "threshold" formed 10-15% of total training volume.

After 3 months of training the final testing including hemodynamic research and exercise testing was carried out. Fig.1 and 2 demonstrate the results of analysis of initial and reached values (4th stage – August 2016) of exercise performance. One can see that athletes from both groups had positive changes in VO_{2max} and power production. Moreover, participants from the 1st group also attained the values of aerobic capacity with no significant difference in comparison to the 2nd group.

One can see that athletes from both groups had positive changes in VO_{2max} and maximum power. Moreover, participants from the 1st group also

Table 4: Hemodynamic parameters at the first and final stage.

Parameter	M±SD			
	1st group		2nd group	
	Initial	Final	Initial	Final
HR at rest, bpm	62.33± 4.76	62.62± 9.74	61.67± 7.4	57.67± 11.55
SV, ml	100.33±9.3	112.5± 15.61*	125.5± 5.5	121.5± 7.78
SI, ml/m²	54.4± 4.34	55.88± 7.36	65.67 ±6.3	59.67± 6.11
EDV, ml	157.3± 15.7	176.13± 26.97*	197.2± 13.7	187± 25.46
EDI, ml/m²	85.67± 7.53	88.38± 12.1	95.67± 19.28	92.33± 11.15
EF, %	62.83± 1.9	63.5± 1.41	63.17± 2.32	63.3± 1.5
Volemia, %	5+16.7	-1.5± 23.5*	6+10.95	3.3± 21.5
Inotropy, %	6.67± 15.01	3±14.47	20±5.81	21.67± 2.89
Vascular tone, %	-8.3± 8.16	3±14.47	-22± 12.77	-19± 11.53

* - Significant differences between hemodynamics parameters at the 1st and 4th stage $P < 0.05$.

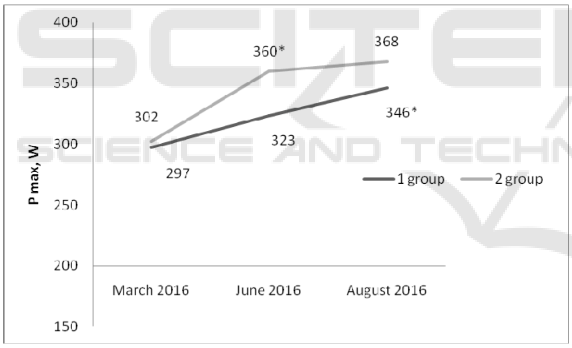

Figure 1: Maximal attained load (P_{max}) during exercise testing at 3 consecutive stages.

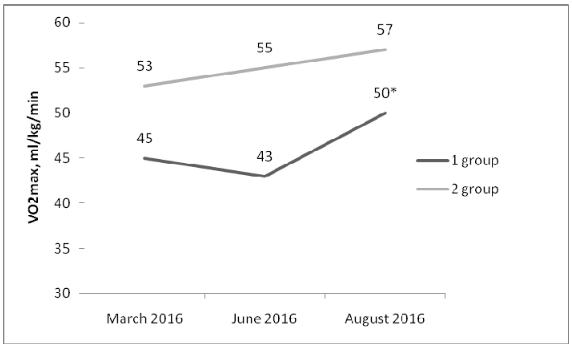

Figure 2: VO_{2max}(ml/kg/min) value obtained during exercise testing at 3 consecutive stages.

attained the values of aerobic capacity with no significant difference in comparison to the 2nd group (Table 4).

4 CONCLUSIONS

Cardiovascular functional state monitoring enables to define the main strategy for training prescription. Combination of hemodynamic and gas-exchange measurements with simultaneous HR registration during exercise testing provides with valuable information for developing a training concept. It is useful for both correct physical loads dozing and sufficient cardiac adaptation to increasing exercise loads, thus it aids amateur athletes to benefit from sports activity and minimize possible medical risks.

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