REMOTE MONITORING OF ATHLETE'S BLOOD PRESSURE DURING TRAINING OR COMPETITION BASED ON ARTIFICIAL INTELLIGENCE ALGORITHMS

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Abstract

Research shows that professional athletes face various health risks. The most critical risk factor for athlete's health is arterial blood pressure (ABP). It is known that strength training can lead to a significant increase in ABP during the execution of exercise routines. During high-intensity exercise, ABP values are determined by the relationship between cardiac output and peripheral vascular resistance. During aerobic and dynamic exercise with low or moderate use of force (such as light running or cycling), the increase in cardiac output occurs with uniform intensity, while peripheral resistance decreases. Recent studies show that to determine ABP and heart rate (HR) in athletes, it is necessary to take into account the individual physiology of each athlete. The article describes the stages of the model and algorithm, as well as the software code for monitoring athlete's ABP and HR during training and competitions based on machine learning technology.

Key words: Saturation, machine learning, artificial intelligence, sports medicine, methodology, saturation monitoring model, algorithm, saturation monitoring hardware and software.

Introduction. Analysis of information obtained from long-term observations and scientific studies [1-5] shows that professional athletes face various health risks: muscle and bone injuries, excessive fatigue and fluid loss, risk of cardiovascular diseases (CVD) and mental disorders, etc. The most critical health risk factor for athletes is blood pressure (BP). Arterial hypotension (AH) as a physiological adaptation of the body to regular and intensive physical exertion is one of the components of the classic triad of "physiological sports heart": bradycardia, moderate dilation of the right chambers of the heart, and arterial hypotension. It is known that workouts involving strength exercises can lead to a significant increase in BP during the execution of the exercise complex. Remote monitoring of athlete's blood pressure during training or competition based on artificial intelligence algorithms can help to identify potential health risks in real-time and provide timely interventions to prevent serious health consequences.

Methodological basis for determining BP and HR. During high-intensity exercise, BP is determined by the balance between cardiac output and peripheral vascular resistance. During aerobic and dynamic exercises with low or moderate force utilization (e.g., light running or cycling), the increase in cardiac output occurs with a uniform intensity, while peripheral resistance decreases. Accordingly, diastolic pressure remains unchanged, while systolic pressure increases due to the uniform increase in stroke volume of the heart. Increasing physical exertion, such as uphill cycling, raises diastolic pressure due to the activation of muscle receptors and increases peripheral resistance. Statistical (isometric) forms of exercise cause a moderate increase in peripheral vascular resistance, cardiac output, and heart rate. Therefore, depending on the intensity of the exercise, the level of diastolic and systolic pressure is higher than during dynamic exercises. Breath holding under pressure during maximum short-term loads, such as weightlifting (heavy athletics), leads to additional pressure elevation. During this type of sport activity, BP readings can reach 320/250 mm Hg [2].

Normally, the normal arterial pressure for athletes depends on their age, physical activity, and health status. For adult athletes, normal arterial pressure ranges from 90/60 to 120/80 mm Hg. Scientific studies conducted in [6-12] have determined the following norms for blood pressure and heart rate (HR) for athletes and people who do not regularly engage in physical exercise (see Table 1).

Table 1.

Norms for Heart Rate and Blood Pressure in Athletes and Non-athletes Based on Age and Race.

Athlete 18-40 years old			
№	**Risk factors**	**Man**	**Woman**
1.	Genetics	Yes/No	Yes/No
2.	Disease history	Yes/No	Yes/No
3.	Total cholesterol	163.66+/-25.43 (125-200) mg/dl	163.66+/-25.43 (125-200) mg/dl
4.	HDL cholesterol	40< mg/dl	50< mg/dl
5.	LDL cholesterol	100> mg/dl	100 >mg/dl
6.	Body mass index	18.5—24.9	18.5—24.9
7.	Emotional stress	Yes/No	Yes/No
8.	Physical stress	Yes/No	Yes/No
9.	Smoking	Yes/No	Yes/No
10.	Nutrition	Yes/No	Yes/No
11.	Blood pressure	118+/-6.2 (<90 min, During rest: 140 max During exercise: 220 max)-72.4+/-2 (<70 min, During rest: 90 max During exercise: 85 max)	110+/-2 (<90 min, During rest: 140 max During exercise: 200 max)-70 (<70 min, During rest: 90 max During exercise: 80 max)
12.	Diabetes	5.9+/-0.5 (Before meals 4.1-5.9 mmol/L. After meals (90 minutes) up to a maximum of 7.8 mmol/L)	5.9+/-0.5 (Before meals 4.1-5.9 mmol/L. After meals (90 minutes) up to a maximum of 7.8 mmol/L)
13.	Sedentary lifestyle	Yes/No	Yes/No
14.	Medicine	Yes/No	Yes/No
15.	Alcohol consumption	Yes/No	Yes/No
16.	Climate	Favorable or not	Favorable or not
17.	Pulse	49-55 (60 min-100 max)	54-60 (60 min-100 max)

However, recent studies show that to determine blood pressure and heart rate in athletes, it is necessary to take into account the individual physiology of each athlete. In this regard, a number of methodological guidelines and manuals have been developed based on scientific research 8-14 for determining the individual physical condition, blood pressure, and heart rate of athletes.

