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The Impact of Sports Activities on the Immune System: Sports Pedagogy

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Abstract: *This article's relevance lies in the growing scientific interest in the links between physical activity and the human immune system. Sports and regular physical exercise are key contributors to overall health and the body's functional capacity. They influence the immune response either directly or indirectly. Accordingly, this systematic review examines current medical and pedagogical studies on how physical activity of varying intensities affects immune function. Sources were selected based on the following criteria: publication in peer-reviewed medical or pedagogical journals within the past two decades, and the use of experimental, quasi-experimental, or clinical research methods. The article outlines the beneficial effects of moderate physical activity and the potential risks of immunodeficiency resulting from excessive or chronic exertion. Furthermore, it emphasises the importance of physical education as a critical component of disease prevention and a key element in rehabilitation within sports pedagogy. In addition, the article reveals the role of physical activity in maintaining the healthy functioning of the human body. It explores medical aspects of rehabilitation in sports pedagogy and discusses how sports activities influence immune response. Finally, the article examines the broader medical impact of physical exercise on the immune system.*

Keywords: *immune system, immunodeficiency, sports pedagogy, exercise physiology, biochemical processes, immunoglobulins (antibodies).*

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Introduction

As seen from the examples of many athletes, the impact of sport on human health is undeniable. The reasons behind the weakening of athletes' immune systems due to physical exercise of varying intensities remain unclear. Regular, moderate-intensity exercise is widely accepted as beneficial for strengthening the body. It plays a key role in preventing and treating conditions such as atherosclerosis, hypertension, obesity, chronic lung diseases, and musculoskeletal disorders. However, high-intensity, prolonged physical exertion has been shown to have negative impacts. Studies have demonstrated that intense training can weaken immune function (Simpson et al., 2020). This makes athletes more susceptible to colds and infections, particularly after extended training sessions, during overtraining syndrome, or even at their peak performance.

One's health is largely influenced by the level of physical activity, as supported by numerous scientific studies (Agha-Alinejad et al., 2022; Forte et al., 2022; Kurowski et al., 2022; Nieman & Pence, 2020). This topic gains particular relevance in the context of integrating medical knowledge into sports pedagogy. This article aims to provide a systematic review of scientific literature examining the effects of physical exertion on the immune system from a medical perspective.

Importantly, the article analyses the work of Ukrainian and international scholars, including Bosenko (2016) and Lucini et al. (2002), among others. It focuses on experimental and review studies that examine the physiological and immunological effects of athletic training. The main criteria for including sources in the review were scientific validity, publication in peer-reviewed journals, thematic relevance, and the inclusion of a medical perspective in the description of physical activity.

Findings confirm that regular, moderate-intensity training benefits overall immune function (Nieman & Wentz, 2019). However, excessive or chronic exertion may lead to immunodeficiency. This dual impact of physical activity highlights the need for an individualised approach to exercise load management. It also underscores the importance of incorporating healthy lifestyle principles into athlete training programmes.

The problem in question is covered extensively in Ukrainian and foreign research. As noted by Kurt and Serdaroğlu (2024), one of the factors that shapes health is physical development. At the same time, the deterioration of health indicators affects the human immune system. The relevance of preventing various diseases is determined by the high prevalence of diseases among preschool and primary school-age children.

One of the most important objectives of health promotion in healthcare and education institutions is to form health-preserving behaviour aimed at satisfying one's vital biological needs. The leading factor of health is one's lifestyle, formed from childhood in daily life, during learning and leisure, as well as in certain natural and climatic conditions. Everyone can significantly influence the environment in which they live and change their way of life with the presence of motivation for health-preserving behaviour.

A detailed analysis of relevant sources shows that the existing scientific evidence largely supports the positive effects of moderate physical activity on the immune system. However, the threshold intensity values that trigger the shift from adaptive to destructive changes are not yet well understood. Despite numerous empirical studies, there is a lack of meta-analyses comparing age, gender, and genetic variables. Furthermore, it can be critically noted that most studies overlook the individual psychophysiological characteristics of athletes, which can significantly influence the immune system.

