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MICRO BIOME POST

THE MICROBIOME AND ATHLETIC PERFORMANCE

Scientific insights and investment landscape

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TABLE OF CONTENTS

1. INTRODUCTION

The human body is host to trillions of microorganisms that collectively form the human microbiome. In recent years, scientists have uncovered that this microbiome—particularly the community of bacteria in the gut—plays a pivotal role in many aspects of health and physiology. Given the importance of nutrition, metabolism, and recovery in sports, it is perhaps no surprise that the gut microbiome is increasingly seen as a factor influencing athletic performance [1]. A growing body of research suggests a

> **bidirectional relationship: exercise and training can modulate the composition of the gut microbiota, while the microbiome itself can affect an athlete's energy metabolism, immune function, and resilience to stress [2][3].**

This has opened up exciting opportunities to harness microbiome science in sports, from probiotic supplements to personalized nutrition strategies.

This report provides a detailed overview of the **connection between the microbiome and sport**.
We begin with a scientific overview of the human microbiome, focusing on the gut microbiota and its key functions. We then examine the mechanisms by which the microbiome may influence athletic attributes like endurance, recovery, inflammation control, metabolism, and injury risk. Next, we review recent scientific studies—including observational comparisons of athletes and non-athletes as well as interventional trials—that shed light on the microbiome's role in sport and physical activity. We discuss how dietary interventions, probiotics, and lifestyle measures can be used to modulate the microbiome for athletic benefit. Finally, we explore the market trends and investment landscape surrounding microbiome-based applications in sport performance (excluding specific product endorsements).

The goal is to provide scientists and investors with a comprehensive, up-to-date synthesis of this rapidly evolving field, supported by references to peer-reviewed literature and current market data.

2. OVERVIEW OF THE HUMAN GUT MICROBIOME

The human gut microbiome is an extremely complex and dense ecosystem, containing thousands of different microbial species (predominantly bacteria, but also archaea, fungi, and viruses) and collectively encoding over 3 million genes [4]. In total, an estimated **40 trillion microbial cells reside in the intestines** – outnumbering human cells and endowing us with metabolic capabilities far beyond what our own genome encodes [5][6]. This rich microbial community carries out a myriad of functions essential to human health. The gut microbes help **digest and ferment dietary compounds** that we cannot break down on our own, releasing additional nutrients and energy (for example, fermenting fiber into short-chain fatty acids) [7][8]. They **synthesize vitamins** (such as certain B vitamins and vitamin K) and **produce bioactive metabolites that influence our metabolism and immune system** [9][10]. The gut microbiota also **plays a key role in immunomodulation** – training and regulating the immune system – and helps defend against pathogens by outcompeting harmful microbes [9]. There is even **cross-talk between the gut microbiome and the nervous system** (the gut–brain axis), **affecting neurotransmitter levels, mood, and stress responses** [11][10].

Despite its overall stability in adulthood, the gut microbiome's composition is dynamic and can be influenced by numerous factors throughout life. **Diet** is one of the dominant forces shaping the microbiota – for instance, diets high in fiber tend to increase the abundance of fiber-fermenting beneficial bacteria, whereas highly processed or low-fiber diets can reduce microbial diversity [12][13]. Other factors such as **age**, **genetics**, **medications** (especially antibiotics), **infections**, **stress**, and **exercise habits** also influence the makeup of one's gut microbiome [14][15]. Because the microbiome is more malleable than the human genome, it offers an attractive target for interventions. Researchers have likened the gut microbiota to a metabolic "organ" that we might tune or modulate to improve health and performance [16][17].

In the context of sports and exercise, interest in the microbiome has grown as evidence mounts that active individuals often have distinct gut microbiota profiles compared to sedentary populations.

> **Athletes tend to harbor a more diverse gut microbiome, with a higher abundance of bacteria considered "health-promoting" (for example, Akkermansia muciniphila, Faecalibacterium prausnitzii, Veillonella, and other SCFA-producing genera)**

Greater microbial diversity is generally associated with metabolic and immune health, and in athletes it has been linked to better nutrient utilization and anti-inflammatory profiles. Indeed, one study of elite rugby players found they had significantly greater gut microbiota diversity than sedentary controls, along with higher levels of beneficial metabolic byproducts [20][21]. Exercise itself is likely a contributor: as discussed later, physical training tends to enrich microbial diversity and function. While an individual's microbiome is relatively stable in the short term, significant changes in lifestyle – including dietary overhauls or new training regimens – can induce measurable shifts in gut microbiota within days or weeks [22] [23].

This plasticity suggests that **interventions targeting the microbiome could potentially yield rapid benefits for athletes**. First, however, we must understand how the microbiome can influence athletic performance.

3. MECHANISMS BY WHICH THE MICROBIOME INFLUENCES PERFORMANCE

Multiple biological mechanisms have been proposed to explain how the gut microbiome can impact athletic performance, endurance, recovery, and injury risk.
Below, we outline several key mechanisms identified by current research.

