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The Impact of Physical Activity on Vaccine Effectiveness: A Narrative Review

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Abstract

Background: While vaccination is a crucial public health tool preventing millions of deaths worldwide every year, its efficacy is often constrained by age, sex, and metabolic health of individuals. In various studies physical activity (PA) both regular and acute, has emerged as a low-cost, modifiable factor capable of modulating immune responses to vaccines.

Objective: This review summarizes evidence on how habitual PA and acute exercise influence vaccine efficacy, exploring the mechanisms and variables (type, timing, intensity) that optimize outcomes across diverse groups.

Material & Methods: A literature search of PubMed and Google Scholar identified studies investigating habitual PA or acute exercise interventions on human immunological responses to vaccines (e.g., influenza, COVID-19).

Results: Habitual physical activity can act as a potent endogenous adjuvant, associated with higher post-vaccination antibody concentrations. It is particularly effective in older adults by countering immunosenescence and extending seroprotection. Acute exercise sessions performed near the time of vaccination also present adjuvant potential, especially for suboptimal vaccine responders. Localized eccentric resistance and aerobic sessions (>90 min) augment antibody titers, though efficacy varies by vaccine platform and demographics.

Conclusions: Physical activity is a safe, accessible non-pharmacological strategy to boost vaccine immunogenicity. While chronic exercise provides a robust physiological foundation, the success of acute exercise as a behavioral adjuvant depends on specific parameters of intensity and timing. Future large-scale randomized controlled trials, particularly in immunocompromised and elderly populations, are necessary to establish formal clinical guidelines.

Key words: physical activity, exercise, vaccination, vaccine efficacy, immunosenescence, behavioral adjuvant, immunogenicity.

1. Introduction

The introduction of vaccines has been one of the greatest advancements in the history of medicine, serving as the backbone of modern infectious disease prevention. Vaccination is widely regarded as one of the safest and most cost-effective public health interventions available. Globally, vaccines prevent an estimated 2 to 3 million deaths every year, and another 1.5 million deaths could be avoided by adequately increasing global vaccination coverage (Lee et al., 2021). Despite the monumental success of immunization programs, infectious diseases remain a significant global health issue, and numerous challenges in vaccinology still need to be addressed. One of the primary concerns is clinical vaccine efficacy. While vaccines are broadly effective, their efficacy varies significantly depending on the specific vaccine and the demographic receiving it. For example, standard influenza vaccinations effectively protect only about two-thirds of the general population and are estimated to be effective in merely 17% to 53% of older adults (Campbell et al., 2010; Ayling et al., 2018). Dozens of factors have been identified that modulate an individual's immune response to vaccination. Variables such as age, sex, level of psychological stress, body mass index (BMI), and psychological attitude all play an important role in determining overall vaccination efficacy (Chastin et al., 2021; Ayling et al., 2018; Sadarangani et al., 2022). Consequently, identifying factors that could be modifiable is becoming a point of growing interest. Many have been identified and studied over the years, e.g. sleep routine, psychological stress, nutrition. One of the behavioral interventions which has been found to have a profound influence is physical activity, which can generally be divided into two categories, chronic physical activity and acute bout of exercise before or after the vaccination (Chastin et al., 2021)

Regular physical activity is widely recognized as a primary modality for the prevention and management of numerous non-communicable diseases, serving as a cornerstone for improving overall cardiovascular and metabolic health (Chastin et al., 2021). It acts as a highly effective, low-cost lifestyle intervention that helps mitigate major global mortality risk factors, such as obesity and cardiovascular events (Sadarangani et al., 2022). It helps enhance cognitive functions in older populations (Dwojaczny & Bejtka, 2023). Furthermore, routine exercise plays a vital role in psychological well-being by reducing stress, anxiety, and the negative effects of social isolation

(Małajewicz et al., 2026). All these factors, when left unchecked, can suppress immunity and further increase the risk of chronic diseases (Silva et al., 2023).