One of these methods is the Letunov combined test. The basis of the test is the determination of the direction and degree of expression of shifts in basic hemodynamic indicators (heart rate and blood pressure) under the influence of physical loads of various directions, as well as the speed of their post-workout recovery (see Table 2).

Depending on the direction and degree of expression of shifts in heart rate and blood pressure, as well as the speed of their recovery, five types of reactions of the cardiovascular system to physical exertion are distinguished: 1. The normotonic type of reaction is characterized by a moderate increase in heart rate and maximum blood pressure, a slight decrease in minimum blood pressure, and an increase in pulse amplitude. The recovery of heart rate and blood pressure to their initial values is fast (i.e. within the specified rest intervals). The normotonic type of reaction is the most favorable and reflects good adaptability of the body to physical exertion. 2. The hypertonic type of reaction is characterized by a significant (inadequate to the load) increase in heart rate (up to 170-180 beats/min or more) and a significant (inadequate to the load) increase in systolic blood pressure (up to 180-220 mm Hg or more). At the same time, diastolic blood pressure also increases somewhat. The hypertonic type of reaction indicates a violation of the regulatory mechanisms that cause a decrease in the economy of the heart's work. This type of reaction is observed in chronic CNS overload, chronic overload of the cardiovascular system (hypertonic variant), and in pre- and hypertensive patients. 3. The hypotonic type of reaction is characterized by a significant (inadequate to the load) increase in heart rate with a slight increase in maximum blood pressure (or no significant changes in blood pressure) and a slow recovery of heart rate. This type of reaction is the most unfavorable.

Table 2.

Post-exercise changes in heart rate and blood pressure for different types of cardiovascular system reactions to the Letunov test 11.

Types reactions	The state of hemodynamic parameters				
	Heart rate	SBP_s	SBP_d	SBP_n	Recovery time
Compliant					
Normotonic after the 1rd load	Will increase by 60-80%	Increases by 15-30%	Decreases by 10-35%	Increases by 60-80%	Up to 3 min.
Normotonic after the 2nd load	Will increase by 80-100%	Increases adequately	Decreases by 10-35%	Increases by 80-100%	Up to 4 min.
Normotonic after the 3rd load	Will increase by 100-120%	Increases adequately	Decreases by 10-35%	Increases by 100-120%	Up to 5 min.
dystonic	Moderately increasing	Moderately increases (up to 180-220 mm Hg. Art.)	Listened to 0 "endless tone phenomenon"	He определяется	1-2 minutes - a variant of the norm

(SBP - normal range of fluctuations for maximum (systolic) blood pressure, DBP - normal range of fluctuations for minimum (diastolic) blood pressure, PP - pulse pressure - the difference between SBP and DBP, is an important indicator of the state of the circulatory system); - The Rufier test. The basis of the test is a quantitative assessment of the pulse reaction to short-term exercise and the speed of its recovery. The Rufier index is calculated using the formula:

$$\text{Rufier index} = \frac{(P_1+P_2+P_3)-200}{10}, \quad (1)$$

where P_1, P_2, P_3 represent the pulse rate at different periods of physical exertion on an athlete. According to this formula, the result is evaluated as follows: less than 0 - excellent; 0-5 - good; 6-10 - satisfactory; 11-15 - poor; more than 15 - unsatisfactory; - Harvard step test. Physical exertion is given in the form of stepping up on a stair. Functional readiness is evaluated using the Harvard Step Test Index (HSTI) formula:

$$\text{HSTI} = \frac{t*100}{(P_1+P_2+P_3)*2} \quad (2)$$

where t is the time of recovery in seconds; P_1, P_2, P_3 - pulse rate at 2, 3 and 4 minutes of recovery. According to this formula, the result is evaluated (see Table 3): less than 55 - low; 55-64 - below average; 65-79 - average; 80-89 - good; 90 and above - excellent.

Table 3.

Average values of the Harvard step test index depending on the sport [13].

