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## Physical Activity as a Modulator of Gut Microbiota Diversity: Evidence from Human Studies

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**Abstract**

**Introduction and purpose:** The human gut microbiota plays a crucial role in maintaining overall health, influencing metabolic, immune, and neurological processes. Physical activity has emerged as a potentially modifiable factor affecting gut microbiota composition and

diversity. The aim of this narrative review was to evaluate current evidence on the impact of physical activity on gut microbiota diversity in humans.

**Brief description of the state of knowledge:** This review was based on a comprehensive search of PubMed and Google Scholar and included studies published between 2010 and 2026. Only studies involving human participants and examining the relationship between physical activity and gut microbiota were considered. Available evidence indicates that physical activity is associated with changes in gut microbiota composition and, in some cases, with increased diversity and a greater abundance of beneficial bacterial taxa. Both observational and interventional studies suggest that exercise may positively influence microbial composition; however, the magnitude of these effects depends on exercise type, intensity, duration, and individual characteristics. Diet was consistently identified as a major confounding factor influencing gut microbiota outcomes.

**Summary:** Physical activity appears to be an important modulator of gut microbiota in humans, with more consistent effects on microbial composition and function than on overall diversity. However, these effects are complex and influenced by multiple interacting factors, particularly dietary habits. Further well-designed human studies are needed to clarify the mechanisms underlying these interactions.

**Keywords:** Gastrointestinal Microbiome; Exercise; Physical Activity; Microbial Diversity; Dysbiosis; Short-Chain Fatty Acids

## 1. Introduction and purpose

The human gut microbiota is a complex and dynamic community of trillions of microorganisms that plays a crucial role in maintaining host health, influencing metabolic processes, immune function, and even neurobehavioral pathways (1,2). In recent years, growing scientific interest has focused on identifying modifiable lifestyle factors that shape the composition and diversity of the gut microbiome (1,2). Among these, physical activity has emerged as a potentially significant determinant of gut microbial health (3–6).

Gut microbiota diversity, commonly assessed through alpha diversity indices such as the Shannon index, is widely recognized as a key indicator of a resilient and functionally stable microbial ecosystem (7,8). In practical terms, greater diversity is often interpreted as reflecting a broader functional repertoire of the microbiome, increased ecological stability, and a greater ability to resist external perturbations such as dietary changes, illness, or medication exposure. Reduced microbial diversity has been associated with a variety of

pathological conditions, including metabolic disorders, inflammatory diseases, and impaired immune responses (8,9). Therefore, understanding factors that can enhance or maintain microbial diversity is of substantial clinical and public health importance, particularly in the context of preventive medicine and lifestyle-based interventions.

Physical activity is well known for its broad health benefits, including improvements in cardiovascular fitness, metabolic regulation, and mental health (10). More recently, evidence has suggested that exercise may also exert beneficial effects on the gut microbiota (1,11). Both observational and interventional studies indicate that physically active individuals tend to exhibit greater microbial diversity and a higher abundance of beneficial bacterial taxa compared to sedentary individuals (4,5,12,13). Moreover, exercise-induced changes in gut microbiota have been linked to increased production of short-chain fatty acids (SCFAs), which play a key role in maintaining intestinal barrier integrity and modulating immune function (14,15).

However, despite increasing interest in this field, the relationship between physical activity and gut microbiota remains complex and not fully understood. The magnitude and direction of microbiota changes appear to depend on multiple factors, including the type, intensity, and duration of exercise, as well as individual characteristics such as age, metabolic status, diet, and baseline microbiota composition (1,3,16–18). This means that the same training intervention may lead to different microbiota responses in different individuals, even when the exercise prescription appears similar on paper. Importantly, diet represents a major confounding factor, as it independently influences gut microbiota and often correlates with physical activity levels (19,20). For this reason, the independent effect of exercise is often difficult to isolate, especially in observational studies and in athlete populations with characteristic dietary patterns. Furthermore, while randomized controlled trials provide evidence for a causal relationship between exercise and microbiota alterations, results are not always consistent, and some studies suggest that exercise alone may not be sufficient to induce substantial or uniform changes without considering dietary context and metabolic phenotype (1,18,21). These inconsistencies highlight the need for a comprehensive synthesis of current evidence.

