

Comparative Analysis of Functional and Pathological Changes in the Cardiovascular and Respiratory Systems of Athletes During Heat Stroke

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Abstract. *In modern sports, athletes are often exposed to intense physical loads in order to achieve high performance. When these loads are carried out in conditions of high temperature. When these loads are carried out in conditions of high temperature and humidity, they can cause significant functional changes in the body. In particular, in high-intensity sports such as basketball and football, more heat is produced in the body. At the same time, the body's ability to regulate temperature becomes more difficult, which affects the functional state of the cardiovascular and respiratory systems. Therefore, studying the effects of heat stress on the body in different types of sports in a comparative way is of great scientific and practical importance. The aim of the study was to determine the characteristics of changes in the cardiovascular and respiratory systems of basketball and football players under heat conditions, as well as their pathophysiological mechanisms. A total of 60 athletes aged 18–25 were included in the study. Physical load was modeled under conditions of high temperature and humidity. During the observation, main hemodynamic and respiratory parameters, heat balance, and metabolic state were assessed. The analysis showed that in response to heat stress, adaptive mechanisms in the body are activated. This is mainly expressed by increased strain on the cardiovascular system and faster breathing. At the same time, in some cases these adaptive mechanisms are not sufficient, leading to pathological changes such as hypovolemia, hyperthermia, rhythm disturbances, and metabolic imbalance. Differences between types of sports were mainly related to the nature and duration of physical load, as well as environmental conditions. Thus, the results show that the effects of heat stress on athletes are complex and may include both adaptation and harmful changes. Therefore, proper planning of training in hot conditions and the use of preventive measures are essential.*

Keywords: *heat stroke, cardiovascular system, respiratory system, dehydration, basketball, football*

Introduction

In recent years, climate change and the increasing intensity of sports activities under high-temperature conditions have further heightened the risks posed by heat stress for athletes. Heat stroke ranks among the leading causes of death during sports activities and is characterized by multi-organ failure. Heat stress disrupts the integrity of the intestinal barrier, facilitating the translocation of bacterial products into the bloodstream (Garcia et al., 2022). The damage to the intestinal epithelium leading to the entry of lipopolysaccharides into the bloodstream plays a crucial role in the development of multi-organ injuries (Lim & Mackinnon, 2006). During intense physical exertion, metabolic processes in skeletal muscles generate a large amount of heat, and its dissipation depends on the effective functioning of the body's thermoregulatory systems.

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However, under conditions of high temperature and humidity, the weakening of heat loss mechanisms can lead to hyperthermia and its severe form, heat stroke. In response to heat stress, the cardiovascular system is the first to become activated. Y. Epstein and W.O. Roberts (2011) demonstrated that during hyperthermia, peripheral vasodilation leads to a reduction in the perfusion of internal organs. The pathogenesis is primarily associated with hyperthermia ($>40^{\circ}\text{C}$), cardiovascular system overload, and systemic inflammatory response syndrome (SIRS). Heat stress is one of the main factors leading to decreased performance and health complication in athletes. However, under conditions of high temperature and humidity, these mechanisms are insufficient, resulting in hyperthermia and peripheral vasodilation. L.W Rowell (1974) noted that cardiac output increases 2-3 times under heat conditions, playing a central role in thermoregulation. Additionally, an increase in ventilation is observed in the respiratory system, aimed at enhancing heat dissipation and optimizing gas exchange. However, under prolonged heat exposure, when these compensatory mechanisms prove insufficient, pathological conditions may arise, including hypovolemia, fluctuations in arterial blood pressure, cardiac arrhythmias, as well as metabolic and respiratory imbalances. In thermoregulatory disorders, blood flow to the skin increases, resulting in hypoperfusion of internal organs. Sweating, dehydration, and a reduction in plasma volume occur. Heat stroke is characterized by a rise in body temperature above 40°C and dysfunction of the central nervous system (Bouchama & Knochel, 2016). Heat and hypoxia contribute to damage of the intestinal barrier. Exercise-induced hyperthermia increases intestinal permeability, allowing endotoxins to enter the systemic circulation (Latiano, 2019). This leads to the development of a "leaky gut", where endotoxins pass into the bloodstream, resulting in endotoxemia, systemic inflammation, and shock. Activation of endothelial cells and a sharp increase in cytokine levels are closely associated with endotoxemia (Leon & Bouchama, 2015). In athletes experiencing heat stroke, this process is of particular significance, as blood flow to the intestines may decrease by up to 80%, leading to rapid disruption of the intestinal barrier. Endotoxemia further exacerbates cardiovascular collapse and aggravates respiratory failure. It is considered one of the key triggers of the systemic inflammatory response during heat stroke (Leon & Bouchama, 2015).

Literature data indicate that the effects of heat stress vary depending on the type of sport. A comparative analysis of the impact of heat stress on the cardiovascular and respiratory systems in basketball and football remains insufficiently investigated. In this context, the aim of the present study is to comparatively examine the functional and pathological changes occurring in the cardiovascular and respiratory systems of basketball and football players under heat conditions, as well as to evaluate the underlying pathophysiological mechanisms of these changes. G.P Lambert (2008) reported that intestinal hypoxia facilitates the translocation of endotoxins into the bloodstream and activates the systemic inflammatory response.

