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Abstract: Background/Objectives: The purpose of the proposed study is disclosure of correlations between the dynamics of the Breathe Rate (BR) and Heart Rate (HR) when performing the intermittent physical operation at maximum power on a cycle ergometer. **Methods:** The stage on the study of the General functional athlete readiness (GFAR) performed using the sports standard "Red Engine" and the cycle ergometer in 16 volunteers (10 men, 6 women) whose average age was 21±1.17 years. To determine the sports potential of the volunteers in this study, we used own Coefficient of Anaerobic Capacity (CANAC Q, beats). Continuous recording of the heart rate and respiratory rate of volunteers in the maximum power sports test was carried out by the "RheoCardioMonitor" device with an athlete functional readiness module based on the method of Transthoracic electrical impedance rheography (TEIRG). **Results:** The degree of correlation of functional indicators (M, HR_M, GFAR) with CANAC Q for the group in full (n=80) occurred at a very high level, which confirmed the effectiveness of using the Coefficient of Anaerobic Capacity (CANAC Q) in assessing the general functional athlete readiness of the volunteers. **Conclusions:** CANAC Q measured in "beats" of the heart and recorded very accurately using the method of transthoracic electrical impedance rheography (TEIRG). For this reason as promising sports PSM-system, CANAC Q can replace the methods for determining the functional athlete readiness by blood lactate concentration and maximum oxygen consumption.

Keywords: sport; heart rate; breathe rate; monitoring; functional athlete readiness; impedance; rheography

1. Introduction

Physiological state monitoring (PSM-systems) is an IT systems used to record various physiological parameters of the human body.[1] The purpose of the PSM-systems is to monitor the viability of a person in extreme conditions (diseases, injuries, extreme physical exertion, etc.)[2]

Generally accepted that the degree of the person's efficiency in the terms of high intensity and tension (sports of high achievements, extreme activities, etc.) determined by complex interactions of the following components: 1) Health condition; 2) Physical (athletic) shape; 3) Technical (special) education; 4) Psychological motivation (morally volitional qualities).

For the clear understanding interactions of these components in athletic pedagogy, the term "Functional Athlete Readiness" is used.[3]

The concept of "Functional athlete readiness" (FAR) has a very complex and multifaceted context.[4]

The FAR may be defined as a relatively settled state of the organism, determined by the level of development of key functions required for the certain sport, as well as their specialized properties that directly or indirectly determine the effectiveness of the competitive activity.[5]

The FAR divided into two types:
a) General functional athlete readiness (GFAR), which characterizes the general physical development and endurance;
b) Special functional athlete readiness (SFAR) depending on the kinds of sport.

2. Methods
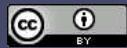
During 2015-2017 Bauman Moscow State Technical University together The University of Alabama (USA) was carried out a scientific project "A study of applicability of a breathing sensor PACT2.0 in determination of aerobic-anaerobic potential of professional athletes (junior ice hockey player)". This study has been approved by the Institutional Review Board for the protection of human subject request for approval of research involving human subjects (IRB Protocol #15-024-ME 2015/12/14), as well as by the Decisions of the Ethics Committee of Bauman Moscow State Technical University No.1 from 2015/11/11 and No.2 from 2016/10/01).

The purpose of this study was disclosure of correlations between the dynamics of the Breath Rate (BR) and Heart Rate (HR) when performing the intermittent operation at maximum power on a cycle ergometer.

The study allowed to determine anaerobic capacity of sportsmen in the framework of their general functional athlete readiness and to evaluate feasibility of developing a sports methodology for diagnostics the state of syndrome chronical overexertion of the heart.

The necessity for this research determined by current requirements of the strategical item of a coach the information about how professional athletes in team kinds of sport (hockey, football, handball, basketball, etc.) match each other in speed-strength qualities with a determination of a possibility for their mutual substitution without loss of a game quality during competitive cycles.

Developed during this study the original PSM-system named the sports standard "Red Engine".

The "Red Engine" solves the global problem in the determination of the individual dynamic of changes in the levels of functional readiness of each sports team member, that allows effectively to maintain high levels of team efficiency in the whole during a competitive macrocycle.

The convenience of this sports functional testing is that it held directly in the conditions of a stadium without involving any complex diagnostic medical equipment.

The heart rate (HR) most often used as a load intensity evaluation criterion in sports.

There is a linear relationship between heart rate and training intensity.[6]

Often, endurance trainings (aerobic exercises) performed by the athletes at the heart rate of about 180 beats per minute (bpm). However, for many athletes this heart rate significantly exceeds their personal aerobic-anaerobic transition area.