Accordingly, this article seeks to reveal the role of sports activities in the healthy functioning of the human body. It also attempts to study the medical aspects of rehabilitation in sports pedagogy and demonstrate the impact of sports activities and rehabilitation on the immune system.

The significance of sports activities in maintaining a healthy body function

Sports activities affect the functioning of the following systems and organs of the human body (Maksymchuk et al., 2022).

The musculoskeletal system. When practising sports, the main load falls on the musculoskeletal system. Muscles are capable of performing movements and contracting under the influence of nerve impulses. Thus, they provide body movement and, consequently, belong to the motor element. Sports can prevent muscle exhaustion as the nerve cells regulating active muscle activity are the first to tire during training. It is important to note that any exercises involve the training of both muscles and the nervous centres responsible for movement. Additionally, with regular sports activities, tendons and ligaments become significantly denser and stronger, while the bones of the skeleton strengthen (Bosenko, 2016).

The respiratory system. There is an increase in lung capacity due to the expansion of the bronchi and the opening of additional alveoli. Indeed, those people who exercise regularly have a better blood supply to the lungs. It follows that the blood is quickly saturated with oxygen and then supplies it to

all other organs of the body. Sports help overcome respiratory diseases such as pneumonia and bronchitis (Degtyarenko, 2016).

The cardiovascular system. Sport improves the ability of the heart muscles to contract, thickens them and makes them more enduring. Importantly, it normalises the pulse function. This particular factor helps overcome pathological changes such as arrhythmia. Besides, blood vessels undergo positive changes as they become more elastic and flexible. For instance, the walls of veins significantly contract, and blood flows to the heart much faster. It prevents such diseases as thrombosis, varicose veins and many others. Thus, physical exercise serves as the "trainer" for vessels and the heart (Degtyarenko, 2016).

Metabolism. Interestingly, physical activity has beneficial effects on metabolism. Metabolism is accelerated, with most fats being expended during sports activities, and fewer fat reserves remaining under the skin. Additionally, reducing the number of atherogenic lipids prevents the development of atherosclerosis. Also, one can observe an accelerated carbohydrate metabolism (Kurowski et al., 2022).

Hormonal balance. The term "hormonal balance" refers to the ratio of hormone levels in the human body. When it is disrupted, there is a sharp jump in weight: either a decrease or an increase. Sports activities and hormones are directly interrelated. During any exercise, the work of the heart and nervous system is maintained, while metabolism is accelerated and regulated. This ensures the stimulation of hormone secretion.

Thus, playing sports can positively impact one's physical and mental health. Three main requirements are identified for successfully maintaining a healthy lifestyle: systematicity, graduality and regularity.

To achieve the positive effects of physical activity on human health, one should engage in the following sports (Buchheit et al., 2007):

Swimming – most muscle groups are involved, including the abdomen, torso, legs and arms; in addition, this sport requires the body to stretch and flex, thereby developing flexibility.

Football (soccer) – it develops the musculoskeletal system, strengthens the immune system, improves endurance and blood circulation.

Basketball – it enhances body movement coordination and peripheral vision, increases lung capacity and normalises the functioning of the cardiovascular system.

Tennis – it helps elongate muscle fibres and develop biceps, triceps and leg muscles; also, the muscles of the abdomen, back and neck are actively engaged.

Hockey – it improves the musculoskeletal system and boosts the immune system; it also helps develop strong character qualities, such as agility, perseverance and a quick reaction time.

Running – it stimulates the production of young cells in the body, enhances breathing and promotes fluid circulation; in turn, this helps eliminate stagnant areas in the human body and increases the movement of all fluids in the body.

Cycling – it helps systematise the functioning of the lungs and respiratory system and actively involves the muscles of the arms, legs and back, while endurance is formed and coordination is improved; it prevents vision problems as one can focus on objects at different distances (Agha-Alinejad et al., 2022).

Most people strive to achieve their goals as quickly as possible and improve their quality of life. The pace and rhythm of life increase, whereas physical strength does not. This leads to problems such as cardiovascular disease, excess weight and psychological problems, which only worsen one's mental state (Forte et al., 2022).