Beyond chronic disease prevention, habitual physical activity is crucial for developing and maintaining a strong immune system and building systemic resilience against infectious agents. (Gasibat, 2021; Sroka et al., 2025). Engaging in the recommended levels of moderate-to-vigorous physical activity (e.g. 150 minutes per week) is associated with a 31% reduction in the risk of contracting community-acquired infectious diseases and a 37% decrease in infectious disease-related mortality (Chastin et al., 2021). By helping to control systemic inflammation and delaying the onset of age-related immunosenescence, regular exercise provides a robust physiological foundation that enhances the body's natural immunological defenses (Chastin et al., 2021; Silva et al., 2023). These mechanisms could potentially increase the response to vaccination in individuals.

Conversely, a single bout of acute exercise e.g. bicep curls triggers a localized inflammatory response characterized by increased blood flow, vascular permeability, and the release of cytokines such as interleukin-6 and type I interferons. This exercise-induced physiological stress enhances lymphatic drainage and promotes leukocytosis, which accelerates the activation and migration of antigen-presenting dendritic cells to the lymph nodes, which could thereby potentially augment antibody production upon vaccination. (Campbell et al., 2010; Pascoe et al., 2014)

Understanding the interaction between physical activity and vaccination has become increasingly relevant in the context of aging populations, the rising prevalence of chronic diseases, and global immunization campaigns, such as those implemented during the COVID-19 pandemic (Sadarangani et al., 2022; Silva et al., 2023). Clarifying whether exercise can serve as a practical, low-cost strategy to optimize vaccine responses carries important implications for both public health and clinical practice (Gasibat, 2021; Hallam et al., 2022).

Therefore, the aim of this narrative review is to summarize the current evidence regarding the effects of physical activity and exercise on vaccine efficacy, discuss the underlying immunological mechanisms, and evaluate how factors such as exercise type, timing, intensity, and vaccine platform influence vaccination outcomes.

2. Research materials and methods

2.1 Data collection

A comprehensive literature search was conducted using the online databases PubMed and Google Scholar to identify relevant publications investigating the relationship between physical activity, exercise, and vaccine-induced immune responses. The search included studies published between January 2007 and December 2024. The following keywords and combinations of terms were used:

“physical activity,” “exercise,” “acute exercise,” “chronic exercise,” “vaccination,” “vaccine efficacy,” “vaccine immunogenicity,” and “immune response.”

Studies were considered eligible if they investigated the effects of habitual physical activity, structured exercise interventions, or acute exercise performed around the time of vaccination on immunological responses in humans. Outcomes of interest included antibody titers, seroconversion, and other markers of vaccine-induced immunity. Randomized controlled trials constituted the primary source of evidence, while observational studies, systematic reviews, and meta-analyses were additionally included to provide broader scientific context. Studies conducted in healthy populations as well as individuals with chronic diseases, metabolic disorders, or immunocompromising conditions were considered eligible. Articles unrelated to the effects of physical activity or exercise on vaccination efficacy, studies conducted exclusively in animal models, and non-English publications were excluded from the review. Due to substantial heterogeneity in study design, exercise protocols, vaccine platforms, and immunological outcomes, the findings were synthesized narratively rather than quantitatively.

2.2. The use of AI

AI was utilized for specific purposes in this research. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Results