Therefore, for calculate training intensity and monitor an athlete's functional state must use him Resting heart rate (HR), Maximum heart rate (HR_{max}), Reserve heart rate (HR_R) and Target heart rate of the transition to completely anaerobic zone (HR_M).

HR_{max} is the maximum number of contractions that the heart may be made within one minute. After twenty years, HR_{max} gradually begins to decline by about one beat per year. So HR_{max} is calculated by the following formula[7]:

$$HR_{max} = 220 - The\ Age\ (years) \qquad (1)$$

For the calculation of the load intensity is also used the method of heart rate reserve (HR_R), which was developed by Finnish scientists Karvonen. HR_R is the difference between HR_{max} and HR rest (HR_0):

$$HR_R = HR_{max} - HR_0 \qquad (2)$$

Knowing the HRR, you can calculate the target of the heart rate (HR_M). Target heart rate (HR_M) is the optimal heart rate, characterizing the transition in the clear anaerobic zone during the intensity of the performed exercise M (%):

$$HR_M = HR_0 + M \times HR_R \qquad (3)$$

At the same time, knowing HR_0 and HR_{max}, according to the Karvonen's formula, it is possible to calculate with what intensity (M) the athlete performs the exercise:

$$M = (HR\ during\ exercise - HR_0)\ /\ (HR_{max} - HR_0) \times 100\% \qquad (4)$$

Thus,

$$M = (HR\ during\ exercise - HR_0) / (220 - Age - HR_0) \times 100\% \qquad (5)$$

The sports standard "Red Engine" was created for a functional testing of the professional athletes during training camps and competitions. The basis of this functional testing is registration of different biometric and anthropometric indicators with the further complex of very difficult mathematical processing.

Based on results of the sports standard "Red Engine", make an individual biomedical program and including recommendations (**Figure 1**):

1) Additional work or rest during educational training camp;
2) Preventive measures;
3) Using of the selective methods of restoring the functions of ATP-system, Aerobic- and Anaerobic-system;
4) Plan of correction of a medical and biological providing and a pharmacological protection in extreme conditions of sport.

«Ice test – 5×54 m», Russian ice hockey junior (18) women's team, 2014/11/04

№	Name	HR start	HR max	M, %	t, s	HRм	ATP-system	Aerobic-system	Anaerobic-system	General adaptation	Adaptation to Special Ice Work	Sports recommendations
1	Белоглазова Дарья	138	174	68,74	46,66	142	5	4	5	4	3,1	Poor motivation.
2	Водопьянова Елена	146	188	81,18	48,63	162	4	2	4	3	2,6	Requires an increase in aerobic work.
3	Канаева Диана	121	180	73,86	47,8	150	5	4	5	3	3,1	Poor motivation.
4	Кадирова Фануза	103	181	74,17	44,33	152	3	5	5	3	3	Poor ATP-system.
5	Штарёва Алевтина	109	179	74,85	46,86	148	4	2	5	3	2,6	Requires an increase in aerobic work.
6	Шохина Анна	130	182	76,10	44,93	153	4	3	4	3	2,7	Requires an increase in aerobic work.
7	Добродеева Екатерина	160	184	75,68	48	157	4	5	4	4	3,2	Poor motivation.
8	Надеждина Мария	103	166	67,47	50,85	130	4	2	5	3	2,4	Requires an increase in aerobic work.
9	Рахимова Алсу	128	179	75,00	47,21	148	4	2	5	3	2,6	Requires an increase in aerobic work.
10	Дорофеева Маргарита	150	188	77,46	49,48	163	4	4	5	3	3,1	Poor motivation.
11	Фалякова Ландыш	101	172	67,57	46,36	140	4	5	4	5	3	Poor motivation.
12	Лихачёва Екатерина	146	171	67,76	47,32	138	5	4	5	4	3	Poor motivation.
13	Верховцева Карина	127	178	71,23	43,83	148	4	4	5	3	2,8	Poor motivation.
14	Кокошкина Мария	130	163	60,14	46,13	128	5	4	5	3	2,6	Poor motivation.
15	Коротких Кристина	140	177	72,61	48,06	146	4	3	5	3	2,7	Requires an increase in aerobic work.
16	Ганеева Лиана	132	182	74,83	47,8	154	4	5	5	4	3,4	Poor motivation.
17	Зубок Дарья	140	191	80,27	46,81	168	5	5	4	5	3,8	Adapted.
18	Пирогова Нина	120	189	80,98	45	164	4	2	5	3	2,8	Requires an increase in aerobic work.
19	Середина Дарья	142	178	73,58	50,52	147	4	3	5	3	2,8	Requires an increase in aerobic work.
20	Боброва Светлана	140	177	66,94	46,56	147	5	3	5	3	2,8	Requires an increase in aerobic work.
21	Гамова Мария	117	182	76,10	49,17	153	4	3	3	3	2,5	High risk of failure of adaptation.
22	Климкина Анна	120	168	67,90	47,88	133	5	3	4	3	2,5	Requires an increase in aerobic work.
23	Лобова Екатерина	116	176	72,84	46,59	144	3	3	4	2	2,2	Requires an increase in aerobic work.
24	Роднова Елизавета	123	178	72,15	48,75	148	4	5	5	4	3,2	Poor motivation.
	Averages on team	128	178	73	47,3	148	4,2	3,5	4,6	3,3	2,8	