Materials and Methods

Comparative experimental study. A comparative experimental study was conducted to assess the effects of heat stress on cardiovascular and respiratory systems in athletes.

Participants. A total of 60 male athletes participated in the study:

Sport	Number	Age (years)
Basketball	30	21 ± 2
Football	30	22 ± 3

All participants were clinically healthy at baseline and had no diagnosed cardiovascular or respiratory diseases prior to the study. All athletes had at least 6 years of training experience.

Environmental conditions. The study was carried out under controlled environmental conditions:

- Temperature: 32 °C
- Relative humidity: 60%
- *Measured parameters.* The following physiological parameters were evaluated:
- Heart rate (HR)
- Systolic and diastolic blood pressure
- Respiratory rate
- Core body temperature
- Maximal oxygen uptake (VO₂ max)
- Body mass loss (as an indicator of dehydration)
- Blood lactate concentration

Exercise protocol. Participants performed a 60-minute high-intensity training session including:

- sprint intervals
- agility drills
- jumping exercises
- sport-specific movements

Measurements were recorded:

1. Before exercise
2. Immediately after exercise
3. 10 minutes after recovery

Statistical analysis. Statistical analysis was performed using SPSS version 26.0. The following statistical methods were applied:

- Student's t-test
- Analysis of variance (ANOVA)
- Pearson correlation analysis

A p-value of <0,05 was considered statistically significant.

Results

Cardiovascular responses

Parameter	Basketball	Football	p-value
HR (post-exercise)	178 ± 8 bmp	184 ± 10 bmp	0,03
Systolic BP	160 ± 12 mmHg	168 ± 14 mmHg	0.04
Core temperature	39.1 °C ± 0,4 °C	39.4 °C ± 0,5 °C	0.02
Dehydration	2.3%	3.5%	0.01

Football players demonstrated significantly higher cardiovascular strain and dehydration levels compared to basketball players.

Respiratory responses

Parameter	Basketball	Football	p-value
Respiratory rate	42 ± 6 breaths/min	36 ± 5 breaths/min	0.04
VO ₂ max	52 ml/kg/min	55 ml/kg/min	0.05
Blood lactate	8.5 mmol/L	7.2 mmol/L	0.03

Basketball players exhibited greater ventilator responses and higher lactate accumulation.

A total of 60 athletes were evaluated in this study. Exposure to heat stress resulted in the development of functional (adaptive) responses in a majority of participants, while a subset of athletes progressed to clinically significant pathological conditions.

Functional changes. Functional (compensatory) responses were observed in 48 athletes (80%). This changes include:

- increased heart rate (physiological tachycardia)
- elevated respiratory rate
- increased body temperature
- enhanced sweating
- mild dehydration

These responses represent normal physiological adaptation mechanisms and were reversible.

Pathological changes. Pathological alteration was identified in 22 athletes (36.7%).

It is important to note that these athletes were part of the group exhibiting functional changes, indicating progression from adaptive responses to pathological conditions. The observed pathological findings included:

- sustained tachycardia (>180 bpm)
- cardiac arrhythmias
- episodes of arterial hypotension
- hyperthermia (>39–40 °C)
- significant dehydration (>3%)
- metabolic disturbances (elevated blood lactate levels)

Overall distribution

Category	Number	%
No significant changes	12	20%
Functional changes only	26	43.3%
Pathological changes	22	36.7%
Total	60	100%

Temporarily withdrawn athletes

A total of 14 athletes (23.3%) were temporarily withdrawn from training due to early signs of physiological overload and heat-related disturbances. Main reasons: excessive heart rate, hyperventilation, dizziness and weakness dehydration. These athletes recovered after appropriate rest and supportive measures.

Permanently withdrawn athletes. Three athletes (5%) were advised to discontinue intensive sports activity due to the development of clinically significant pathological conditions. *Reasons: Cardiovascular disorders:* persistent tachycardia, arrhythmias, arterial hypotension. *Severe hyperthermia:* core body temperature >40 °C, signs of exertional heat stroke. *Metabolic disturbances:* blood lactate >10 mmol/L, metabolic imbalance.

Discussion

The results of this study show that heat stress causes significant physical strain in athletes, expressed through adaptive responses of the body. However, in some participants these adaptive mechanisms were no sufficient, leading to pathological conditions. The transition from a functional to a

pathological state is mainly related to impaired thermoregulation and excessive strain on the cardiovascular system. Athletes exposed to prolonged or intense heat are at increased risk of dehydration, hyperthermia, and unstable blood circulation.

Practical implications. Based on the findings, the following preventive strategies are recommended: implementation of heat acclimatization programs, maintenance of adequate hydration, monitoring environmental conditions, adjustment of training intensity in hot environments, early identification of heat-related symptoms

Conclusion

Heat stress has a significant impact on cardiovascular and respiratory function in athletes. While the majority of athletes develop functional adaptive responses, a substantial proportion progresses to pathological conditions under excessive heat exposure. These findings underline the importance of preventive strategies and proper management of training in hot environments to reduce the risk of heat-related complications.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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