Given the growing body of literature and the heterogeneity of findings, a narrative review approach is particularly suitable to integrate and critically evaluate existing studies. This review aims to provide an up-to-date overview of the impact of physical activity on gut microbiota diversity in humans, with particular emphasis on the role of exercise type, intensity, and duration, as well as potential confounding factors.

The significance of this research area extends beyond sports science, as exercise-induced modulation of the gut microbiota may also influence broader systemic processes, including inflammation and host metabolism.

The aim of this narrative review was to evaluate current evidence on the impact of physical activity on gut microbiota diversity in humans, with particular attention to exercise type, intensity, duration, and the modifying role of diet. This review was based on a literature search conducted in PubMed and Google Scholar for studies published between 2010 and 2026. Only studies involving human participants and examining the relationship between physical activity or exercise and gut microbiota composition or diversity were included. Original research articles, systematic reviews, and meta-analyses published in English or Polish were considered. Animal studies, conference abstracts, editorials, and non-peer-reviewed sources were excluded. Due to the heterogeneity of the available evidence, a qualitative synthesis was performed.

## **2. Description of the State of Knowledge**

### **2.1. Effects of Physical Activity on Gut Microbiota Diversity**

A growing body of evidence indicates that physical activity is associated with measurable alterations in gut microbiota composition and, to a lesser extent, diversity in humans, a conclusion also supported by recent systematic reviews and meta-analyses (3,6). Across both observational and interventional designs, physically active individuals often present distinct microbial profiles compared with sedentary counterparts (4,5,12). These differences are not always expressed as uniform increases in richness or evenness, but they often reflect meaningful shifts in the relative abundance of taxa associated with metabolic and anti-inflammatory functions. Higher alpha diversity—commonly assessed using indices such as Shannon or Simpson—is frequently interpreted as a marker of a more resilient ecosystem. However, a critical distinction must be made between changes in microbial composition and global diversity metrics. Diversity indices should therefore be interpreted cautiously, because they do not always capture functionally important compositional changes that may occur even in the absence of large shifts in global diversity. Current evidence suggests that while physical activity may modulate specific bacterial taxa and functional metabolic pathways—such as those involved in SCFA production—its impact on alpha diversity (e.g., Shannon index) remains inconsistent. Exercise appears to preferentially influence the relative abundance of beneficial microbes rather than consistently increasing the overall richness of the ecosystem.

Observational studies demonstrate associations between cardiorespiratory fitness, habitual physical activity, and microbiota characteristics, including the relative abundance of taxa linked to beneficial metabolic functions such as short-chain fatty acid (SCFA) production (13,22). However, these associations do not necessarily imply a direct causal relationship and may be influenced by confounding factors such as diet and lifestyle.

Evidence from interventional studies suggests that exercise can induce shifts in microbial composition, although effects on alpha diversity are variable and may differ across populations such as older adults and individuals with impaired glucose metabolism (1,3,21). For example, structured exercise interventions have been shown to modulate microbiota composition and metabolic activity, with increases in SCFA-related pathways, while changes in overall diversity are often modest or absent (1,16). Importantly, some studies report that microbiota alterations may be transient and partially reversed following cessation of training (1).

Overall, current evidence suggests that physical activity modulates the gut microbiota; however, its impact on diversity appears heterogeneous and context-dependent, with more consistent effects observed at the level of microbial composition and function rather than global diversity metrics.

This heterogeneity is consistent with recent meta-analytic evidence suggesting that exercise may improve selected diversity indices, particularly Shannon diversity, while overall findings remain sensitive to study design, population characteristics, and methodological differences (6). Taken together, these findings suggest that the influence of physical activity on the gut microbiota should be interpreted primarily in terms of compositional and functional modulation rather than as a simple and universal increase in diversity.

