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LATEST FINDINGS ON THE ROLE OF GUT MICROBIOTA IN EFFORT TOLERANCE AND FATIGUE PERCEPTION DURING ENDURANCE EXERCISE: A NARRATIVE REVIEW

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ABSTRACT

Background: The gut microbiota has emerged as an important modulator of athletic performance in endurance sports. Through the gut–brain and gut–muscle axes, microbial metabolites influence central fatigue, perceived exertion, effort tolerance, and endurance capacity. Although the general relationship between gut microbiota and exercise has been extensively reviewed, its specific role in effort tolerance and fatigue perception during prolonged endurance exercise remains poorly synthesized.
Aim: This narrative review aims to synthesize the most recent evidence (2020–2026) on the role of gut microbiota composition, stability, and the effects of probiotic and prebiotic interventions in modulating effort tolerance and fatigue perception during endurance exercise.
Material and Methods: A comprehensive literature search was conducted in PubMed and Scopus in April 2026. Randomized controlled trials published between 2020 and 2026 were included. After screening, six studies were selected for the narrative synthesis.
Results: The synthesis suggests that greater gut microbial stability during dietary periodization is associated with superior endurance performance. Selected probiotic and prebiotic interventions showed strain-specific potential to enhance muscular endurance and reduce fatigue. However, results were heterogeneous, with some interventions (e.g., inulin and multi-strain probiotics) producing neutral effects.
Conclusion: Emerging evidence indicates that the gut microbiota may play a significant role in effort tolerance and fatigue perception during endurance exercise. Nevertheless, the current literature is limited by small sample sizes, heterogeneous populations, and a lack of studies involving elite endurance athletes. High-quality, long-term randomized controlled trials are warranted to establish clinical applicability.

KEYWORDS

Gut Microbiota, Endurance Exercise, Effort Tolerance, Fatigue Perception, Gut-brain Axis, Probiotics, Prebiotics

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Introduction

Endurance exercise is characterized by prolonged, sustained efforts at moderate to high intensity, placing considerable demands on multiple physiological systems. In such demanding conditions, two interrelated factors play a pivotal role in determining performance: effort tolerance (the ability to sustain physical work despite accumulating stress) and fatigue perception (the subjective sensation of tiredness and the conscious decision to reduce or maintain intensity). Fatigue during endurance exercise arises from both peripheral mechanisms (e.g., depletion of muscle glycogen, accumulation of metabolites, neuromuscular fatigue) and central mechanisms (e.g., reduced motor drive, altered motivation, increased rating of perceived exertion – RPE). Despite decades of research, the precise integration of these mechanisms, particularly the central component of fatigue perception, remains only partially understood.

Although the general relationship between exercise and gut microbiota has been recognized for over a decade (Clark & Mach, 2016; Mach & Fuster-Botella, 2017), the specific influence of the microbiome on effort tolerance and fatigue perception during prolonged endurance exercise has only recently begun to be elucidated. Foundational reviews highlighted the role of the gut–brain axis in exercise-induced stress and fatigue (Clark & Mach, 2016) and summarized how endurance training modulates microbial composition and diversity (Mach & Fuster-Botella, 2017).

In recent years, the intestinal microbiota has gained recognition as a significant, yet still underexplored, modulator of exercise physiology. Comprising trillions of microorganisms, the gut microbiome produces a wide array of bioactive metabolites, including short-chain fatty acids (SCFA), secondary bile acids, and neurotransmitters or their precursors. These metabolites interact with the host through the bidirectional gut–brain axis and the emerging gut–muscle axis. Via vagal afferents, immune signaling, and humoral pathways, microbial products can influence central nervous system function, serotonin and dopamine metabolism, hypothalamic–pituitary–adrenal axis activity, and skeletal muscle bioenergetics. Consequently, the gut microbiota may affect not only substrate utilization and systemic inflammation but also psychological aspects of performance such as motivation, tolerance to discomfort, and subjective fatigue.

While the general association between gut microbiota composition and athletic performance has been summarized in several narrative and systematic reviews, the majority of studies have focused on broad outcomes such as VO_2max, time to exhaustion, or the incidence of gastrointestinal symptoms during exercise. Far fewer investigations have specifically addressed the role of the microbiome in effort tolerance and perceived fatigue during prolonged endurance tasks. This represents an important gap, as fatigue perception often limits performance before objective physiological limits are reached.

Since 2022, a new wave of original research has begun to fill this gap. Observational evidence has linked greater microbial stability during acute dietary periodization with superior endurance performance in highly trained athletes (Furber et al., 2022). Targeted probiotic interventions have demonstrated improvements in endurance capacity and fatigue resistance through mechanisms involving testosterone synthesis and muscle strength (Wen et al., 2025; Lee et al., 2024). Prebiotic and substrate-directed approaches, such as inulin or α-cyclodextrin, have produced mixed yet mechanistically valuable results concerning short-chain fatty acid production and hepatic glucose output (Torquati et al., 2025; Morita et al., 2023). At the same time, some multi-strain probiotic strategies have shown limited effects on gastrointestinal integrity and symptoms in endurance runners (Lennon et al., 2024).