Researchers believe that the cause of this change is one's inability to manage one's time and monitor one's health. People tend to demonstrate weak willpower and a lack of self-discipline. One effective way to address these issues is to engage in physical activity (Chen, 2007).

Sports activities truly make one healthier, improve one's physique and contribute to development in various areas. Scientific medicine supports physical activity even for elderly people, however, at a moderate pace. Engaging in sports brings positive effects on the circulatory system, the respiratory system, thinking, metabolism, hormonal balance and the endocrine system.

Furthermore, performing various exercises helps develop the body and improve posture. For instance, spine problems can become less pronounced.

The impact of sports activities and rehabilitation on the immune system

Today, the issue of maintaining health is relevant for both society and the younger generation. Research by many experts indicates a steady deterioration in the health status of the population of Ukraine. The main reason behind this is young people's disinterest in a healthy lifestyle. Even in adulthood, not everyone understands how important it is to take care of oneself and one's body.

Indeed, school-age children and adolescents should be able to rapidly process large arrays of information. Consequently, this cannot but affect their perception and thinking. They live in a time when their emotions, desires and aspirations are prone to the influence of passing trends and news from the world, where new needs and ways of their implementation arise with incredible speed. The rhythm of life dictates constant changes. It accelerates the introduction of advanced technologies into the educational process and contributes to the worsening of the environmental situation.

The issue of a healthy lifestyle has become more acute than ever. The measures aimed at improving health should be systematic and comprehensive. Professional skills, along with a teacher's personal interest and assigned tasks, largely determine the choice of methods for organising activities to promote a health-preserving attitude (Nieman & Wentz, 2019).

It is during school age that young people gain the psycho-physiological foundations of a healthy lifestyle needed to prevent diseases. The main criterion for one's physical health should be one's energy potential – the ability to consume energy from the environment, accumulate it and mobilise it to support physiological functions. As rightly noted by ancient philosophers, one's activity determines one's well-being.

Effective acquisition of educational material is one of the most important objectives of today's schoolchildren, which is greatly complicated by external and internal factors. Physical activity is the most important condition for the comfortable influence of mental loads on the body and its comprehension of theoretical material. Motor activity contributes to the positive functioning of the entire system of internal organs. It activates processes responsible for the endurance of the body, the ability to perform mental tasks, visual concentration, creative thinking, and processing of information. Thus, physical exercise, balanced motor activity and muscular development directly affect brain performance. It has been shown to increase the overall level of health and endurance of the brain and strengthen the nervous system.

Everyone requires a strong and effective immune system. This is especially important when external factors such as work stress, seasonal changes, improper nutrition, and a sedentary lifestyle are present in everyday life. The combination of these factors can make one more vulnerable and thus lead to a weakened immune system. The immune system protects the body from attacks by potentially harmful microorganisms.

Physical activity helps optimise the body's defences against infection. In the conditions of the COVID-19 pandemic, this is more important for many people than ever before. Fortunately, recent research provides a clear

understanding of how physical exercise affects the immune system and how to approach exercises to achieve promising results (Agha-Alinejad et al., 2022).

Physical exercise mobilises immune cells to fight pathogens and inflammation throughout the body and helps slow the impact of ageing on immune function. Physical activity can also flush bacteria out of the lungs and airways and cause changes in antibodies or white blood cells to help fight infections.

Physical exercises effectively reduce the risk and severity of chronic diseases that can increase inflammation levels in the body. This inflammation leads to worse outcomes when the immune system attempts to fight infection. For example, in New York, patients with obesity, diabetes and heart disease have the worst outcomes from COVID-19 (Mesci et al., 2021).

To strengthen the immune system, it is extremely essential to apply the correct approach to the most effective exercises during physical education classes. Below are the scientifically proven strategies for this particular purpose (Palamarchuk et al., 2020): a) focusing on consistency; b) maintaining intensity; c) observing recovery periods; d) switching from cardio to strength training; and e) exercising outdoors.

Regular physical exercise is the most important factor in providing immune benefits for individuals. At the same time, consistency is crucial due to the constant accumulation of new results from exercise with existing ones. Each workout adds advantages compared to the previous one.