Enhanced energy harvest and fuel utilization: gut microbes enable the host to extract extra energy from food by fermenting otherwise indigestible carbohydrates (fiber) into short-chain fatty acids (SCFAs) like acetate, propionate, and butyrate [24]. These SCFAs are absorbed and can contribute up to ~10% of a person's daily caloric energy on a high-fiber diet [24]. In athletes, this microbial energy boost may help sustain prolonged endurance exercise. Certain bacteria can also metabolize exercise-induced byproducts into useful fuel. For example, studies found that marathon runners experience a bloom in Veillonella bacteria after races; Veillonella consume lactic acid (lactate) produced by hard-working muscles and convert it into propionate, an SCFA that the body can use for additional energy [25][26]. Notably, when researchers gave Veillonella bacteria to mice, the mice ran 13% longer on a treadmill test, demonstrating how microbial metabolism of lactate into propionate can directly enhance endurance capacity[27][26]. A microbiome rich in fiber-degrading and lactate-utilizing species can thus improve an athlete's energy economy by both harvesting extra calories and recycling metabolic byproducts into fuel.

Modulation of inflammation and recovery: the gut microbiome profoundly influences systemic inflammation. Beneficial gut bacteria produce metabolites (like butyrate) that have anti-inflammatory effects – they help maintain the gut lining, preventing leakage of pro-inflammatory endotoxins, and they interact with immune cells to promote anti-inflammatory responses [28][29]. In athletes, controlling inflammation is crucial for recovery from training and for injury prevention. Excessive inflammation after intense exercise can delay muscle repair and contribute to soreness or fatigue. A healthy microbiome can mitigate this by strengthening the intestinal barrier and reducing circulating inflammatory markers [28].

For instance, a higher abundance of butyrate-producing bacteria (such as Faecalibacterium prausnitzii) is associated with better gut barrier integrity and lower baseline inflammation [29]. By keeping inflammation in check, the microbiome may accelerate muscle recovery and reduce tissue damage from strenuous exercise, thereby allowing more consistent training with less downtime.

Immune function and infection resistance: intense training, especially at the elite level, can strain the immune system and increase susceptibility to illness (often upper respiratory tract infections) [30]. The gut microbiome is a central player in immune defense; a diverse and balanced microbiota helps educate the immune system and can enhance resistance to pathogens. Studies have noted that athletes with certain microbiome profiles experience fewer and shorter infections. For example, one trial found that 4 weeks of probiotic supplementation halved the incidence of respiratory illness symptoms in endurance athletes compared to placebo [31]. Mechanistically, gut microbes stimulate mucosal immunity (e.g. increasing IgA secretion) and can inhibit pathogenic bacteria, thereby reducing the likelihood that an athlete falls ill [32].

Maintaining a robust gut microbiome may thus help athletes avoid missed training days due to colds, flu, or gastrointestinal bugs – a benefit that can significantly impact performance over a season.

Metabolic regulation and body composition: the composition of one's microbiome can influence metabolic hormone levels, nutrient absorption, and even body composition. Gut microbes interact with dietary components to modulate blood glucose and lipid metabolism, which can affect an athlete's energy levels and weight management.
Certain microbial metabolites (including SCFAs and secondary bile acids) improve host metabolism by enhancing insulin sensitivity and fat oxidation [33][34].
Experiments in animals have revealed a direct "gut–muscle axis" whereby the microbiota can alter muscle energy utilization and storage. For example, transplanting gut microbiota from highly fit athletes into germ-free mice was shown to improve the mice's metabolic health – they had better glucose control and larger muscle glycogen stores than controls [35]. (Interestingly, the mice's endurance performance improved only when they also underwent exercise, suggesting the microbiome's benefits manifest most when paired with training.)

The microbiome also affects how well we absorb macronutrients; a richer diversity is linked to more efficient extraction of amino acids and other nutrients from the diet [7][36]. In one human study, athletes who took probiotics alongside protein supplements had significantly higher circulating amino acid levels and gained more lean muscle (e.g. greater improvements in leg press strength) compared to those who consumed protein alone [37][38]. This implies the probiotics enhanced protein absorption and reduced muscle damage, allowing superior training adaptations. In summary, a microbiome tuned for metabolic efficiency could help optimize an athlete's fuel utilization and body composition (higher lean mass, lower fat mass).

