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Physiological Indicators of Athletes in Post-Competition Recovery in the Sport of Auto Rally in Hot Climates and Its Coefficient of Change

Jienbayev Baxtiyar Biysenbaevich

PhD Student, Department of General Biology and Physiology, Karakalpak State University, Uzbekistan

Abstract **Aim:** This study investigates the physiological reactions of the autonomic systems and overall bodily functions in athletes engaged in auto rally sports under hot climates, focusing on the relationship between workload intensity and physiological adaptations. The research aims to identify the causes of physiological changes during extreme physical exertion and evaluate recovery mechanisms. **Methods:** Physiological assessments, including the Harvard Step Test and RWS170 Test, were conducted to evaluate athletes' workload capacity, oxygen uptake, and post-exertion recovery. Heart rate variability, systolic blood pressure, and electrocardiogram (ECG) parameters were analyzed under high-temperature conditions (35–40℃). **Results:** Significant physiological adaptations were observed, including increased heart rate recovery efficiency, bradycardia in highly trained athletes, and dynamic changes in ECG parameters (e.g., S-T interval fluctuations). Athletes exhibited enhanced functional reserves, with rapid restoration of autonomic functions post-competition. **Conclusion:** The study highlights the critical role of physiological adaptations in mitigating heat stress during auto rally competitions. Structured training programs tailored to hot climates can optimize athletes' performance and recovery.

Keywords Auto rally, Harvard Step Test, Physiological adaptation, Systolic pressure, Recovery coefficient, Thermal stress

1. Introduction

Uzbekistan, due to its geographical location in Central Asia and the diversity of its natural environment, is considered a favorable region for developing various practical and technical sports, as well as extreme tourism. The vast desert zones of Uzbekistan are suitable for auto and motorcycle rallies and cross-country races, while the mountainous areas are ideal for parachuting, hot air ballooning, and winter sports. The development of these activities and the organization of international competitions serve to attract foreign investors and tourists.

2. Literature Review

One of the critical aspects related to motorsport is the comprehensive analysis and study of the autopilot and navigator's physiological state before, during, and after competitions. Several studies have been conducted to examine the specific characteristics that emerge in the crew's bodies, particularly the pilot's, when driving a car under training and competition conditions [1], [2], [3], [4]. However, it is important to note that all these studies were carried out in low-temperature climatic conditions, ranging from -15℃ to +10℃. Investigating the mechanisms of optimal adaptation of the driver's body to various abiotic factors in rally competitions held in extreme, high-temperature climatic conditions, as well as conducting research in this direction and developing specialized guidelines and methodological recommendations, is of significant current scientific and practical importance.

The literature repeatedly emphasizes the necessity of improving key aspects of physical training to enhance the professional skills of racing drivers. It is noted that this factor directly influences the performance of athletes in competitions [5], [6], [7], [8]. Furthermore, in several scientific studies, authors stress the need to integrate various training components in the process of preparing highly qualified athletes. This places high demands on ensuring an optimal balance of individual factors that determine the preparedness level of race drivers. However, in the existing literature on training specialized rally drivers, these issues are insufficiently addressed and not widely discussed in practical terms.

* Corresponding author:
baxtiyarjienbaev9985@gmail.com (Jienbayev Baxtiyar Biysenbaevich)
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3. Research Methods

Among the broad range of issues concerning the training of highly qualified rally racers, the matters of structuring training sessions and monitoring the physical and mental abilities of athletes, which form the general framework of physiological preparation, have not been adequately studied.

As with any sport, technical sports require athletes to possess a certain level of theoretical knowledge and practical skills. Observations of the "Muynak Rally" Uzbekistan Open Championship, which has been held regularly in Uzbekistan over the past six years, demonstrate that extreme climatic conditions, particularly dry and hot weather, along with other abiotic factors, are having a significant negative impact on the physical performance of athletes and the outcomes of competitions.