Immunologists used to be rather concerned about the "open window" theory. This theory was characterized by short-term suppression of the immune system following an acute bout of endurance exercise. However, two years after immunologists first challenged this theory in 2018, research in 2020 confirmed that increasing the intensity of exercise did not suppress immunity or increase the risk of infection.

High-intensity exercises, typically considered to raise the heart rate more than 85% of the maximum value (220 minus one's age), can be part of any physical exercise programme aimed at improving the immune health of schoolchildren. Physical education classes can include running, cardio workouts, as well as fast-developing strength training. Illnesses after high-intensity workouts are usually associated with rapid recovery. As intensity, frequency and duration of exercises increase, the amount of rest, which is important for the child's body to recover from stress and become stronger, needs to be increased too.

There are several signs that children may need more recovery time: fatigue, severe muscle pain after a training session lasting more than three days and a decrease in training productivity.

Recovery methods during physical education classes may include the following components: a) breathing exercises; b) light walking; c) relaxed conversation; d) low-intensity yoga; and e) muscle relaxation or stretching exercises.

Each intense training session increases the body's immunity at the cellular level. Moreover, maintaining a healthy level of muscle mass can strengthen immunity. Both cardio and strength training should be used for optimal immunity and overall health. The use of aerobic exercise during physical activity strengthens the entire body. Examples of aerobic activity include jogging, swimming and cycling. Strength training may include bodyweight exercises (such as squats and push-ups), as well as exercises with free weights, resistance bands or other equipment.

Regardless of where active exercise is performed (in a gym or outdoors), any of them can bring invaluable benefits to the immune system. However, there are additional advantages to outdoor training. Being outdoors increases the level of vitamin D, which supports the immune system. Besides, physical exercises outdoors can strengthen the immune system by activating the body's parasympathetic system for relaxation and digestion. Usually, available options for active recreation include walking, running, cycling and performing weighted exercises such as push-ups on the grass or from a bench. The impact of sunlight, especially in the morning, can help regulate the body's circadian rhythms for further strengthening a healthy immune system.

As is known, physical exercises play a fundamental role in preventing major chronic diseases. Scientific research over many years has been focused on understanding the mechanisms underlying the benefits of movement. Many areas of research into the effects of physical exercise on metabolism show that it can improve the immune function of the body. The mechanisms underlying these benefits include: a) improving humoral immunity (production of antibodies that bind to viruses, bacteria and foreign substances); b) stimulating the release of certain substances (such as mitogen-activated protein kinase (MAPK/ERK), AMP-activated protein kinase (AMPK), target of rapamycin (TOR) associated with improved recognition of antigens (substances recognized as dangerous by the immune system).

One of the main factors that affect the immune system is physical activity and its regularity. Regular physical activity at moderate intensity levels can boost the immune system. A sedentary lifestyle increases the risk of infectious and other diseases.

The impact of physical exercise on the immune system: a medical perspective

Physical exercise can have diverse effects on the human immune system. After intense physical exertion, there is an increase in leukocyte count, while their functional activity is significantly reduced. This includes the suppression of the antigen-presenting capacity of macrophages, decreased natural killer (NK) cell activity, a reduction in T-lymphocyte numbers, suppression of lymphocyte proliferation in response to T-mitogens and a decline in immunoglobulin levels in the blood or saliva during competitive events.

Stress responses to physical activity are mediated through the sympathoadrenal and hypothalamic-pituitary-adrenocortical systems, resulting in elevated levels of catecholamines and glucocorticoids. Catecholamines are associated with granulocytosis and lymphocytosis, while glucocorticoids contribute to lymphopenia. Other hormones, such as glucagon, growth hormone, insulin, thyroid hormones, prolactin and sex hormones, also play a role in modulating immune function (Proshchuk, 2022).