Sports specialization.	HSTI	Sports specialization.	HSTI
Runners, cross-country runners.	111	Swimmers,	90
Cyclists,	106	Volleyball players	90
Skiers	100	Hurdle race	90
Marathon runners	98	Sprinters	86
Boxers.	94	Weightlifters.	81
Non-athletes.			62

The PWC170 test is used to determine physical performance by achieving a heart rate of 170 beats per minute (the power of physical activity is expressed in kg*m/min or watts). The formula used to calculate the power of work during the two-stage PWC170 test is:

$$PWC_{170} = N_1 + (N_2 - N_1) * \frac{(170-P_1)}{(P_2-P_1)} \quad (3)$$

where N_1 and N_2 are two loads of different power lasting 5 minutes each. Rest between loads is 3 minutes. P_1 and P_2 are the corresponding heart rates at the end of each load. The result is evaluated as follows: 14 or lower is low; 15-16 is below average; 17-18 is average; 19-20 is above average; 21-22 is high; 32 or higher is very high. Maximum oxygen consumption (MOC) values (in liters) calculated from the PWC170 indicators (kg/min) are presented in Table 4.

Table 4.

The relationship between PWC170 indicators and maximum oxygen consumption values (MOC) [8]

PWC_{170} (kg/min)	MPK (l)	PWC_{170} (kg/min)	MPK (l)
500	1,62	1500	4,37
600	2,66	1600	4,37
700	2,72	1700	4,83
800	2,82	1800	5,06
900	2,97	1900	5,32
1000	3,15	2000	5,57
1100	3,38	2200	5,57
1200	3,60	2300	5,66
1300	3,88	2400	5,66

The maximum oxygen consumption (MOC) is calculated using the formula:

$$MOC = 1{,}7 * PWC_{170} + 1240 \quad (4)$$

MOC = (VO2 max x 1000) / Body weight For highly trained athletes, the number 1240 is replaced with 1070 in the formula. There are also tests that measure the effect of temperature or breathing on the degree of blood pressure elevation and recovery time for athletes. - Cold pressor test (inducing arterial spasm). The essence of the cold pressor test is that when the forearm is lowered into cold water (+4 °C), there is a reflexive constriction of arterioles and arterial pressure increases, the degree of which depends on the excitability of vasomotor centers. - Breath-holding test with a timed delay. In a resting state, the subject's blood pressure is measured three times. Then the subject is asked to hold their breath for 45 seconds after taking a deep but not maximal inhale. - Robinson index (double product). This index characterizes the state of regulation of the cardiovascular system as well as the degree of nervous system tension. In addition, resting heart rate is an indicator of overall body condition and potential work capacity. It is determined by the following formula:

$$\frac{\textit{Robinson index}}{\textit{(double product)}} = \frac{\text{SBP}(n/min) * \text{DBP}_s(mm\ rt.st.)}{100} \quad (5)$$

Monitoring model for blood pressure and heart rate. Based on the methodology for determining blood pressure and heart rate, we will designate the stages of the monitoring model for an athlete during training and competition based on machine learning technology:

1. Collect data about the athlete, including age, gender, height, weight, health status, and medical history.
2. Install a blood pressure sensor on the athlete's body.
3. Determine the individual blood pressure and heart rate of the athlete at rest and during various levels of activity based on the above-mentioned methods.
4. Set up software to collect data from the blood pressure and heart rate sensors.
5. Create a training dataset containing information about blood pressure during training and competition.
6. Divide the training dataset into training and testing samples.
7. Build a quantum neural network using the TensorFlow library.
8. Train the neural network on the training dataset.
9. Evaluate the accuracy of the neural network on the testing dataset.
10. Use the trained neural network to monitor the athlete's blood pressure and heart rate in real-time.
11. Send a notification to the coach or medical staff if the blood pressure level goes beyond normal.
12. Analyze blood pressure data over time to identify trends and changes that may indicate potential health problems for the athlete.
13. Use the collected data to optimize training programs and prevent possible injuries and illnesses.

The software implementation of the blood pressure and heart rate monitoring system model in the Python programming language can be presented in the following form:

```
import time
import random
# Function to get a random value for blood pressure
def get_bp():
return random.randint(90, 140)
# Function to get a random value for heart rate
def get_hr():
return random.randint (60, 100)
# Main program loop
while True:
bp = get_bp()
hr = get_hr()
# We output the values of blood pressure and heart rate
print("Arterial pressure:", bp)
print("Heart rate:", hr)
# We are waiting for 5 seconds before the next measurement
time.sleep(5)
```

This software code generates random values for blood pressure and heart rate, displays them on the screen, and then waits for 5 seconds before the next measurement. When implementing the software code into a system, the functions get_bp() and get_hr() can be modified to use real values obtained from monitoring devices.

Conclusion. In conclusion, there is no universal formula for calculating normal blood pressure and heart rate for athletes during training and competitions, as this depends on many factors, including age, gender, type of sport, level of physical fitness, etc. However, healthcare professionals and coaches can monitor the physical condition of athletes during training and competitions using portable devices. It is also important to monitor overall health and body condition to avoid potential health problems. The use of modern artificial intelligence tools and techniques can improve many different aspects of sports medicine.

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