3.1.1. Chronic Physical Activity and Vaccine Responses

Habitual physical activity acts as a potent endogenous adjuvant that provides long-lasting benefits to immune function. Meta-analyses and cohort studies demonstrate that individuals adhering to regular moderate-to-vigorous physical activity programs are associated with a 31% lower risk of community-acquired infectious disease and significantly higher antibody concentrations following vaccination (Chastin et al., 2021; Dinas et al., 2022). Long-term exercise interventions lasting between 12 weeks and 10 months consistently improve several markers of baseline immune competence. These adaptations include elevated concentrations of T-helper (CD4+) cells, increased mucosal immunity through higher salivary IgA levels, and reductions in chronic systemic inflammation, creating a physiological environment favorable for antigen recognition and pathogen clearance (Chastin et al., 2021; Barni et al., 2023). Chronic training has also been associated with increased proportions of anti-apoptotic immune cells and enhanced pathogen clearance capacity. These long-term adaptations appear to improve immune homeostasis through reductions in chronic systemic inflammation, attenuation of immunosenescence, and preservation of adaptive immune function. Proposed mechanisms include maintenance of naïve T-cell pools, reductions in exhausted or senescent T-cells, enhanced natural killer (NK) cell cytotoxic activity, and preservation of leukocyte telomere length, collectively supporting more effective immune surveillance and vaccine responsiveness (Chastin et al., 2021; Barni et al., 2023; Wong et al., 2019).

3.1.2. Modalities of Chronic Exercise

Studies investigating chronic physical activity as a vaccine adjuvant employed three primary exercise modalities: aerobic training, resistance or combined training, and mind-body exercise interventions (Pascoe et al., 2014; Barni et al., 2023).

Aerobic training was the most frequently utilized modality and appears to be the primary driver of enhanced vaccine antibody responses (Chastin et al., 2021; Dinas et al., 2022). Interventions typically consisted of walking, running, or cycling performed at moderate-to-vigorous intensity levels, such as 55–75% of heart rate reserve or VO2max (Pascoe et al., 2014). These programs were generally structured as 3 to 5 sessions per week lasting 25 to 60 minutes per session, with total intervention durations ranging from 12 weeks to 10 months (Pascoe et al., 2014; Barni et al., 2023).

Some studies incorporated resistance training either alone or in combination with aerobic exercise (Barni et al., 2023). Resistance protocols commonly targeted large muscle groups using exercises such as squats, bench presses, hamstring curls, and shoulder presses performed to concentric failure (Barni et al., 2023). Combined interventions frequently paired aerobic conditioning with strengthening and flexibility activities and were usually performed three times weekly over 8 to 12 weeks (Barni et al., 2023).

Alternative modalities, particularly Taiji (Tai Chi Chuan) and Qigong, were also associated with enhanced immune responses (Pascoe et al., 2014; Barni et al., 2023). These interventions incorporated balance, postural alignment, and concentration exercises and were typically practiced for 30 to 60 minutes per session, 3 to 5 times weekly, over periods lasting 12 to 20 weeks (Pascoe et al., 2014; Barni et al., 2023).

3.1.3 Chronic Exercise Results in Specific Populations

The most consistent evidence supporting the adjuvant effects of chronic physical activity has been observed in older adults, a population particularly susceptible to immunosenescence and reduced vaccine efficacy. Systematic reviews indicate that older adults maintaining regular moderate exercise programs exhibit significantly greater antibody and cell-mediated responses following vaccination compared with sedentary peers (Pascoe et al., 2014). For example, a 10-month cardiovascular exercise intervention performed at 60–70% VO2max induced significantly longer-lasting seroprotective antibody responses to influenza vaccination, maintained for up to 24 weeks post-vaccination compared with flexibility and balance controls (Pascoe et al., 2014). Similar benefits have also been observed with mind-body exercise interventions. Older adults practicing Taiji and Qigong for 20 weeks demonstrated significantly higher anti-influenza antibody titers at both 3 and 20 weeks post-vaccination compared with non-exercising controls (Pascoe et al., 2014).

These benefits were also observed during the COVID-19 pandemic. Older adults participating in long-term combined aerobic and resistance training prior to the pandemic demonstrated significantly higher SARS-CoV-2-specific IgG and IgA concentrations following ChAdOx-1 vaccination compared with non-practitioners (Silva et al., 2023).