## **2.2. Influence of Exercise Type, Intensity, and Duration**

The impact of physical activity on gut microbiota is influenced by exercise characteristics, including type, intensity, and duration, with recent evidence suggesting that exercise intensity may produce distinct microbiome and metabolic signatures in clinical populations (18). Different exercise modalities appear to exert distinct effects on microbial composition and functional outputs.

Aerobic exercise has been most consistently associated with beneficial microbiota-related outcomes, including enrichment of SCFA-producing taxa and improvements in metabolic profiles (1), although recent work suggests that the magnitude of these effects may vary according to exercise intensity and underlying metabolic disease (18).

Resistance training may also influence gut microbiota, although available evidence suggests that its effects may differ in magnitude and taxonomic specificity, likely reflecting differences in metabolic demand and physiological adaptation.

While moderate-intensity physical activity is generally associated with favorable shifts in microbial profiles, the impact of exercise is not strictly linear. In other words, greater training load does not automatically translate into more favorable microbiota-related outcomes. High-intensity or excessively prolonged exertion, particularly in endurance athletes, may produce mixed or adverse outcomes. Specifically, such extreme physiological loads can increase intestinal permeability, alter splanchnic blood flow, and trigger transient dysbiosis, often accompanied by gastrointestinal symptoms. This observation suggests that the relationship between exercise and gut health follows a context-dependent pattern in which moderate and well-tolerated training may be beneficial, whereas chronic excessive load may become physiologically disruptive.

The duration of exercise interventions also plays a critical role, as some studies suggest that structured interventions can shift microbial composition without necessarily producing robust or lasting changes in overall diversity across all populations (1,21). Short-term interventions may induce temporary changes in microbial composition, while longer-term and consistent physical activity appears necessary to sustain microbiota adaptations (1).

Collectively, these findings indicate that the relationship between physical activity and gut microbiota is not binary but depends on exercise characteristics, reinforcing the importance of considering training parameters when interpreting microbiome-related outcomes.

### **2.3. Athletes vs. Sedentary Individuals**

Comparative studies between athletes and sedentary individuals provide additional insight into the relationship between physical activity and gut microbiota. Athletes often exhibit distinct microbial profiles and, in some cases, higher diversity compared with less active populations (4,5,13).

In addition to compositional differences, athlete microbiota is frequently enriched in taxa associated with metabolic efficiency, including those involved in SCFA production and lactate metabolism (23). These adaptations may reflect increased energy demands and substrate utilization associated with regular training.

However, these differences cannot be attributed solely to physical activity. Athletes typically follow specific dietary patterns—often characterized by higher intake of protein, fiber, or carbohydrates—which independently influence gut microbiota composition (19). Therefore, diet represents a major confounding factor in athlete–sedentary comparisons.

Moreover, excessive or prolonged physical exertion may have complex physiological effects. While moderate exercise is associated with beneficial outcomes, high training loads may increase intestinal permeability and gastrointestinal symptoms, potentially influencing microbiota stability.

Overall, athlete–sedentary comparisons support an association between high levels of physical activity and distinct microbiota profiles; however, these findings should be interpreted within the broader context of lifestyle and dietary factors. It is particularly important to remember that athletes differ from sedentary controls not only in training volume, but also in sleep patterns, stress exposure, recovery practices, body composition, and nutritional strategies. As a result, athlete–sedentary comparisons are informative, but they do not by themselves prove that physical activity is the sole driver of the observed microbiota differences.

#### **2.4. Mechanisms Linking Physical Activity and Gut Microbiota**

Several biological mechanisms have been proposed to explain the relationship between physical activity and gut microbiota, involving multiple interconnected pathways. A primary mechanism involves the increased abundance of taxa such as *Faecalibacterium* and *Roseburia*, which enhance the production of short-chain fatty acids (SCFAs) like butyrate. These metabolites are critical for maintaining epithelial integrity and modulating systemic immune responses (14,15).