These competitions primarily involve training athletes on a specially prepared route organized along the territories surrounding the Aral Sea through Muynak and the Ustyurt Plateau. This unique 455-kilometer-long route in Central Asia is distinguished by its complexity, diverse terrain, and passage through ecologically challenging areas. Natural abiotic factors - such as strong winds, high levels of sand and dust, uneven roads, high concentrations of NaCl salts in sandy areas, as well as air temperatures around 35-40℃ in May when the competition is held - negatively affect the health of athletes and the effectiveness of technical equipment operation. Furthermore, the heat emitted from car engines, along with the negative impact of sportswear and helmets on the body's heat exchange, creates an additional physiological load on athletes, particularly drivers and navigators [9, 208-215].

Methods for determining the level of athlete endurance.

To determine the optimal solution to the aforementioned problems, a series of experimental studies were conducted. Within this framework, the **Harvard Step Test** and the **PWC_{170} test** were employed to assess the level of endurance and work capacity of rally athletes. These tests are among the most effective methods for determining the level of physical fitness of athletes.

During the study, new scientific data were obtained on the mechanisms of physiological changes occurring in the body in relation to various physical loads, the functional reserves of the organism, and its adaptive capabilities. Depending on the intensity of the load, the degree of oxygen utilization by the body and oxygen "debt" indicators were determined, and their differences across various sports were analyzed.

The obtained scientific results can be applied as the primary methodological tool in planning training processes for sections specializing in extreme sports, establishing normative indicators, and developing individual training programs for athletes.

4. Results and Analysis

The practical significance of this study lies in its ability to identify the causes of the main physiological states that arise in the body during physical exercises - fatigue, pre-start condition, physiological stability, the formation of motor skills, and other processes. The obtained data will serve as a foundation for determining the possibilities of effective utilization of the body's existing functional reserves under conditions of physical exertion.

In the initial seconds and minutes of a competition, the contraction force of skeletal muscles sharply increases, and the contraction movement becomes rapid and powerful. This process is characterized by the provision of necessary energy mainly through the breakdown of adenosine triphosphate (ATP) and other phosphorus-containing compounds. Despite the intensive muscle activity in the early stages of sports movement, oxidation processes do not occur with sufficient intensity. Over time, as a result of the activation of the cardiovascular and respiratory systems, oxidative processes in the body intensify. However, this process does not start immediately, as it takes time for the heart and lungs to enter a specific working regime.

During physical work or competition, the body's vegetative functions change primarily through heart rhythm. For example, in car rally competitions, the heart rate increases significantly in the first 7-12 minutes. These indicators depend on the level of the body's physical preparation for work. Warm-up exercises play an important role in bringing the functions of the cardiovascular system to an optimal working state. Conversely, in competitions without warm-up, the body's vegetative functions cannot adapt to intense physical loads.

It should be particularly emphasized that, unlike sports requiring maximum effort in a short period of time, motorsport is a long-distance activity characterized by high stress and intensive information exchange. Under such conditions, the muscles of athletes' palms, arms, and legs are in continuously alternating static and dynamic states. This leads to an increase in fatigue during prolonged physical activity. It is during this period that arterial blood pressure (systolic pressure) rises. This condition is associated with an increase in the total volume of blood circulating in the cardiovascular system [10, 23-31].

The speed or delay in skill development depends on several factors, including the nature of muscle activity, the athlete's level of preparedness and personal characteristics, as well as the quality and duration of warm-up exercises. The faster the skill is formed, the higher the effectiveness of the sports movement. This results in increased motor activity and delayed onset of fatigue.

It is observed that the work capacity of those who systematically engage in sports is several times higher than that of those who do not. This demonstrates that physical exercises serve to mobilize various reserve capabilities of the body. These reserves are manifested through morphological, biochemical, physiological, and psychological indicators.

The organism's **morphological reserves** are determined by the structure and level of development of tissues and organs. Regular sports training has a positive effect on the development of morphological structures.

Physiological reserves are determined by the functional activity of the body's systems. These indicators are high in an athlete's body, which is reflected in processes such as endurance to physical loads, the efficiency of the oxygen delivery system, and energy metabolism.

