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Effects of Exercise on the Immune System and Vaccination Effectiveness

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Abstract. In recent years, the interaction between exercise and immune function has received much attention in the context of vaccine efficacy research. In particular, the rapid popularization of global vaccines during the COVID-19 epidemic has made factors affecting immune response a key issue in the field of public health. The effects of different types, intensities, and timing of exercise on influenza, COVID-19, and other vaccine reactions are investigated in this study. Exercise is a modifiable lifestyle element. Research has found that acute moderate-intensity exercise before vaccination can enhance antibody production, while long-term regular training can help maintain immune memory. Meanwhile, exercise can indirectly enhance immune system function by improving mental health, reducing the negative effects of chronic stress. These results indicate that exercise affects innate and adaptive immunity through mechanisms such as cytokine regulation, improvement of immune cell circulation, and alleviation of chronic inflammation, suggesting that tailored "exercise prescriptions" may be included in vaccination plans to optimize immune protection. This paper emphasizes the importance of exercise in the immune system, provides objective recommendations, and outlines future research directions, providing a scientific basis for enhancing vaccine efficacy and immune function through exercise.

Keywords: Immune function, improvement, influenza vaccines

1. Introduction

One important tactic to lower the death and morbidity rates from numerous infectious diseases is vaccination. Countries with strong access and rapid roll-out of the vaccine have seen dramatic reductions in new cases and deaths. The first line of protection against invasive microbes is immunity.. Regular physical activity and exercise are the main strategies for preventing non-communicable diseases and exerting anti-inflammatory effects [1,2]. For many infectious diseases, vaccination is a common approach to prevention. However, individual biological differences and living habits can affect the efficacy of vaccines. Individual differences such as age and gender [3]. Vaccine efficacy varies from person to person, with particularly low responses in immunocompromised populations [4]. There is evidence suggesting that exercise in terms of lifestyle may affect the efficacy of vaccines. The public's understanding of physical exercise has improved as a result of the epidemic [5]. Affected by the novel coronavirus pneumonia (COVID-19) and influenza, most domestic and foreign studies have focused on whether exercise affects these two

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vaccines, while research on HPV, pneumococcal vaccine, hepatitis B vaccine, tetanus vaccine, diphtheria vaccine, and meningococcal vaccine remains limited. Given the increasing diversity of vaccine types and the growing public awareness of physical activity, it is necessary to study the impact of different exercise intensities and durations on different types of vaccines.

2. The impact of exercise on the efficacy of influenza vaccines

Understanding the biological and behavioral aspects impacting vaccine effectiveness has grown more crucial in light of the recent rapid development and deployment of vaccines, particularly during the COVID-19 pandemic. These factors not only impact individual protection but also shape public health strategies aimed at improving population-level immunity and vaccine coverage outcomes. Vaccine efficacy varies according to individual physical conditions, including age, gender and other factors, including declining antibody levels, viral variants prevalent during the study period, and the prevalence of COVID-19 in the population [3,6]. Exercise is one of the factors that affects both Vaccine effectiveness [7].

There is growing evidence that influenza vaccination, a successful non-pharmacological intervention, is improved by different degrees of physical activity (PA) and exercise intensity. For the intensities of exercise, a comprehensive meta-analysis that synthesized results from 38 studies involving approximately 6000 participants found a statistically significant improvement in antibody titers among those engaging in chronic aerobic exercise compared to other types of intervention, including acute aerobic exercise, acute resistance exercise, acute routine daily exercise, fitness levels, and physical activity levels. The number of influenza antibodies rises with chronic aerobic exercise. There is a moderate and clinically significant improvement in immunological response, as evidenced by the standardized mean difference (SMD) of 0.49 for chronic exercise and a confidence interval (CI) of 0.25–0.73. The conclusion that aerobic exercise primarily drove the overall improvement in influenza antibody response is supported by the subgroup analysis: the standardized mean difference (SMD) for aerobic exercise is 0.39, with a confidence interval (CI) of 0.19–0.58. Although both long-term duration and aerobic form are important, subgroup analyses revealed that this effect was primarily attributable to aerobic interventions. In contrast, chronic resistance or combined exercise types did not produce statistically significant improvements, highlighting aerobic activity as the primary contributor to the observed immunological benefits. If chronic exercise is not adopted, the local muscle damage caused by resistance exercise in acute exercise will prompt immune cells to target that area, which can maximize the effect of acute exercise [8].