Therefore, the aim of this narrative review is to provide a comprehensive synthesis and critical evaluation of the most recent evidence (2022–2025) concerning the role of gut microbiota in modulating effort tolerance and fatigue perception during endurance exercise. By integrating findings from six carefully selected studies employing both observational and interventional designs, this review seeks to summarize current empirical data, elucidate potential mechanistic pathways linking the gut microbiome with endurance performance, highlight consistencies and discrepancies across studies, and propose directions for future research in this rapidly evolving intersection of microbiology, exercise physiology, and sports nutrition.

Methodology

This narrative review was undertaken to synthesise the most recent evidence (2020–2026) concerning the role of gut microbiota in effort tolerance and fatigue perception among endurance athletes. A systematic literature search was conducted in PubMed database between March and April 2026. The search strategy combined terms related to gut microbiota, microbiome, endurance exercise, effort tolerance, and fatigue perception. No language restrictions were applied.

The initial unrestricted search yielded 63 records. Following the application of filters limiting results to randomized controlled trials (RCTs) published between 1 January 2020 and 10 April 2026, eight studies remained. In addition, the reference lists of relevant articles and reviews were manually screened to identify any further eligible publications. After full-text evaluation, two studies were excluded: one involving older, non-athletic adults and another focused on sprint swimming performance. Consequently, six studies fulfilled all predefined inclusion criteria and were incorporated into the narrative synthesis.

In addition, two foundational papers (Clark & Mach, 2016; Mach & Fuster-Botella, 2017) were incorporated to provide broader mechanistic and historical context regarding the gut–brain axis and the general relationship between endurance exercise and gut microbiota.

Studies were included if they were randomized controlled trials examining the relationship between gut microbiota (composition, stability, diversity, or associated metabolites) and parameters related to endurance performance, effort tolerance, or fatigue perception. Eligible studies involved endurance athletes or trained individuals performing prolonged endurance exercise, as well as relevant preclinical animal models. Studies evaluating probiotic or prebiotic interventions in the context of endurance capacity were also considered. Studies were excluded if they focused exclusively on anaerobic or sprint-type performance, involved populations not relevant to endurance athletes (e.g., older sedentary adults), or did not assess outcomes directly related to effort tolerance, fatigue perception, time to exhaustion, or muscle endurance in the context of prolonged exercise.

Due to the emerging nature of the field, high heterogeneity in study designs, participant populations, and outcome measures, as well as the limited number of large-scale trials in elite endurance athletes, a narrative (rather than systematic) approach was adopted. This allowed for a flexible and thematic synthesis of the available evidence. Data were extracted on study design, participant characteristics, intervention details, microbiota-related findings, endurance and fatigue outcomes, and proposed mechanisms of action. The results were organized thematically according to gut microbiota composition and stability, mechanistic pathways (gut–brain and gut–muscle axes), and the effects of probiotic and prebiotic interventions.

Results

The narrative synthesis of six randomized controlled trials provides insights into the potential influence of gut microbiota on effort tolerance and fatigue perception during endurance exercise. The included studies covered a range of approaches: observational data on gut microbial stability in elite athletes (Furber et al., 2022), interventional trials assessing specific probiotic strains on muscular endurance and fatigue markers (Lee et al., 2024; Wen et al., 2025; Lennon et al., 2024), and prebiotic strategies targeting fermentation and energy metabolism (Torquati et al., 2025; Morita et al., 2023). The findings reveal both promising strain-specific benefits and notable inconsistencies across different interventions and populations.

Gut Microbial Stability and Dietary Periodization

Greater gut microbial stability during dietary periodization was significantly associated with superior endurance performance in elite endurance athletes. A high-carbohydrate diet helped maintain microbial stability and was linked to better performance outcomes, whereas a high-protein diet led to reduced microbial stability and a noticeable decline in endurance capacity (Furber et al., 2022). These results highlight the importance of gut microbiome stability when athletes undergo significant nutritional changes during intensive training periods (Furber et al., 2022).

Effects of Probiotic Interventions

Probiotic supplementation demonstrated strain-specific benefits. A six-week intervention with a combination of Lactococcus lactis subsp. lactis LY-66 and Lactobacillus plantarum PL-02 significantly improved muscle strength, explosive power, muscular endurance, and body composition in young trained adults undergoing both resistance and endurance training (Lee et al., 2024). The supplementation also led to an increase in the abundance of Akkermansia muciniphila (Lee et al., 2024).

Limosilactobacillus reuteri CCFM1388 enhanced exercise endurance in a fatigue model. The positive effects were linked to favorable changes in bile acid metabolism, increased cholesterol absorption, and elevated testosterone biosynthesis. A small human component of the study additionally showed improvements in quadriceps muscle strength, supporting the potential role of the gut–muscle–hormone axis (Wen et al., 2025).

A multi-strain probiotic cocktail containing Pediococcus acidilactici, Lactobacillus plantarum, and Bifidobacterium animalis subsp. lactis was safe and well-tolerated in endurance runners, but did not significantly reduce gastrointestinal symptoms during running or improve overall performance parameters (Lennon et al., 2024).