Physical activity has been associated with an increased abundance of SCFA-producing bacteria, such as *Faecalibacterium* and *Roseburia*, which are linked to anti-inflammatory effects and metabolic health (12,24). These functional shifts may partly explain the systemic benefits of exercise.

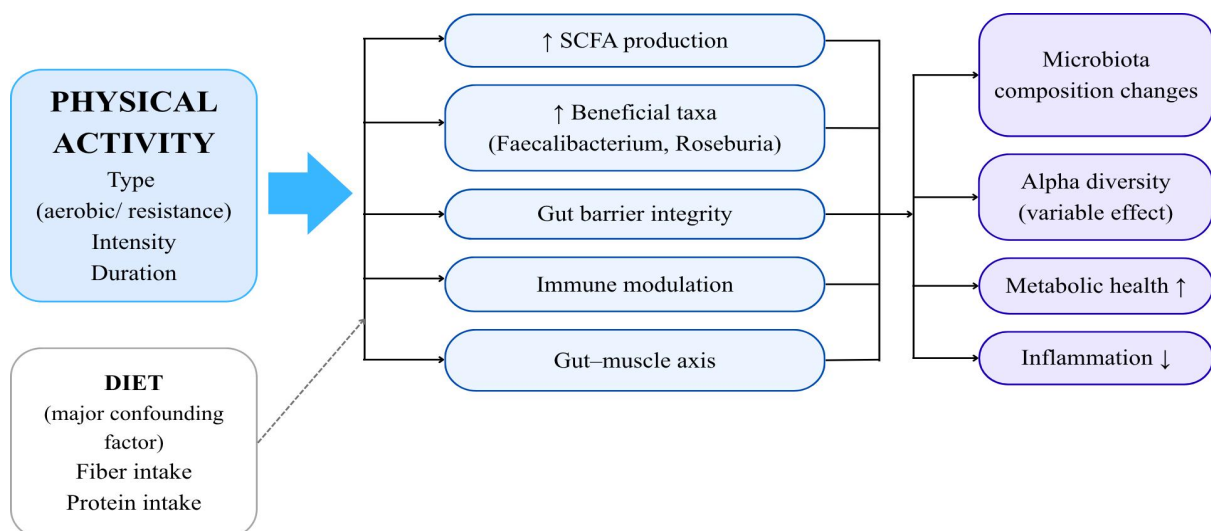
Exercise also influences immune regulation and gut barrier function. Regular physical activity is associated with reduced pro-inflammatory signaling, improved epithelial integrity, and a more balanced interaction between the host immune system and intestinal microorganisms, which may promote a more favorable microbial environment (2,14). These effects are clinically relevant because maintenance of the intestinal barrier limits the translocation of harmful microbial products and may help reduce low-grade systemic

inflammation. In this way, physical activity may shape the microbiota not only directly through physiological changes in the gut, but also indirectly by modifying the host environment in which microbial communities function.

Beyond metabolic byproducts, the "gut-muscle axis" highlights a bidirectional interaction where specific microbes contribute to energy metabolism and lactate utilization, directly influencing physical performance. These observations suggest that exercise-related microbiota changes may have functional consequences extending beyond the intestinal environment itself. However, these adaptations are often more consistently reflected in functional outputs and specific taxonomic shifts rather than uniform increases in global diversity (23).

This distinction is vital for interpreting research results, as a reliance on diversity metrics alone may obscure functionally relevant microbiota adaptations induced by training. Moreover, because these compositional shifts may be transient and partially reversed after the cessation of exercise, sustained physical activity is likely required to maintain a stable and health-promoting microbial profile.

Despite these advances, the underlying mechanisms remain incompletely understood and are likely influenced by multiple interacting factors, including diet, training status, and baseline microbiota composition. A major limitation of the current evidence base is the heterogeneity of study designs and the difficulty in isolating the independent effect of physical activity from dietary influences.