The high physical activity group demonstrated stronger antibody responses than those with moderate activity levels, with the statistical test yielding $Chi^2 = 10.35$ and $p < 0.01$. High-intensity physical activity can enhance the antibodies produced by healthy individuals after influenza vaccination, and this effect does not become apparent until more than four weeks after vaccination. This effect seems to occur within four weeks after vaccination, and the proportion among the elderly (i.e., those over 64 years old) is more pronounced compared to young people (i.e., those under 23 years old). Forty-five minutes of moderate-intensity resistance exercise can reduce adverse reactions on the day of injection in the elderly, but it has no significant effect on antibody levels [9]. Additionally, it was discovered that whereas the proportion of women was adversely connected with physical activity, the proportion of men was positively connected with the generation of influenza vaccine antibodies following physical activity. For influenza vaccination, a young male who engages in regular chronic aerobic exercise will experience the most enhanced effectiveness of the vaccination, and vice versa.

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3. The positive effect of exercise on the antibody of the COVID-19 vaccine after vaccination

Nonetheless, it is well recognized that moderate to high levels of physical activity can improve immune function, as seen by higher responses to vaccination that are mediated by cells or antibodies. Following influenza and keyhole limpet hemocyanin (KLH) vaccination, people who regularly exercise or participate in exercise treatments have higher levels of IgG and IgM, according to both observational and interventional studies. Patients with autoimmune rheumatic disease (ARD) who are physically active had much higher vaccine responses than those who are not, according to a number of markers, such as seroconversion rate, geometric mean titer (GMT), and fold increase in antibody levels. Notably, the magnitude of improvement is often more pronounced in ARD patients than in non-ARD populations, suggesting that exercise serves as a compensatory enhancer of vaccine efficacy in immunocompromised individuals [10]. There may be a ceiling effect in younger populations, where an already strong antibody response cannot be further enhanced through intervention. This suggests that exercise therapies may be more beneficial for people with lower antibody responses to vaccinations (such older adults) than for people with stronger immune systems [4]. Additionally, the anti-spike antibody response in recipients of solid organ transplants declined following the first dose (17%) and second dose (54%) of the SARS-CoV-2 mRNA 1273 or BNT162b2 vaccination. Furthermore, the majority of specialists (75.5%) stated that public health programs, particularly those conducted during the COVID-19 epidemic, had a good effect on raising public awareness of physical fitness. They said that after seeing the detrimental consequences of a drop in physical fitness, people are more inclined to seize various chances for exercise in order to "prepare themselves for potential infection or vaccine response." Consequently, public perceptions of the campaign's impact on immune response and vaccine efficacy have also evolved [5].

4. Exercise's impact on the efficacy of other vaccines

Despite increasing interest in exercise as a behavioral adjuvant to vaccination, evidence about HPV vaccines is extremely limited. Adolescent recipients of the quadrivalent HPV vaccine (Gardasil) who engaged in upper-body resistance band exercise for 15 minutes before to each dose did not significantly differ in their antibody titers for HPV16 or HPV18 between exercise and control in a single randomized controlled experiment. Consequently, unlike influenza or COVID-19 vaccines, there is no clear support that acute exercise enhances the immunogenicity of HPV vaccination [11].

For pneumococcal vaccination, physical activity levels' exercise does not affect vaccine effectiveness post 4weeks and 6 months, whereas moderate aerobic interventions such as brisk walking did not affect either young or older subjects [7]. The findings imply that in order to improve the antibody response to vaccination, more vigorous activity is needed [4]. There is a negative correlation between physical exercise and the immunological response to the hepatitis B vaccine [12].. Only males benefit from exercise when it comes to meningococcal immunization. For the diphtheria vaccine, adverse effects from acute aerobic exercise were identified 48 hours after vaccination. Exercise for fitness level has no effect on antibodies against the tetanus vaccine, nor does it correlate with levels of physical activity at six weeks and six months. However, acute aerobic exercise was associated with adverse effects up to 48 hours after vaccination. In addition, for malaria and polio vaccines, there is insufficient data on the impact of campaigns on their vaccine efficacy [7].