The availability of energy substrates influences the condition of lymphoid cells, with glucose and glutamine serving as key energy sources. Glutamine supports 35% of the energy needs of lymphoid cells and is crucial for nucleotide metabolism. Muscle tissue is the primary source of glutamine in peripheral blood. A decline in glutamine levels can lead to a weakened T-cell response. High-volume and intense training significantly impacts the hormonal system. After such exercise, there is a prolonged decrease in testosterone and other hormones involved in anabolic processes. Due to the energy demands of this type of training, the body prioritizes the replenishment of energy substrates. As a result, the secretion of hormones that facilitate the synthesis of structural and contractile proteins is reduced. This shift affects the immune responsiveness of athletes, especially younger ones. To fully understand the impact of physical exercise on the immune system, it is essential to analyse the physiological and biochemical processes occurring in muscles during physical activity (Agha-Alinejad et al., 2022).

Table 1 provides a schematic overview of the effects of physical activity on the immune system from a medical standpoint.

Table 1. The effects of physical activity on the immune system from a medical standpoint

Factor	Mechanism of action	Consequences for the immune system	Notes/sources
Exhaustive physical activity	Changes in the quantity and activity of immune cells	↑ Leukocytes, ↓ NK cells, ↓ T lymphocytes, ↓ IgA/IgM in saliva/blood	Proshchuk (2022)
Catecholamines (adrenaline, noradrenaline)	Activation of the sympatho-adrenal system	↑ Granulocytes, ↑ lymphocytes	Stress response
Glucocorticoids	Activation of the hypothalamic-pituitary-adrenal axis	↓ Lymphocytes, immunosuppression	Proshchuk (2022)
Intense training	Exhaustion of energy resources, ↓ glutamine	↓ T-cell proliferation, ↓ immunoglobulin synthesis	Agha-Alinejad et al. (2022)
Glutamine (amino acid)	Energy source for lymphoid cells	↓ Level → ↓ immune response	Main source – muscles
Hormone secretion (insulin, testosterone, human growth hormone)	Depends on the energy state	↓ Anabolism → ↓ recovery of immune cells	Surai (2023a; 2023b)
Hydrogen ions (H+) and lactate	↓ pH, metabolic disturbance	Cell damage, oxidative stress, ↓ immunoglobulins	Lipid peroxidation
Physiological "acidification"	Anaerobic glycolysis → ↑ lactate, H+	Cell structure damage, apoptosis	Anaerobic threshold phase
Protein and glucose deficiency after activity	Protein catabolism	Breakdown of immunoglobulins, ↓ synthesis of new cells	Liu (2019)
Regenerative mechanisms after training	↑ Protein synthesis, ↑ DNA/RNA activity	Enhanced immune response, ↑ mass of immune organs	With proper recovery
Endocrine response (pituitary, thyroid gland)	↑ Hormones → ↑ bone marrow stimulation	↑ Stem cell division	LaGree et al. (2019)

Source: the authors' own conception

In a simplified representation, it appears as follows. Skeletal muscle is diverse, with different types of muscle fibres categorised by their innervation. These include slow-twitch muscle fibres (STMF) or oxidative muscle fibres

(OMF), intermediate muscle fibres (IMF) and fast-twitch muscle fibres (FTMF) or glycolytic muscle fibres (GMF), typically found in the outer layers of muscle tissue. As external load increases, following Henneman's "size principle", OMF with high oxidative capacity are the first to contract, relying on fatty acids as a substrate. However, during the initial 10-20 seconds, energy is supplied by adenosine triphosphate (ATP) and creatine phosphate (CrP). To sustain the required power output, the central nervous system (CNS) recruits additional motor units as phosphagen concentration decreases in active muscle fibres (Surai, 2023a).

With a gradual increase in load, heart rate (HR), oxygen consumption (OC) and pulmonary ventilation (PV) also rise, while the levels of lactic acid and H+ remain stable. OMF have a high density of mitochondria, enabling aerobic glycolysis (glycogen-pyruvate-mitochondria-carbon dioxide and water) through the enzyme LDH-H (heart-type lactate dehydrogenase).

