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Sports and immunity: Analyzing the relationship between physical activity and immune response in athletes

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ABSTRACT

Problem: Physical activity has a complex relationship with immune function in athletes, where moderate exercise is generally beneficial, but intense training may suppress immunity. This systematic literature review examines how different exercise intensities impact immune responses in athletes, aiming to identify optimal training parameters for immune health. **Purpose:** The aim of this systematic literature review is to analyze the effects of various exercise intensities on immune function in athletes to determine training parameters that support optimal immune health. **Methods:** This study utilized a systematic literature review approach, gathering and analyzing scientific articles on the effects of exercise on athlete immune function. Articles were sourced from Scopus using search terms such as "Exercise," "Physical Activity," "Sports," and "Immune Response," with a focus on studies published within the past five years that evaluate exercise interventions on immune enhancement in athletes. After collecting relevant articles, descriptive analysis was conducted to identify consistent patterns and findings. **Results:** Intense and prolonged exercise can lead to immunosuppression in athletes, increasing susceptibility to infections and chronic conditions. However, moderate exercise enhances immune function, promoting beneficial responses such as improved lymphocyte distribution and antibody production post-vaccination. Key immune markers like NLR, PLR, and SII offer valuable insights into athletes' immune status and can assist in monitoring health and performance. **Conclusion:** Moderate exercise supports immune health, while intense exercise may suppress it. Athletes should balance training intensity and monitor immune markers to maintain optimal health and performance.

Keywords: exercise, immune function, athletes, immunosuppression, training intensity.

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Introduction

As the importance of physical activity in preserving overall health and avoiding disease becomes more widely acknowledged, the connection between exercise and immune function has become a crucial topic of research. area of investigation, fueled by the growing recognition of physical activity's role in maintaining general health and preventing disease (Igamberdievna & Igamberdievna, 2023). The immune system, responsible for defending the body against pathogens and maintaining homeostasis, is directly influenced by various external factors, including diet, stress, sleep, and exercise. Physical activity, from recreational sports to high-intensity training, is one of the key modifiable factors that can impact immune responses, potentially enhancing or, in some cases, impairing the body's natural defense mechanisms. Given the wide prevalence of exercise in various forms, a clear understanding of how different exercise modalities impact immune health is increasingly relevant to public health (Sattler, 2017).

Studies in exercise immunology suggest that regular, moderate-intensity exercise is associated with a decreased incidence of infection and improved immune function. This effect is attributed to the mobilization of immune cells, improved circulation, and the modulation of inflammatory responses(Chastin et al., 2020). However, exercise's impact on immunity is complex, with different exercise intensities and durations eliciting varied immune responses. For instance, while moderate exercise appears to strengthen immune surveillance and functionality, high-intensity and prolonged exercise may temporarily suppress immune function, leaving the body vulnerable to infection and illness in the hours or days following such exertion. This phenomenon,

known as the "open window" theory, suggests that athletes engaging in high-frequency or high-intensity training may face increased infection risk, an area of significant debate within the field (Walsh & Oliver, 2016).

Despite these findings, the precise nature and extent of physical activity's influence on immune function remain partially understood. The variability in study results concerning exercise intensity, type, and individual physiological responses points to significant gaps in the literature. Specifically, there is ongoing debate about the thresholds of exercise intensity and duration that optimize immune health versus those that may cause immunosuppression (Gleeson, 2007). Moreover, differences in methodologies, sample populations, and metrics for immune assessment have led to inconsistent findings, highlighting the need for a systematic approach to synthesize existing evidence.

This systematic review aims to provide a comprehensive evaluation of recent literature examining the complex interactions between exercise and immune function. By reviewing studies that explore various forms of physical activity and their effects on immune health, this review seeks to clarify the underlying mechanisms, potential benefits, and risks associated with exercise-induced immune changes. This paper is structured as follows: first, it presents an overview of immune function and its interaction with physical activity; second, it discusses the differential effects of exercise intensity and duration on immune health, focusing on both the protective aspects and potential risks of exercise-induced immunosuppression. Finally, recommendations for future research and practical applications are provided, aimed at guiding athletes, practitioners, and public health professionals toward optimal exercise regimens for immune health.