In general, any type of physical exercise serves to activate the body's existing reserve capabilities. Studies show that a person uses only 30-35% of their total physical capabilities in everyday life. If this utilization reaches 45-50%, a state of physical and mental fatigue is observed. Engaging 60-65% of the reserve potential is characteristic only of individuals with strong endurance, and such a load is difficult to maintain for an extended period. As a result, the body is forced to reduce or stop physical activity based on a self-protective reflex.

Physical exercises have a powerful effect on the muscular system's functioning. They promote muscle mass growth, leading to morphological formation and structural changes in muscles. Notably, **muscles that work under static tension** are more prone to hypertrophy compared to dynamic muscles. Muscle hypertrophy occurs through an increase in muscle fiber volume, specifically through the condensation of myofibrils.

Changes in muscle tissue during training are characterized not only by morphological alterations but also by **biochemical changes**. Specifically, an increase in protein content in the sarcoplasm and a rise in contractile proteins in myofibrils are observed. One of the main functional properties of skeletal muscles is their contractile force. The speed of muscle contraction and relaxation plays a crucial role in ensuring movement coordination.

Vegetative systems - blood, circulatory, and respiratory systems - play a key role in determining the body's overall functional activity, as well as its capacity to perform physical work. Under the influence of physical exertion, the functional activity of these systems is heightened, which enhances the body's work capacity.

Certain indicators of the autonomic nervous system's activity, including heart rate and oxygen uptake, are maintained within physiological norms in an athlete's body under conditions of physical exertion. This state indicates the high level of preparation of athletes and the adaptability of their functional systems.

Physical loads also positively influence the activity of athletes' central nervous system. Specifically, the constant stereotypical formation of motor reflexes ensures a balance between excitation and inhibition processes. This enhances the psychophysiological sensitivity of athletes, contributes to the formation of a stable response to stress factors, and strengthens overall mental stability.

Regardless of the type of muscular activity – whether it is cyclic, acyclic, or dynamic movement - each physical load requires a certain amount of energy from the body. This directly affects the body's oxygen utilization rate, through which the organism's reserve capacity is determined.

In sports that require extreme speed and high concentration, such as motorsport, the body encounters strong vibrations, high levels of sensory input, and the need for rapid decision-making. In these situations, a significant release of the hormone adrenaline is observed, resulting in the body entering a state of stress. Consequently, changes occur in the activity of the cardiovascular system. Specifically, arterial blood pressure, as well as systolic and minute volumes of the heart, are altered.

However, in highly trained athletes, these changes remain within physiological norms or are restored in a short time. Particularly before and during competitions, there may be deviations from the norm in heart rate and blood circulation indicators, but during the recovery period, these indicators quickly return to their baseline state. In this regard, athletes' bodies are distinguished by the effectiveness of their recovery mechanisms compared to non-athletes (Table 1).

Some of the studied physiological indicators of highly skilled rally athletes and athletes from other sports are prone to change regardless of age characteristics. For example, in buggy and motocross athletes, bradycardia and sinus arrhythmia observed at rest are widespread, regardless of age differences. Such conditions are the result of a high level of physical fitness and indicate physiological adaptations of the heart.

Table 1

Indicators	Training process													
	Preparation							Competition						
	Resting state	Work during pulse			Recovery pulse			Resting state	Work pulse			Recovery pulse		
		110-120	140-150	170-180	140-150	110-120	80-90		110-120	140-150	170-150	140-150	110-120	80-90
M	0.99	0.53	0.41	0.34	0.42	0.52	0.71	1.09	0.54	0.43	0.43	0.42	0.53	0.71
a	0.137	0.010	0.005	0.0	0.018	0.035	0.085	0.193	0.022	0.015	0.015	0.023	0.051	0.118
%V	13.8	1.89	1.22	0.0	4.3	6.7	12.0	17.7	4.1	3.5	3.2	5.5	9.6	16.6
X min	0.78	0.51	0.40	0.34	0.39	0.45	0.56	0.79	0.59	0.415	0.325	0.58	0.44	0.58
X Max	1.28	0.55	0.42	0.43	0.45	0.60	0.93	1.35	0.59	0.450	0.335	0.47	0.67	1.05
X	0.45	0.04	0.02	0.0	0.08	0.15	0.37	0.66	0.09	0.035	0.010	0.09	0.23	0.47