Source: author's own elaboration (based on 1,5,15).

**Figure 1. Conceptual model illustrating the relationship between physical activity and gut microbiota in humans.**

Physical activity (type, intensity, and duration) influences gut microbiota through multiple physiological and biochemical mechanisms, including increased short-chain fatty acid (SCFA) production, modulation of beneficial bacterial taxa, improved gut barrier integrity, and immune regulation. These changes primarily affect microbial composition and metabolic function, while effects on overall diversity remain variable and context-dependent. Diet acts as a major confounding and modifying factor influencing gut microbiota outcomes.

## **2.5. The Synergistic Effect of Diet and Physical Activity**

A growing body of evidence suggests that the impact of physical activity on the gut microbiota is closely intertwined with dietary patterns. High-fiber diets, rich in prebiotics, appear to act synergistically with exercise to promote the growth of saccharolytic bacteria, such as *Bifidobacterium* and *Lactobacillus* (8,20). These microbes ferment undigested carbohydrates into SCFAs, which further enhances the anti-inflammatory effects of physical training (15).

Conversely, high-protein diets frequently consumed by athletes to support muscle hypertrophy may lead to distinct microbial adaptations (19). While protein is essential for recovery and muscle remodeling, excessive intake of animal protein without adequate fiber may shift the microbiota toward a more proteolytic profile and alter the production of metabolites that may negatively affect colonic health (20). This highlights the fact that exercise does not operate in isolation, but interacts continuously with the nutritional environment in which it is performed. Therefore, the “athlete’s gut” reflects both physical training and dietary patterns, suggesting that exercise-induced microbial shifts cannot be fully understood without considering macronutrient distribution, fiber intake, and overall dietary quality.

## **2.6. Interpretation of Current Evidence**

Current evidence suggests that physical activity is an important modulator of gut microbiota; however, its effects are complex and not uniformly reflected in global diversity metrics, a conclusion reinforced by recent systematic reviews and meta-analyses (3,6). While some studies report increased microbial diversity in physically active individuals, others demonstrate modest or non-significant changes, indicating that the effects of exercise are context-dependent and influenced by multiple factors (1,4,5,12).

Overall, the relationship between physical activity and gut microbiota appears context-dependent rather than universally directional. Exercise appears to preferentially influence specific microbial taxa and metabolic functions rather than consistently increasing overall diversity.

Variability in diet, baseline microbiota composition, age, training status, and metabolic health may significantly influence observed outcomes (3,17,18). More broadly, this complexity is also evident in non-athlete populations, particularly in older adults and metabolically compromised individuals, in whom physical activity interacts with obesity,

metabolic syndrome, and habitual diet in shaping gut microbial structure (3,17). In particular, diet remains a major confounding factor, as it independently shapes gut microbiota and often correlates with physical activity levels (19).

Another important consideration is the magnitude and persistence of microbiota changes. While some intervention studies report exercise-induced adaptations, these effects may be modest, transient, or population-specific, and may require sustained physical activity to be maintained (1,18,21).

From a mechanistic perspective, exercise-related changes in SCFA production, immune regulation, and gut barrier integrity likely play key roles (15). Additionally, emerging evidence supports the gut–muscle axis as a potential pathway linking microbiota composition with exercise performance (23).

Notably, much of the available evidence is derived from relatively small-scale or heterogeneous studies, which may limit the generalizability of findings. Sample sizes are often modest, intervention durations vary considerably, and many studies differ in the degree to which diet, medication use, or baseline metabolic status are controlled. A major limitation of the current evidence base is the substantial heterogeneity in study design, including differences in exercise protocols, participant characteristics, dietary control, and microbiome assessment methodologies. This heterogeneity makes direct comparison between studies difficult and partly explains why conclusions regarding diversity outcomes remain less consistent than conclusions regarding compositional or functional changes.