Method

The method used in this study is a systematic literature study that collects and analyzes various scientific sources. The data collection process is carried out by searching for articles from Scopus, the search string used were "Exercise" OR "Physical Activity" OR "Sports" OR "Endurance Training" OR "Resistance Training" OR "Physical Fitness" AND "Immune System" OR "Immunity" OR "Immune Response" OR "Immune Function" OR "Immunological which includes original article published in the last five years, studies evaluating the effects of exercise intervention on enhancing athlete immune. After collection, articles that met those criteria were analyzed descriptively to identify consistent patterns and findings regarding the effects of exercise intervention on enhancing athlete immune. Figure 1 illustrates the article selection process employed in this study.

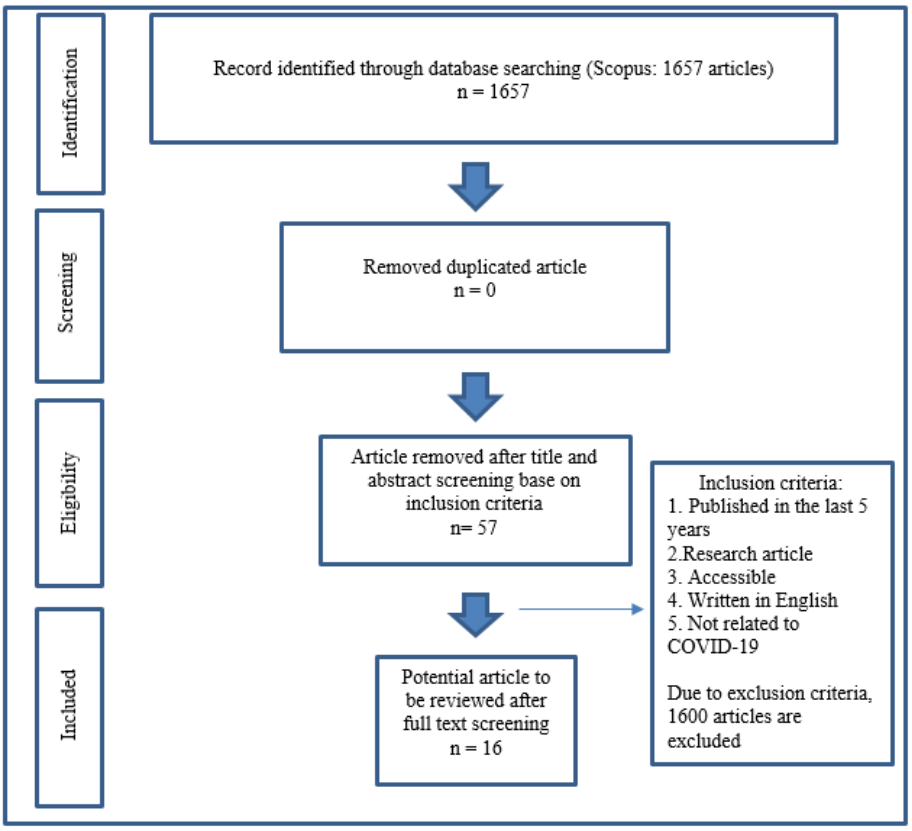

Figure 1. PRISMA flowchart of the study selection process

Results

Table 1 presents a critical appraisal analysis of sixteen selected journals.