As external power continues to increase, a threshold is reached where all OMF are engaged, and IMF begin to be recruited. These fibres have fewer mitochondria, so once ATP and CrP are depleted (10-20 seconds), anaerobic glycolysis kicks in, facilitated by the LDH-M enzyme (muscle-type lactate dehydrogenase). This process follows the pathway: glycogen-pyruvate-lactate + hydrogen ions. The lactate and H+ then enter the OMF through the bloodstream, inhibiting fat oxidation and prompting glycogen oxidation. When all OMFs are active, lactate levels in the blood rise, leading to increased pulmonary ventilation (H+ in the blood interacts with buffer systems, releasing non-metabolic CO2, which stimulates breathing). This marks the aerobic threshold (AET), i.e., the power level at which all OMF are recruited, reflecting the strength of these fibres. During this phase, ATP and CrP are resynthesized through oxidative phosphorylation.

Further increases in power result in the recruitment of glycolytic muscle fibres. With a low mitochondrial density, these fibres intensify anaerobic glycolysis, spreading lactate and H+ throughout the body. As lactate enters OMF and IMF, it is converted back into pyruvate (via LDH-H). However, since the mitochondria are overwhelmed with metabolites, respiration becomes significantly more intense (CO2 stimulates CNS chemoreceptors), leading to a decrease in CO2 concentration in the blood.

The rate at which lactate is released from glycolytic muscle fibres (GMF) is compared to its oxidation rate in oxidative muscle fibres (OMF). When carbohydrates are oxidised, ATP production in the mitochondria reaches maximum speed. This is known as the anaerobic threshold (AT). The external power (oxygen consumption) reflects the maximum oxidative capacity of OMF.

As external power continues to increase, the dynamic equilibrium is disrupted, leading to blood "acidification" from unoxidized metabolites (H+, lactate, CO2). This causes increased activity in the respiratory muscles and the heart, which in turn raises oxygen consumption, as the muscles decrease their oxygen uptake (with the glycolytic muscle fibres ceasing their activity). At this point, maximum oxygen consumption (VO2 max) is observed.

A well-designed training routine enhances protein synthesis not only in the trained muscles but throughout the entire body. Four primary factors facilitate protein synthesis in cells: a) the availability of free amino acids, b) the concentration of anabolic hormones in the blood, c) the increased concentration of creatine (Cr) in muscle tissue, and d) elevated hydrogen ion (H+) levels.

The last three factors are closely tied to physical exercise. ATP energy is essential for forming actin-myosin complexes, with ATP resynthesis occurring from creatine phosphate (CrP) reserves and the release of free Cr.

Moreover, Cr promotes ATP production through glycolysis in the cytoplasm, aerobic oxidation in the mitochondria, and at the membranes of the sarcoplasmic reticulum (SR).

Cr accumulation also stimulates protein synthesis in skeletal muscle (to a lesser extent in other organ tissues) by enhancing transcription in the nucleolus of muscle fibres. An increased concentration of H+ enlarges the pores in cell membranes (due to disruptions in the quaternary and tertiary structures of protein molecules), allowing Cr and hormones to enter cells, thereby facilitating access to genetic information and DNA molecules. This process also accelerates mRNA formation, which has a lifespan of no more than five minutes during physical activity. At the same time, within that timeframe, it successfully initiates the rapid synthesis of cellular organelles, particularly in myofibrils.

This synthesis process lasts between 4 to 7 days and is influenced by the volume of mRNA generated during training. Supporting this, research on blood urea concentration in athletes measured in the morning while fasting shows that, following strength training, blood urea levels remained lower than normal for 3 to 4 days, suggesting that synthesis processes dominated over degradation (Surai, 2023b).

Physical exercise activates all bodily systems and organs, while the cardiovascular, respiratory and endocrine systems experience the greatest strain. The immune system, which includes various lymphoid organs and clusters of lymphoid cells (such as the thymus, spleen, lymph nodes, Peyer's patches and stem cells in the bone marrow), reacts to physical stress. As endocrine gland cells hypertrophy and release more hormones, this inevitably

stimulates the division of stem cells in the bone marrow and other organs. The endocrine system is composed of the pituitary gland, thyroid, parathyroid glands, pancreas, adrenal glands and gonads. The hormones secreted from these glands regulate metabolism, growth and overall development in the body. Major hormones are synthesised through a direct pathway, while some steroid hormones and releasing factors follow an indirect route. Hormone secretion occurs spontaneously, ensuring a consistent level of circulating fluids. In this regard, the physiological and biochemical processes in muscles can either stimulate or inhibit protein biosynthesis.