Despite growing interest in this field, clear causal pathways linking specific exercise parameters to microbiota-mediated health outcomes remain insufficiently defined. These findings may have practical implications for the development of exercise-based strategies aimed at improving metabolic and gastrointestinal health.

## **2.7. Future Perspectives and Clinical Implications**

Despite the promising findings regarding the exercise-microbiota link, several gaps in the literature remain. Most available studies are cross-sectional, making it difficult to establish definitive causality, although newer randomized and controlled studies in populations with prediabetes and type 2 diabetes are beginning to address this limitation (18,21). Future research should prioritize longitudinal interventions with standardized exercise protocols and rigorous dietary controls to isolate the independent effects of physical activity.

Furthermore, the integration of multi-omics approaches—combining 16S rRNA sequencing with metagenomics, metabolomics, and proteomics—is essential to move beyond

taxonomic descriptions and understand the functional capacity of the microbiota. Such an approach would make it possible to determine not only which bacterial taxa are present, but also what they are doing, which metabolites they produce, and how these metabolic outputs may interact with host physiology during and after exercise. This is particularly important because functionally relevant microbiota changes may occur even when changes in overall diversity appear modest. From a clinical perspective, understanding these relationships opens the door to personalized "exercise-microbiome" prescriptions. Such interventions could potentially be used as adjunctive therapies for metabolic disorders, obesity, and inflammatory bowel diseases (IBD). Identifying specific "responder" phenotypes could allow clinicians to tailor physical activity recommendations to an individual's baseline microbial profile, optimizing both metabolic outcomes and athletic performance. Particular attention should also be paid to aging populations, as older adults may exhibit distinct microbiota responses to exercise due to age-related reductions in microbial diversity and the frequent coexistence of metabolic comorbidities (3,17).

### **3. Summary**

Physical activity represents an important modulator of gut microbiota; however, its effects on microbial diversity are variable and context-dependent. Current evidence suggests that exercise more consistently influences microbial composition and metabolic function than global diversity metrics.

The relationship between physical activity and gut microbiota is influenced by multiple interacting factors, including exercise modality, intensity, duration, diet, and individual characteristics. While moderate exercise appears to promote beneficial microbial adaptations, the effects of more intensive training remain dependent on context and physiological load.

Importantly, exercise-induced microbiota changes may be transient, highlighting the need for sustained physical activity to maintain beneficial adaptations. The interaction between physical activity and diet should also be considered when interpreting microbiota-related outcomes.

Regular physical activity may represent a supportive non-pharmacological strategy for maintaining gut microbiota homeostasis and could be considered as an adjunct in the prevention and management of gastrointestinal disorders; however, further clinical studies are required to establish specific recommendations.

Overall, physical activity should be regarded as a key lifestyle factor influencing gut microbiota and overall health. Its role is particularly important because it represents a modifiable behavior that may contribute not only to cardiometabolic health, but also to the maintenance of intestinal homeostasis and host–microbiome balance. Future research should focus on well-designed longitudinal human studies with standardized methodologies to better understand the relationship between physical activity and gut microbiota and to identify which individuals are most likely to benefit from specific exercise strategies.

### **Disclosure Section**

The submission has not been previously published, nor is it under consideration by another journal.

### **Author Contributions**

Conceptualization: J.K. and M.R.;

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Resources: M.R., Z.B. and A.L.;

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Writing – original draft preparation: J.K., M.M. and N.P.;

Writing – review and editing: M.R., M.C., Z.B. and A.L.;

Visualization: M.M. and N.P.;

Project administration: J.K.

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No new data were generated or analyzed in this study. All information discussed in this review was derived from previously published sources cited in the reference list.

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### **Conflicts of Interest**

The authors declare no conflict of interest.

### **Declaration of the Use of Generative AI and AI-Assisted Technologies**

During the preparation of this work, the authors used ChatGPT (OpenAI, USA) for the purpose of organizing the literature and refining the language to improve clarity and academic tone. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

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