M, % - intensity of ice work; **t, s** - time of run «Ice test»; **HRм** - heart rate transition of the mixed zone to the anaerobic zone

(green)	- very well	(blue)	- middling
(yellow)	- good	(red)	- bad

Figure 1. Pedagogical interpretation of the sports standard "Red Engine" results.

3. Results

The created sports standard "Red Engine" turned out to be very effective in the training of professional athletes. The "Red Engine" was validation by the methods for determining the athlete functional readiness by blood lactate concentration and maximum oxygen consumption.

However, it requires the use of special software that is not available to a wide audience of users. For this reason, we decided to simplify this method in the diagnostic variant of study only General functional athlete readiness.

The stage on the study of the General functional athlete readiness (GFAR) performed using the sports standard "Red Engine" and the cycle ergometer in 16 volunteers (10 men, 6 women) whose average age was 21±1.17 years. All volunteers were members of our University sports club.

Using test based on the achievement by athletes of the maximum power of muscle load in five series of 45′′, in which the heart rate rises to maximum values, followed by recovery pauses of 90′′.

To determine the sports potential of the volunteers in this study, we used own Coefficient Anaerobic Capacity (CANAC Q, beats):

$$Q = \sqrt{\frac{HR_{start}}{BR_{start}} \cdot \frac{HR_{finish}}{BR_{finish}}} \qquad (6)$$

Continuous recording of the heart rate and respiratory rate of volunteers in the maximum power sports test was carried out by the "RheoCardioMonitor" device with an athlete functional readiness module based on the method of Transthoracic electrical impedance rheography (TEIRG).[8–12]

The method of Transthoracic electrical impedance rheography, which allows registering (allows to register) the frequency characteristics of the volunteer's bioimpedance response on the sport test of maximum power, thereby simultaneously recording the characteristics of his productive work of the heart channel, the effectiveness of the blood gas transport function, as well as to reliably assess its reactivity and adaptive potential.[13]

In technical terms, the "ReoCardioMonitor" system represents a two-channel impedance-measuring converter, a patient's cable system. The first channel designed to measure the transthoracic impedance of the chest (base and pulse components, impedance-breathing pattern) with an ECG measurement channel from the same impedance electrodes. The transthoracic channel used to calculate stroke output and cardiac output. The second channel measures breathing pattern.[14]

The measurement method is tetrapolar. A source that creates an alternating current of high frequency connected to the current electrodes. The signal recorded from potential electrodes. With an increase in the distance between the current and potential electrodes, their influence on each other decreases and the accuracy of the measurement result increases.[13]

The use of such a scheme for applying electrodes ensures greater uniformity of the current passing through the investigated area and reduces the effect on the measurement result of resistance variations at the electrode-skin interface.[14]

Contact with the patient's body was provided with disposable ECG electrodes of the White Sensor 4500 made "Ambu" company, electrode size 50×48 mm. The inner electrodes, marked in blue in the diagram, are measuring and registering the voltage change $\Delta U(t)$, which is used to calculate and register the impedance signal dZ. External electrodes are required to pass AC ~ I with high frequency and low amplitude. The change in impedance is recorded as a function of time Z(t).

Classification of the studied functional indicators shown in **Table 1**.

Table 1. Classification of the studied functional indicators.

Indicators	Result	Score
The intensity of the performed exercise (M, %)*	≥ 85	A
	80-84.9	B
	75-79.9	C
	≤ 74.9	D
Target heart rate of the transition to completely anaerobic zone (HR$_M$, bpm)*	≥ 171	A
	161-170	B
	151-160	C
	≤ 150	D
General functional athlete readiness (GFAR, units)*	≥ 3.5	A
	3.0-3.4	B
	2.5-2.9	C
	≤ 2.4	D
Coefficient Anaerobic Capacity (CANAC Q, beats)	≥ 10.1	A
	7.5-10	B
	5.5-7.4	C
	≤ 5.4	D

* - classification of Russian Ice Hockey Federation.[4.]

4. Discussion

The results of the study (**Table 2**) measure the low levels of the General Functional Athlete Readiness of volunteers: on average GFAR=2.5 units (Score "C") were in all test series. Professional athletes must have a GFAR of at least 3.5 units.