Positive associations between chronic physical activity and vaccine responses have also been reported in populations with metabolic comorbidities. In older adults with elevated cardiometabolic risk profiles, physical activity was associated with dose-dependent increases in antibody responses to influenza A/H3N2 vaccination independent of body mass index and waist circumference (Sadarangani et al., 2022). Similarly, elderly women accumulating high daily step counts (>18,500 steps/day) exhibited greater innate and adaptive immune activation and higher post-vaccination antibody titers compared with less active individuals (Gasibat, 2021).

In younger healthy adults, the effects of chronic exercise appear less pronounced. However, elite athletes engaged in intensive long-term training demonstrated significantly greater induction of vaccine-specific T-cells and neutralizing antibodies following tetravalent influenza vaccination compared with recreationally active controls (Dinas et al., 2022). Additionally, regular exercise in young men was associated with greater long-term maintenance of influenza-specific IgG antibody concentrations 12 months after vaccination compared with sedentary controls (Pascoe et al., 2014). However, researchers caution that the timing of vaccinations around an athlete's training schedule is critical. Excessively prolonged or strenuous bouts of exercise, such as completing a marathon or repeatedly training to exhaustion over several hours, may temporarily suppress immune function leading to impaired responses to vaccination (Pascoe et al., 2014).

3.2.1 Acute Exercise and Vaccine Responses

Acute exercise performed in close temporal proximity to vaccination has emerged as a potential endogenous adjuvant capable of enhancing both humoral and cell-mediated immune responses (Pascoe et al., 2014). Evidence suggests that a single exercise session may augment vaccine responses particularly in some populations when baseline vaccine immunogenicity is relatively weak or suboptimal (Campbell et al., 2010).

The mechanisms underlying acute exercise-induced immunoenhancement are believed to involve increased blood flow, elevated vascular permeability, localized muscle damage, and activation of antigen-presenting dendritic cells through the release of pro-inflammatory cytokines including interleukin-6 (IL-6) and granulocyte-macrophage colony-stimulating factor (GM-CSF) (Hallam et al., 2022; Pascoe et al., 2014). Additional mechanisms may include plasmacytoid dendritic cell activation and increased type I interferon (IFN-α) production, both of which may facilitate antibody class switching and antibody production (Hallam et al., 2022).

3.2.2 Exercise Modalities and Safety

The immunological efficacy of acute exercise depends strongly on exercise modality, duration, and intensity.

Localized eccentric resistance exercise, including bicep curls and lateral raises, has demonstrated the ability to increase vaccine-specific antibody responses (Edwards et al., 2007). Studies comparing eccentric exercise performed at 60%, 85%, and 110% of one-repetition maximum (1RM) reported similar adjuvant effects across all intensity levels, suggesting that severe tissue damage is not required to obtain immunological benefits. Comparable effects were also observed when exercise was performed immediately, 6 hours, or 48 hours before vaccination (Campbell et al., 2010; Pascoe et al., 2014).

Aerobic exercise has produced more variable outcomes depending primarily on exercise duration. Prolonged aerobic activity appears most effective. For example, 90 minutes of light-to-moderate intensity exercise performed immediately after vaccination significantly increased antibody titers following influenza (H1N1) and COVID-19 vaccination (Hallam et al., 2022). By contrast, shorter aerobic sessions such as 45-minute brisk walks frequently failed to significantly enhance antibody titers following pneumococcal or influenza vaccination (Long et al., 2012).

From a safety perspective, acute exercise performed prior to vaccination is generally well tolerated, inexpensive, and does not appear to increase local or systemic adverse effects. Some studies have even suggested reductions in the occurrence of adverse events following immunization (AEFI), including fever (Elzayat et al., 2021). However, excessively strenuous exercise performed on the day of vaccination may increase the likelihood of systemic adverse reactions and is therefore not recommended (Kenzaka et al., 2021).