Effects of Prebiotic Interventions

Inulin supplementation successfully increased colonic fermentation, as evidenced by elevated hydrogen production, but failed to improve endurance cycling performance in a 15 km time trial or alter blood short-chain fatty acid concentrations (Torquati et al., 2025).

α-Cyclodextrin, a selective substrate for Bacteroides uniformis, significantly improved endurance exercise performance in both animal models and young active males, most likely by increasing hepatic glucose production during prolonged effort (Morita et al., 2023).

Discussion

The findings of this narrative review indicate that gut microbiota plays a meaningful, albeit complex and strain-specific, role in modulating effort tolerance and fatigue perception during endurance exercise. One of the most consistent observations was the positive association between greater gut microbial stability during dietary periodization and superior endurance performance in elite athletes (Furber et al., 2022). Selected probiotic and prebiotic interventions also demonstrated promising effects. Supplementation with Limosilactobacillus reuteri CCFM1388 and the combination of Lactococcus lactis subsp. lactis LY-66 with Lactobacillus plantarum PL-02 improved endurance parameters and fatigue resistance (Wen et al., 2025; Lee et al., 2024), whereas α-cyclodextrin enhanced performance likely through increased hepatic glucose output via Bacteroides uniformis (Morita et al., 2023). In contrast, inulin and certain multi-strain probiotics yielded neutral results (Torquati et al., 2025; Lennon et al., 2024).

These results build upon earlier foundational work. Over a decade ago, Clark and Mach (2016) highlighted the importance of the gut–brain axis in exercise-induced fatigue and stress, while Mach and Fuster-Botella (2017) emphasized the bidirectional relationship between endurance training and gut microbiota composition. Recent studies have advanced this field by providing more targeted evidence on microbial stability and specific interventions directly linked to effort tolerance and perceived fatigue.

The heterogeneous outcomes observed across studies highlight the highly individualized nature of microbiota–exercise interactions, which depend on athletes' training status, baseline microbiome composition, dietary context, and the specific demands of the exercise protocol. For instance, Furber et al. (2022) clearly demonstrated that microbial stability is highly sensitive to dietary changes, with high-carbohydrate diets supporting both stability and performance, while high-protein diets had the opposite effect.

Several interconnected mechanisms appear to underlie these effects. Microbial stability helps maintain gut barrier integrity and reduces low-grade systemic inflammation, thereby delaying fatigue onset (Furber et al., 2022). Short-chain fatty acids produced by beneficial bacteria serve as an additional energy substrate for skeletal muscle and the liver, while also exerting anti-inflammatory and mitochondrial-supporting effects. Through the gut–brain axis, microbial metabolites influence neurotransmitter balance (e.g., serotonin and GABA), vagal signaling, and perceived exertion. Furthermore, the gut–muscle axis seems relevant, particularly via modulation of bile acid metabolism and testosterone levels (Wen et al., 2025). Notably, Lee et al. (2024) also reported an increase in Akkermansia muciniphila abundance following probiotic supplementation, a species increasingly associated with improved metabolic health and reduced inflammation.

Additionally, the findings of Morita et al. (2023) provide interesting mechanistic insight by demonstrating that selective stimulation of Bacteroides uniformis through α-cyclodextrin can enhance hepatic glucose production during prolonged exercise, offering a potential alternative energy pathway that may help sustain performance when muscle glycogen stores become depleted.

Nevertheless, the current body of evidence remains limited and heterogeneous. The majority of studies involved small sample sizes, short intervention periods, and recreationally active individuals rather than elite endurance athletes. Furthermore, the observed effects are highly strain-specific and context-dependent, which restricts the ability to draw firm, generalizable conclusions at present.

From a practical perspective, targeted modulation of the gut microbiota using specific probiotic strains or prebiotics may offer a valuable complementary nutritional strategy for endurance athletes, especially during periods of high training load or dietary periodization. However, due to substantial inter-individual variability and the preliminary nature of the evidence, routine supplementation cannot yet be broadly recommended.

Future research should prioritize large-scale, long-term randomized controlled trials conducted in well-trained and elite endurance athletes. Particular emphasis should be placed on personalized, microbiome-guided approaches and the complex interplay between gut microbiota, periodized nutrition, and training load.

Conclusions

This narrative review highlights the gut microbiota as an emerging and promising modulator of effort tolerance and fatigue perception in endurance exercise. While greater microbial stability and selected probiotic/prebiotic interventions show encouraging potential, the existing evidence is still limited in quantity, quality, and generalizability.

The field is transitioning from broad observational associations toward more precise, mechanism-driven interventions. Future high-quality, long-term studies in elite endurance athletes, incorporating personalized microbiome approaches and periodized nutrition, will be critical to determine whether microbiota-targeted strategies can become a meaningful component of performance optimization in sports science.

Disclosure: Artificial intelligence was used solely as a linguistic and editorial aid to improve language clarity, readability, and formatting of the manuscript. All scientific content, literature search, selection and interpretation of studies, as well as the final intellectual content and conclusions were conceived, critically evaluated, and prepared by the authors.

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