Table 1. Literature Review Summary of Results

Researchers	Article Title	Research Results
(Malsagova et al., 2023)	Influence of sports training in foothills on the professional athlete's immunity	Intense and prolonged physical activity, especially at anaerobic thresholds without nutritional support, can lead to exercise-induced immunosuppression in athletes, characterized by decreased leukocyte counts and diminished humoral immunity, increasing susceptibility to infections and chronic diseases.
(Simpson et al., 2020)	Can exercise affect immune function to increase susceptibility to infection?	Athletes may experience higher infection rates, particularly upper respiratory infections, due to factors like intense training, anxiety, and environmental stressors. The paper debates whether exercise alone increases infection risk or if other factors contribute significantly to immune system alterations.
(Zacher et al., 2023)	Cellular integrative immune markers in elite athletes	The study indicates that integrative immune markers like NLR, PLR, and SII can reflect athletes' immune status, showing associations with aerobic fitness and potential responses to training load, aiding in monitoring health and performance in elite athletes.
(Simpson et al., 2021)	Exercise and adrenergic regulation of immunity	The paper highlights that exercise training positively impacts immunity by enhancing catecholamine signaling through leukocyte β-adrenergic receptors, promoting the mobilization of effector lymphocytes, and improving immune function, which is crucial for athletes in mitigating disease and inflammation.
(Papp et al., 2021)	Regular exercise may restore certain age-related alterations of adaptive immunity and rebalance immune regulation.	The paper highlights that regular exercise positively influences the immune system in older adults, improving the distribution of lymphocyte subtypes and enhancing immune regulation, which may help delay or reverse immunosenescence and maintain appropriate immune functions.
(Fink et al., 2024)	Sex differences in exercise-induced modulation of the humoral immune response to influenza vaccination	The study indicates that physical activity, particularly in athletes, enhances immune responses to influenza vaccination. Athletes exhibited higher antibody titers compared to non-active individuals, highlighting the positive impact of regular exercise on immune system function and overall health.
(Baek et al., 2020)	Exercise training reduces the risk of opportunistic infections after acute exercise and improves cytokine antigen recognition.	The paper indicates that exercise training, including acute exercise, does not increase the risk of opportunistic infections in athletes. Instead, it enhances immune function through antigen-specific responses, suggesting a positive relationship between exercise and immune system health in athletes.
(Langston et al., 2023)	Regulatory T cells shield muscle mitochondria from interferon-γ–mediated damage to promote the beneficial effects of exercise	The paper highlights that exercise induces an inflammatory response in skeletal muscles, with regulatory T cells (Tregs) playing a crucial role in modulating this response, protecting against inflammation, and supporting muscle

		adaptations, which can enhance athletic performance and immune function.
(Sellami et al., 2021)	Age and sport intensity-dependent changes in cytokines and telomere length in elite athletes.	The study highlights that exercise-associated immune responses, influenced by sport intensity, affect cytokine levels and oxidative stress markers in elite athletes, suggesting that higher intensity sports may enhance immune function and mitigate aging effects compared to lower intensity sports.
(Sellami et al., 2021)	Key viral immune genes and pathways identify elite athletes with URS.	The study indicates that habitual intense exercise in elite athletes may increase upper respiratory symptoms (URS) due to altered immune gene expression, particularly highlighting the upregulation of interferon-stimulated genes and viral signaling pathways associated with immune responses.
(Constantini et al., 2023)	The effect of exercise-induced hypoxemia on immune responses among endurance-trained athletes	The paper investigates exercise-induced hypoxemia's effects on immune responses in endurance athletes, revealing that immune marker perturbations were not significantly greater in athletes experiencing hypoxemia compared to those without, indicating complex interactions between intense exercise and immune system responses.
(Panagoulias et al., 2023)	Shifting gears: Study of immune system parameters of male habitual marathon runners	The study indicates that long-term marathon running leads to permanent changes in immune parameters, including a stable pro-inflammatory cytokine profile and increased regulatory T cells, suggesting endurance sports significantly influence athletes' immune system dynamics.
(Via et al., 2024)	Pedalling toward a deeper understanding of exercise effects on immune function	The paper discusses how exercise influences immune function, highlighting that acute exercise increases anti-inflammatory cytokines and leukocytes, but strenuous exercise can induce transient immunosuppression, affecting athletes' immune responses and potentially impacting their overall health and performance.
(Morgado et al., 2020)	The cellular composition of the innate and adaptive immune system is changed in blood in response to long-term swimming training	The study indicates that high training loads in competitive swimming can lead to a decrease in certain immune cell counts, potentially increasing susceptibility to upper respiratory symptoms, highlighting the complex relationship between intense physical activity and athletes' immune system health.
(Lobo et al., 2022)	A single bout of fatiguing aerobic exercise induces similar pronounced immunological responses in both sexes	Regular moderate-intensity physical exercise stimulates the immune system, enhancing protection against diseases. This study indicates that both male and female athletes exhibit similar acute immunological responses to aerobic exercise, suggesting comparable immune system training effects across sexes.
(Orysiak et al., 2021)	The impact of physical training on neutrophil extracellular traps in young male athletes–a pilot study	Intensive training can impact athletes' immune systems, leading to muscle damage and inflammation. Neutrophils and neutrophil extracellular traps (NETs) play a role in this response, indicating a potential disturbance in immune function following rigorous physical activity.