3.2.3 Population-Specific Differences

The effectiveness of acute exercise as a vaccine adjuvant varies according to age, sex, and baseline health status. Acute exercise frequently demonstrates sex-specific immunological effects. Following influenza vaccination, acute eccentric exercise enhanced cell-mediated immunity predominantly in men while selectively improving antibody responses in women (Edwards et al., 2007). Conversely, men exhibited enhanced antibody responses to thymus-independent meningococcal A vaccines following acute stress or exercise, whereas women showed little measurable benefit (Edwards et al., 2008).

While older adults stand to benefit most from behavioral interventions due to immunosenescence, randomized trials investigating acute exercise in this demographic remain inconsistent. For instance, acute eccentric resistance exercise failed to significantly enhance antibody or cell-mediated responses following influenza vaccination (Edwards et al., 2015; Elzayat, 2022). This suggests that age-related declines in inflammatory signaling may attenuate the local adjuvant effects of acute muscle stress. Conversely, in older women, moderate aerobic exercise has demonstrated efficacy, improving effect of influenza vaccination for suboptimal responders with low pre-vaccination titers (Ranadive et al., 2014). Furthermore, acute aerobic interventions seem to be beneficial regardless of body composition. A 90-minute bout of light-to-moderate aerobic exercise performed immediately after the Pfizer-BioNTech COVID-19 vaccination consistently increased serum antibodies across a cohort where nearly half the participants were classified as overweight or obese (Hallam et al., 2022)

3.3 Vaccine Type and Platform Differences

The influence of exercise on vaccine responses has been investigated across multiple vaccine platforms, including influenza, pneumococcal, meningococcal, diphtheria, tetanus, and SARS-CoV-2 vaccines.

Overall, exercise-related immunoenhancement has been reported across multiple vaccine types, although the magnitude of benefit depends strongly on baseline vaccine immunogenicity and the presence of a potential “ceiling effect.” Highly immunogenic full-dose vaccines often induce near-maximal immune responses in healthy individuals, limiting the potential for additional enhancement through exercise. For instance, acute upper-body resistance exercise did not enhance antibody responses to the highly immunogenic HPV vaccine in healthy adolescents (Bohn-Goldbaum et al., 2019). In contrast, exercise may substantially augment responses to weaker or reduced-dose vaccines (Edwards et al., 2012). Beneficial effects have been reported for both thymus-dependent and thymus-independent vaccines, indicating that exercise-mediated enhancement is not exclusively dependent on T-cell pathways. Similar findings have also been reported for modern SARS-CoV-2 vaccine platforms, including mRNA, vector-based, and inactivated vaccines. For example, aerobic exercise following administration of the Pfizer-BioNTech COVID-19 vaccine increased anti-RBD IgG antibody concentrations (Hallam et al., 2022).

However, findings remain inconsistent in certain populations and vaccine settings. In patients with spondyloarthritis, acute resistance exercise performed prior to a CoronaVac booster dose failed to further enhance an already robust neutralizing antibody response (Gualano et al., 2022). Additionally, while some studies reported beneficial effects for meningococcal vaccines, others investigating diphtheria and tetanus vaccines demonstrated null or potentially adverse outcomes (Edwards et al., 2008; Dinas et al., 2022). These inconsistencies suggest that the effectiveness of exercise as a vaccine adjuvant depends on interactions between vaccine platform, baseline immunogenicity, population characteristics, and exercise timing or modality.

4. Discussion

4.1 Methodological Heterogenicity

Studies suggest a clear influence of exercise on vaccine efficacy, which is most prominent in the studies considering chronic physical activity. Results on acute bouts of exercise remain mixed. The notable inconsistencies in the literature are driven by several critical differences across study designs. Methodologies vary drastically in exercise modality (aerobic vs. resistance/eccentric), intensity, duration, and the timing of the exercise relative to the injection. Furthermore, sex-specific differences, or sexual dimorphisms, are frequently observed but vary by vaccine type (Edwards et al., 2007; Edwards et al., 2008). For example, acute exercise prior to influenza vaccination has been shown to enhance antibody responses primarily in women, whereas the same intervention prior to meningococcal A vaccination enhances responses primarily in men (Edwards et al., 2007; Edwards et al., 2008). Age is another major differentiator; while chronic exercise reliably boosts immunity in older adults, acute exercise interventions often fail to elicit the same robust local inflammatory signals in older populations as they do in young, healthy adults (Elzayat et al., 2021; Long et al., 2012).