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5. Exercise's impact on the immune system

As for the immune function itself, moderate exercise can strengthen immunosurveillance, and long-term repetitive exercise can bring multiple health benefits. The focus has shifted to innate immune cells like neutrophils in more recent studies. The most physically active individuals in a cross-sectional research of 211 older adults, for instance, had considerably greater neutrophil chemotactic accuracy toward interleukin-8 (IL-8), even though their migratory speed remained constant [13]. Similarly, both moderate-intensity continuous training (MICT) was shown to enhance neutrophil and monocyte function in sedentary individuals, and so does and high-intensity interval training (HIIT). Notably, despite 57% less total training time, HIIT achieved comparable immune benefits to MICT, demonstrating its time efficiency and suitability for innate immune enhancement [14].

Heart disease, cancer, and other chronic inflammatory illnesses are among the non-communicable diseases that can be effectively prevented by engaging in physical activity throughout one's lifetime [7]. Besides enhancing the overall immune system, one reason for this effect is that exercise has anti-inflammatory properties. During exercise, contracting skeletal muscles actively secrete interleukin-6 (IL-6), a key myokine, into the bloodstream. Strong anti-inflammatory mediators including interleukin-10 (IL-10) and interleukin-1 receptor antagonist (IL-1ra) are produced in response to IL-6. These substances contribute to the reduction of systemic inflammation by inhibiting the activity of pro-inflammatory cytokines such as TNF-α and IL-1β. Exercise also promotes an increase in regulatory T cells (Tregs), which are capable of producing IL-10. This contributes further to the suppression of excessive immune responses and helps prevent autoimmunity. Moreover, monocytes express Toll-like receptors (TLRs) on their surface, which detect danger signals and initiate inflammatory responses. The expression of these receptors is downregulated by physical activity, which results in decreased antigen presentation, a decrease in total immune activation, and a decrease in the production of pro-inflammatory cytokines (such as TNF-α and IL-1β). This can protect key metabolic tissues, such as fat, from inflammatory damage [2]. By strengthening the immune response against the vaccine's component antigens, frequent exercise may also help to maintain and develop immunological memory, which could eventually increase the longevity of vaccine-induced protection [1]. Physical and psychological symptoms of anxiety and sadness can be lessened by exercise. Exercise therapy can be regarded as an independent or supplementary treatment option. Because aerobic exercise has significant benefits in improving depressive symptoms and certain benefits in alleviating anxiety symptoms [15].

In conclusion, although the choice of exercise according to the vaccine type is the best choice, it will cost a lot of extra time and effort. And there are no authoritative training recommendations for different vaccines. Therefore, stratification according to population is a simple and feasible method. The elderly and immunocompromised people need long-term exercise, while the young people can try acute exercise to strengthen the vaccine effect because of their strong immunity. It must be emphasized that the above is only to improve vaccine efficacy, and long-term exercise itself is more beneficial to the human body. The benefit is to reduce the probability of disease. The recommendations are to perform one moderate-intensity aerobic exercise session before vaccination and to maintain a long-term exercise routine [7].

More research is required in the future to examine how exercise affects other vaccines, particularly those that are not influenza or COVID-19, like the hepatitis B, meningococcal, and HPV vaccines. Looking ahead, the integration of personalized exercise protocols with vaccination presents a promising direction for maximizing immunological outcomes. Given the variability in immune status across individuals—shaped by age, sex, physiological condition, and vaccine type—future research should explore algorithm-based interventions that tailor exercise prescriptions

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accordingly. Such models could recommend specific exercise modes (e.g., aerobic vs. resistance), intensities, and timing windows based on individual profiles, enhancing both safety and vaccine efficacy.

In parallel, the development of biomarker-guided strategies may further refine this synergy. Measuring immunological and inflammatory indicators before exercise, such as NK cell activity, TNF-α, and IL-6, may help predict a person's likelihood of responding well to exercise-enhanced vaccination. This “pre-vaccination immune fitness screening” model may be especially beneficial for vulnerable populations, including the elderly or immunocompromised, allowing clinicians to recommend the most effective and personalized combination of physical activity and immunization. Together, these approaches represent a shift toward precision immunology—where exercise is not only a health behavior but a scientifically optimized adjunct to vaccine response.