Discussion

This systematic review highlights the nuanced relationship between exercise and immune function, underscoring both the benefits and potential risks of different exercise intensities on immune health. The findings reinforce that moderate, regular exercise generally enhances immune surveillance and reduces the risk of infections (Simpson et al., 2020). Such activity triggers beneficial immune responses by mobilizing leukocytes, increasing circulation, and moderating inflammatory markers (Morgado et al., 2020). These adaptations not only improve overall immune readiness but may also have cumulative effects on chronic disease prevention and longevity. However, our review also identifies a threshold at which exercise may shift from being immunoprotected to potentially immunosuppressive. High-intensity or prolonged exercise sessions often seen in competitive athletes have been shown to create an "open window" period where immune function is temporarily impaired, increasing susceptibility to infections (Walsh & Oliver, 2016)). This immunosuppressive effect is believed to result from a combination of hormonal, metabolic, and physical stress factors that alter leukocyte counts, reduce immunoglobulin levels, and elevate pro-inflammatory cytokines. Athletes undergoing such regimens without adequate recovery time may face increased risks of upper respiratory tract infections (URTI) and other immune-related health concerns, presenting a critical consideration for sports professionals.

A particularly important aspect revealed by this review is the influence of individual differences on immune responses to exercise. Factors such as age, gender, baseline fitness, and genetic predisposition all modulate how one's immune system responds to physical stress. For instance, older adults may experience a diminished adaptive response, and women may have varying hormonal influences on immune reactivity compared to men. Personalized training regimens that account for these variables may therefore be essential in maximizing health benefits while minimizing immune risks associated with exercise (Foo et al., 2017).

Additionally, evidence suggests that alternating high-intensity exercise with recovery and incorporating periodized training may help maintain immune function while allowing athletes to achieve performance goals. Periodization models that integrate low-intensity recovery sessions and carefully monitored high-intensity workloads have shown promise in reducing immune suppression and maintaining higher immunocompetence over time (Atakan et al., 2021).

The dual effects of exercise on immune health offer practical implications for both elite athletes and the general population. For athletes, tailored training regimens that incorporate recovery periods and monitor immune biomarkers could mitigate risks of immunosuppression. For public health, promoting moderate-intensity physical activity can serve as a preventive measure, enhancing immunity and lowering the incidence of immune-related diseases, such as infections and inflammatory conditions. Health guidelines for exercise should therefore emphasize a balance between activity intensity and recovery, especially for populations at risk of immune compromise. This review, while comprehensive, is subject to several limitations. The studies included vary widely in terms of methodology, sample size, and outcome measures, which limits the generalizability of findings. Furthermore, most studies primarily involve young, healthy, and often male subjects, underscoring a need for more diverse sample populations. Future research should focus on longitudinal studies with larger and more varied demographics, particularly older adults, children, and those with underlying health conditions, to better understand how exercise can be optimized for immune health across the lifespan.

Conclusion

This review consolidates evidence that exercise plays a dual role in modulating immune health, where moderate activity enhances immune function, but intensive exercise can increase susceptibility to infections if not balanced with adequate recovery. These findings emphasize the need for personalized and periodized training approaches to maximize immune benefits while mitigating risks. By advancing our understanding of exercise immunology, this review offers a foundation for future research and practical guidelines aimed at optimizing exercise for immune health in both athletic and general populations. Future investigations might also explore the molecular mechanisms underlying exercise-induced immune modulation, including the roles of the gut microbiome and epigenetic factors. Moreover, randomized controlled trials examining recovery strategies, such as nutrition, sleep, and stress management, could provide actionable insights into mitigating exercise-induced immunosuppression.

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