4.2 Clinical Implications

Utilizing exercise as a behavioral adjuvant holds considerable promise for clinical practice and public health (Gasibat, 2021; Edwards et al., 2012). Unlike traditional pharmacological adjuvants, exercise is a safe, low-cost, and broadly accessible intervention that avoids expensive clinical trials and does not appear to significantly increase adverse reactogenicity (Gasibat, 2021). This is particularly vital for aging populations or those with metabolic co-morbidities who typically exhibit sub-optimal responses to standard immunizations (Sadarangani et al., 2022; A.R. Pascoe et al., 2014). From a practical standpoint, engaging in standard daily activities or mild-to-moderate exercise on the day of vaccination is entirely safe and does not hinder vaccine efficacy; however, patients should be advised to avoid highly strenuous or exhaustive physical exertion on the exact day of their appointment, as it may increase the incidence of systemic adverse reactions such as fatigue or headache (Kenzaka et al., 2021).

4.3 Limitations

Despite encouraging data, several limitations restrict the generalizability of current findings. A pervasive issue in acute exercise trials is the reliance on young, healthy, and immunocompetent cohorts (Edwards et al., 2012; Pascoe et al., 2014). Because these individuals naturally mount maximal immune responses, a "ceiling effect" often masks the true adjuvant potential of the intervention (Gasibat, 2021; Edwards et al., 2012). Additionally, many randomized controlled trials suffer from small sample sizes, reducing statistical power and elevating the risk of Type II errors (Hallam et al., 2022; Gualano et al., 2022). Mechanistically, studies frequently rely on systemic measurements of cytokines (e.g., plasma IL-6) rather than assessing the local microenvironment at the injection site, which may fail to accurately reflect dendritic cell recruitment (Hallam et al., 2022). Finally, many observational studies assessing chronic physical activity or adverse side effects rely on self-reported questionnaires, which are highly susceptible to recall bias and subjective interpretation (Chastin et al., 2021).

4.4 Future Research

To translate these findings into standardized clinical guidelines, particular emphasis should be placed on large-scale randomized controlled trials focusing on at-risk, immunocompromised, and older populations who stand to benefit most from immune enhancement. Investigations are needed to clarify the optimal dose-response relationship of acute exercise, specifically identifying the ideal modality, intensity, duration, and timing relative to vaccine administration. Furthermore, future studies should routinely stratify data by sex to better understand the mechanisms driving sexual dimorphism in vaccine responses and incorporate localized tissue assessments to precisely track the antigen-presentation pathways driven by exercise-induced inflammation.

5. Conclusion

In conclusion, current evidence suggests that physical activity represents a promising non-pharmacological behavioral adjuvant capable of enhancing vaccine efficacy and supporting immune function. Regular physical activity improves baseline immunity, may counteract immunosenescence, and appear particularly beneficial for older adults and individuals with chronic metabolic conditions. In addition, acute exercise performed around the time of vaccination may augment immune responses, especially in populations with suboptimal vaccine responsiveness or when lower-immunogenic vaccines are administered. As a safe, accessible, and low-cost intervention, physical activity could contribute meaningfully to global vaccination strategies. However, the available literature remains limited by methodological heterogeneity, varying exercise protocols, and the frequent “ceiling effect” observed in healthy populations. Therefore, further large-scale, standardized randomized controlled trials are needed to determine the optimal type, intensity, and timing of exercise interventions and to better understand the mechanisms underlying exercise-induced immunoenhancement.

Disclossure

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Conflicts of Interest

The authors declare no conflict of interest

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