As a result, changes occur in the mass of the adrenal glands, pituitary gland, thyroid gland and gonads, which in turn promote the synthesis of structural proteins during training. The immune system's functionality is reliant on the proper functioning of other organs and systems. Thus, any disruption in these systems should inevitably impact the immune status of the athlete (LaGree et al., 2019).

Protein structure catabolism in athletes is caused by several factors: 1) an inappropriate combination of training volume and intensity, particularly when performing high-oxygen consumption exercises for extended periods (over 40 seconds), which leads to an elevated concentration of H+; 2) inadequate nutrition before and after workouts, resulting in a lack of essential building materials and nutrients; and 3) when blood glucose levels drop, proteins and hormones are used as metabolic substrates (Liu, 2019).

The excessive buildup of unoxidized metabolites can damage cells, some of which are subsequently eliminated. Hydrogen ions initiate lipid peroxidation reactions, leading to the fragmentation of mitochondrial enzymes and intensifying catabolic processes. During periods of intense (and not always sustained) muscle activity, the body draws on creatine phosphate (CrP), ATP, fatty acids, glycogen and plastic materials (free amino acids) for energy, eventually using protein structures such as hormones, mitochondria, immunoglobulins and others.

The changes in the immune system described above include various types of suppression of IgA and IgM in mucosal secretions. These also involve the phenomenon of disappearing antibodies and immunoglobulins. Such changes can be attributed to the detrimental effects of H+ ions, increased lactate levels, and reduced blood pH on the protein structures of different organs and tissues.

Conclusions

Thus, the article highlights how physical culture contributes to the healthy functioning of the human body. It proves that sport affects the

functioning of the following systems and organs: the musculoskeletal system, the respiratory system, the cardiovascular system, metabolism and hormonal balance.

The article explores the medical aspects of rehabilitation in sports pedagogy. It follows that complex medical rehabilitation for individuals engaged in sports is essential. It is accompanied by recommendations for the training process. These measures aim to increase the level of physical health and efficiency. They also help restore functional reserves and adaptive abilities that have been diminished due to the negative impact of physical exertion or illness. The use of individual rehabilitation programmes in the athlete training system allows one to achieve a high level of preparedness and reduces the number of injuries and illnesses.

Importantly, the article justifies how sports activities and rehabilitation affect the immune system. Given today's lifestyle, physical culture is an influential element in strengthening immunity and maintaining health. Various scientific studies and observations confirm the impact of physical culture and sports on one's physical and psychological state. Society makes significant efforts to promote a proper attitude towards physical culture and sports among young people. According to Hippocrates (2021), who lived in the 5th century BC, gymnastics, physical exercises, and walking should become an integral part of the daily life of anyone who wants to maintain efficiency, health and a full and joyful life.

The article reveals the role of physical exercise in maintaining the healthy functioning of the human body. It investigates the medical aspects of rehabilitation within sports pedagogy. It also highlights the impact of sports activities and rehabilitation on the immune system.

Meanwhile, the study of the relationship between physical activity and immune system function holds significant international importance. It addresses key global issues related to health and workforce productivity. In many countries, physical activity is viewed as a way to enhance physical strength. Also, it serves as part of a broader preventive system that helps maintain psychophysiological balance.

The authors' conclusions rely on a detailed analysis of international sources and review articles from leading medical journals. These sources consistently highlight how different training intensities influence immune competence.

A key contribution of this work is the multidisciplinary approach the authors employed. By integrating medical, physiological, and pedagogical perspectives, they emphasise the importance of an adaptive approach to

training loads. This approach is crucial for developing individualised physical activity programmes in sports, education, and healthcare.

To further understand how sports impact the immune system, differentiated training programmes should be developed. These programs should be tailored to one's immune system status and age-related factors. Additionally, long-term studies on various training cycle lengths are necessary. Expanding research to include children, adolescents, and older adults will help identify age-related dynamics in immune responses. Furthermore, there is a need for further interdisciplinary research at the intersection of neuroscience, endocrinology, and sports pedagogy.

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