6. Conclusion

This paper emphasizes exercise’s dual role in enhancing vaccine effectiveness and boosting immunity in unvaccinated individuals. Regular physical activity improves antibody responses to both common vaccines (e.g., influenza, COVID-19) and less studied ones (e.g., HPV, pneumococcal, hepatitis B), while also benefiting mental health, reducing inflammation, and regulating immunity—particularly valuable for those with weakened immune systems. Current evidence shows moderate aerobic and resistance exercise around vaccination enhances humoral and cellular immunity, with stronger effects in older adults and those with chronic conditions. Consistent exercisers exhibit higher antibody titers and more durable immunity than sedentary individuals. Though most research focuses on COVID-19 and influenza vaccines, preliminary data suggest benefits for other vaccines, which remain underexplored. For unvaccinated individuals, exercise strengthens immune surveillance, enhances regulatory T-cell activity, and reduces pro-inflammation, improving disease resistance. This study highlights exercise as a low-cost, accessible adjunct to immunization, offering synergistic protection at individual and population levels amid rising vaccine-preventable diseases. Limitations include short-term studies, varied exercise protocols, and limited research on less common vaccines and immunocompromised groups. Future longitudinal, large-scale RCTs should identify optimal exercise parameters for different vaccines, clarify mechanisms, and develop personalized recommendations accounting for age, sex, and health. Addressing these gaps will inform evidence-based guidelines to maximize vaccine efficacy and immune resilience.

References

[1] Campbell, J. P. et al. (2018). Debunking the myth of exercise induced immune suppression: Redefining the impact of exercise on immunological health across the lifespan. Frontiers in Immunology, 9, Article 648.
[2] Gleeson, M. et al. (2011). The anti inflammatory effects of exercise: Mechanisms and implications for the prevention and treatment of disease. Nature Reviews Immunology, 11(9), 607–615.
[3] Bachmann, M. et al. (2024). Disparities in response to mRNA SARS-CoV-2 vaccines according to sex and age: A systematic review. New microbes and new infections, 63, 101551.
[4] Long, J. E. et al. (2012). Vaccination response following aerobic exercise: can a brisk walk enhance antibody response to pneumococcal and influenza vaccinations?. Brain, behavior, and immunity, 26(4), 680–687.
[5] Gelius, P. et al. (2021). Impact of the First Wave of COVID-19 on Physical Activity Promotion in the European Union: Results From a Policymaker Survey. Journal of physical activity & health, 18(12), 1490–1494.
[6] Lau, C. S. et al. (2022). Considerations in Understanding Vaccine Effectiveness. Vaccines, 11(1), 20.
[7] Dinas, P. C. et al. (2022). Effects of Exercise and Physical Activity Levels on Vaccination Efficacy: A Systematic Review and Meta-Analysis. Vaccines, 10(5), 769.

DOI: 10.54254/2753-8818/2025.AU27124

[8] Bohn-Goldbaum, E. et al. (2022). Physical activity and acute exercise benefit influenza vaccination response: A systematic review with individual participant data meta-analysis. PLOS ONE, 17(6), e0268625.
[9] Bohn-Goldbaum, E. et al. (2019). Acute exercise decreases vaccine reactions following influenza vaccination among older adults. Brain, Behavior, and Immunity - Health, 1, 100009.
[10] Bohn-Goldbaum, E. et al. (2019). Acute exercise does not improve immune response to HPV vaccination series in adolescents. Papillomavirus research (Amsterdam, Netherlands), 8, 100178.
[11] Gualano, B. et al. (2022). Association between physical activity and immunogenicity of an inactivated virus vaccine against SARS CoV 2 in patients with autoimmune rheumatic diseases. Brain, Behavior, and Immunity, 101, 49–56.
[12] Asamoah Sakyi, S. et al. (2024). Evaluation of Immune Characteristics and Factors Associated with Immune Response following Hepatitis B Vaccination among Ghanaian Adolescents. Advances in virology, 2024, 9502939.
[13] Bartlett, D. B. et al. (2016). Habitual physical activity is associated with the maintenance of neutrophil migratory dynamics in healthy older adults. Brain, behavior, and immunity, 56, 12–20.
[14] Bartlett, D. B. et al. (2017). Neutrophil and monocyte bactericidal responses to 10 weeks of low-volume high-intensity interval or moderate-intensity continuous training in sedentary adults. Oxidative Medicine and Cellular Longevity, 2017(1).
[15] Banyard, H. et al. (2025).The Effects of Aerobic and Resistance Exercise on Depression and Anxiety: Systematic Review With Meta-Analysis. International journal of mental health nursing, 34(3), e70054.