Table 2. Results of the study of the General Functional Athlete Readiness with using the method "Red Engine" in all series.

Indicators	1st series	2nd series	3rd series	4th series	5th series
HR_{start}, bpm	102,8±13,6	137,1±15,7	144,4±17,9	148,2±15,1	152,1±16,2
HR_{finish}, bpm	158,4±15,7	167,9±14,7	173,1±11,9	173,9±11,6	176,8±11,9
BR_{start}, rpm	17,1±6,9	19,4±4,7	22,1±5,7	23,4±4,7	24,1±6,0
BR_{finish}, rpm	33,7±6,5	35,1±5,1	37,6±7,2	39,5±7,9	40,0±7,6
M, %	66,7±8,4	65,9±7,2	67,7±5,9	67,2±7,1	68,4±7,0
HR_M, bpm	129,5±18,1	134,7±17,4	134,7±17,4	140,1±15,7	143,4±15,7
GFAR, units	2,51±0,70	2,48±0,63	2,59±0,64	2,54±0,60	2,61±0,57
CANAC Q, beats	5,7±1,29	5,9±0,87	5,7±1,13	5,4±0,92	5,5±0,99

The value of the individual intensity (power) of the exercise (M) did not reach 70% (Score "D") in any of the test series. The threshold value of anaerobic metabolism (HR_M) does not go beyond 145 bpm (Score "D"). The professional sports quality level must at least 171 bpm.

Positive correlations of functional indicators (M, HR_M, GFAR) with the Coefficient of Anaerobic Capacity (CANAC Q) were registered in the first two test series. However, during continuing series of work with increased power the correlations between the functional indicators began to destroy due to the pronounced fatigue of the volunteers (**Table 3**).

Table 3. The degree of correlation of functional indicators with CANAC Q in all series of the study.

Indicators	1st series	2nd series	3rd series	4th series	5th series
M, %	r=0,50	r=0,41	r=0,18	r=0,09	r=0,02
	p<0,01	p<0,01	p>0,05	p>0,05	p>0,05
HR_M, bpm	r=0,55	r=0,40	r=0,19	r=0,08	r=0,04
	p<0,01	p<0,01	p>0,05	p>0,05	p>0,05
GFAR, units	r=0,53	r=0,51	r=0,38	r=0,29	r=0,33
	p<0,01	p<0,01	p<0,05	p>0,05	p>0,05

The average maximum heart rate (HR_{finish}) of volunteers in all series could not overcome the mark of 170.0±14.8 bpm, although according to the Karvoner's formula, their maximum heart rate must reach 199 bpm. The heart rate start (HR_{start}) was 136.9± 23.7 bpm.

The maximum breath rate (BR_{finish}) also turned out to be excessively high 37.1±7.4 rpm. At the same time the breath rate start (BR_{start}) was 21.2 ± 6.2 rpm, which also indicates a very weak physical working capacity of this group of volunteers.

The average CANAC Q of volunteers in all series could not overcome the mark of 5.6±1.07 beats (Score "C").

The degree of correlation of functional indicators (M, HR_M, GFAR) with CANAC Q for the group in full (n=80) occurred at a very high level (**Table 4**), which confirmed the effectiveness of using the Coefficient Anaerobic Capacity (CANAC Q) in assessing the General functional readiness of an athlete.

Table 4. The degree of correlation of functional indicators with CANAC Q for group in full.

Indicators	Group in full (n=80)	Degree of correlation with CANAC Q
M, %	67,2±7,2	r=0,241; p<0,01
HR$_M$, bpm	137,5±17,1	r=0,237; p<0,01
GFAR, units	2,55±0,63	r=0,406; p<0,01

5. Conclusion

Thus, the results of the study showed a very low average level of the General Functional Athlete Readiness among university sports club volunteers when using the sports standard "Red Engine" (GFAR=2.55±0.63 units with the required level of more than 3.7 units). Moreover, the same result was obtained using a new sports indicator − the Coefficient Anaerobic Capacity (CANAC Q), which amounted to 5.6 ± 1.07 beats with the required level of more than 10.1 beats.

The fundamental idea of CANAC Q is calculating of the ratio of increase in heart rate (HR) to increase of breath rate (BR) during intensive physical activity: than less BR spent to achieve maximum heart rate, thereby will be higher the anaerobic capacity of athletes. CANAC Q measured in "beats" of the heart and recorded very accurately using the method of transthoracic electrical impedance rheography (TEIRG). For this reason, as promising sports PSM-system, CANAC Q can replace the methods for determining the athlete functional readiness by blood lactate concentration and maximum oxygen consumption.

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