Additionally, other indicators, such as minute blood volume, cardiac output force, and heart rate, have specific characteristics during the post-exercise recovery period. The functional activity of arterial blood vessels depends on the body's state of fatigue at the end of the competition. The response of blood vessels during muscular activity can be determined based on the athletes' condition while performing exercises. During physical exertion, the body's oxygen demand and uptake change, while the activity of the body's functional reserves is observed.

As athletes' fitness level increases, the effect of pulmonary ventilation improves, and the function of the respiratory system, including pulmonary and circulatory activities, becomes more stable. At the same time, in sports such as long-distance running or buggy and motocross racing, despite the low physical load, clear changes in the electrocardiogram (ECG) are observed after competition. Compared to rally drivers, these athletes show more changes in their ECG indicators. For example, a decrease in T-wave amplitude, ST-segment depression, and prolonged atrioventricular conduction were observed. These indicators reflect the specific characteristics of the athletes' cardiac activity and describe their physiological state.

A rapid change in the length of the S-T interval under the influence of physical exertion indicates a physiological response of the athlete's heart myocardium. By analyzing ECG indicators, the functional state of the heart during the recovery period of athletes is determined. By testing athletes with various workloads and analyzing their ECG parameters, including changes in the S-T interval, the following conclusions were drawn:

1. **Changes in the S-T interval** are an indicator of the heart's response to physiological stress. This interval changes rapidly after physical exertion, reflecting the adaptive characteristics of the heart.
2. **In highly skilled athletes**, a relatively low heart rate and bradycardia are observed after physical exertion. This indicates a balance between automatic regulation of the athlete's cardiac activity (autoregulation) and regulation by the central nervous system (centralized control).
3. **In less trained athletes**, the heart rate per minute can be higher, even if the volume of work performed is small. In this case, bradycardia and sinus arrhythmia may be observed. This demonstrates the conditions under which the athlete's body operates at a high level and shows adaptive changes in cardiac function.

Furthermore, the heart's electrical system and electrocardiogram indicators can present various challenges for athletes, regardless of their level of qualification or training. Changes in these indicators reflect the overall physiological state of athletes and the maximum efficiency of their muscular system. ECG readings obtained during physical exercises or during the recovery period help to gain a deeper understanding of changes in the athlete's cardiac function.

5. Conclusions

Based on the above literature review and our own experience, drawing from the data we have collected and analyzed, the following conclusions can be made about the impact of physical exercises on the body's functional activity and reserve capabilities:

1. **Physical loads and functional systems**: Regardless of the type of sport, when physical load is established within physiological norms, it positively affects the functional systems of the body. Physical exercise improves all of the body's systems, including the heart, circulatory, and respiratory systems, which enhances overall health and athletic performance.
2. **Athletes' recovery period**: Physical loads also have a positive effect on athletes' recovery period. Within the framework of physiological norms, athletes recover quickly and their bodies' reserve capabilities return to action, which improves their physical and mental state.
3. **Muscle activity and oxygen uptake**: During physical exercise, the body's oxygen uptake indicator changes, which reflects athletes' reserve capabilities and muscle performance efficiency. As athletes' fitness level increases, their body improves breathing and blood circulation.
4. **Highly skilled athletes and heart function**: In highly skilled athletes, heart function returns to normal after physical exertion, and physiological conditions such as bradycardia or sinus arrhythmia are observed. These conditions indicate a high level of physiological adaptation in athletes.
5. **Physical loads and the nervous system**: Physical exercises also have a positive effect on the activity of athletes' nervous systems, which in turn contributes to the improvement of their psychophysiological state. Emotional and mental stability helps athletes engage more effectively in physical activities with higher loads.

Overall, physical training improves the body's functional activity and prepares athletes for high-level performance, while ensuring the effective functioning of all bodily systems.

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