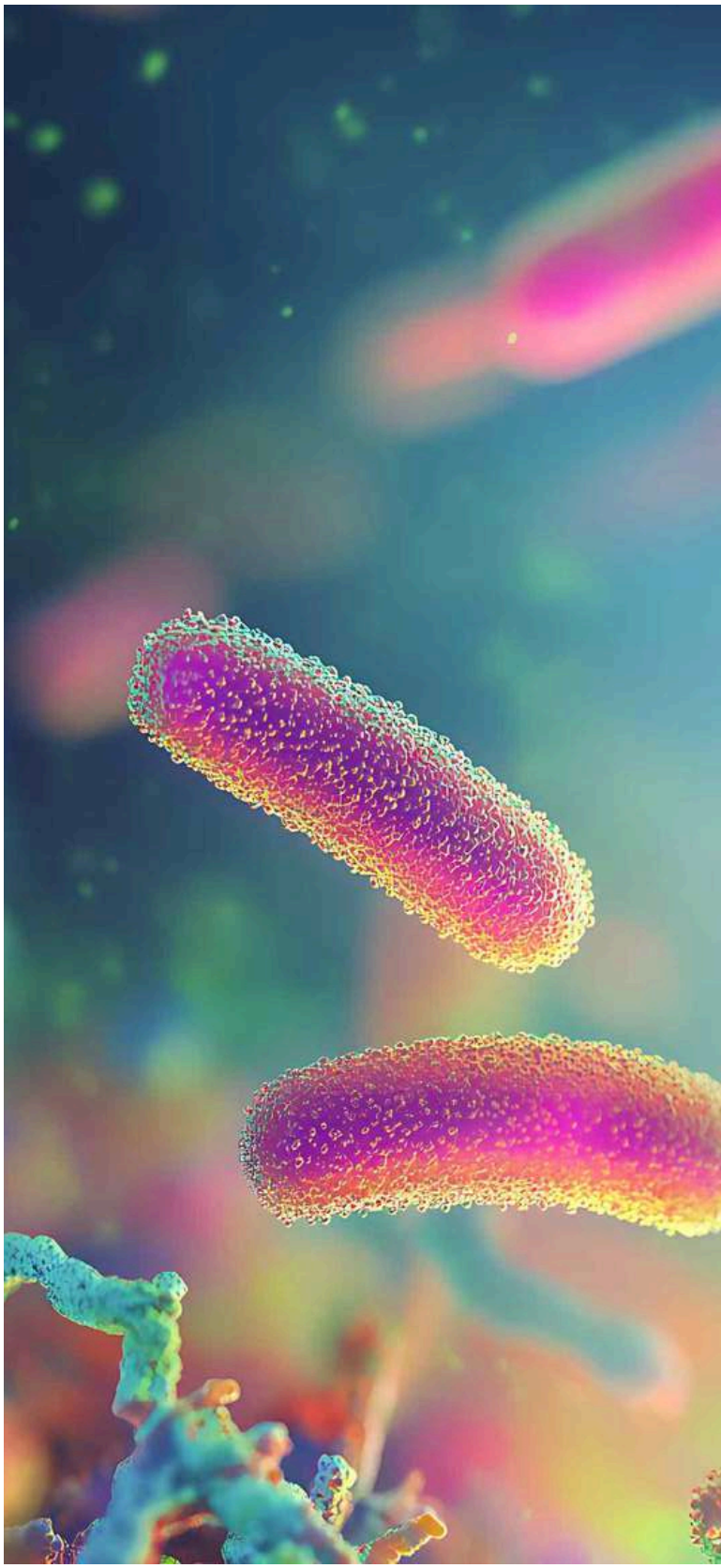
Gut–Brain Axis and stress resilience: performing at a high level in sport is not just physical – mental factors like focus, anxiety, and pain tolerance also play a role. The gut microbiota can produce neurotransmitters and neuromodulators (such as GABA, serotonin, and tryptophan metabolites) that influence brain function [10]. Through the gut–brain axis, the microbiome may affect an athlete's stress hormone levels and psychological state. Emerging research shows certain probiotic strains can reduce anxiety and lower cortisol (the stress hormone) levels [39][40]. Athletes under intense training stress who take probiotics have reported improvements in mood and cognitive function (for example, sharper attention and lower anxiety before competitions) in some studies [41][40]. These effects are thought to arise from microbiome-induced modulation of inflammation and direct neural signaling via the vagus nerve.
A healthy gut microbiome might thus contribute to mental resilience and optimal brain function under the pressures of training and competition, indirectly boosting performance by improving sleep, motivation, and decision-making.

Injury prevention and tissue repair: although data are still emerging, there are indications that the microbiome can affect musculoskeletal health and injury risk. By reducing systemic inflammation, a balanced gut microbiota may help protect against chronic inflammatory conditions or overuse injuries. Gut microbes also produce compounds (such as SCFAs) that can promote tissue repair – for example, butyrate has been shown to stimulate muscle cell differentiation and may aid in muscle regeneration after injury [42][24].
Moreover, SCFAs can influence bone metabolism; animal studies suggest that gut-derived butyrate enhances exercise-induced bone formation and

and bone density [43].
Another factor is the gut barrier: intense exercise sometimes increases intestinal permeability ("leaky gut"), which allows endotoxins into circulation and can trigger inflammation and heat stress.
A healthy microbiome (with bacteria like Akkermansia that strengthen the mucous lining) helps maintain barrier integrity [44], potentially preventing endotoxemia during hard exercise and thereby reducing the risk of heat stroke or other inflammation-related issues.
Overall, by keeping the immune system primed, inflammation low, and recovery pathways active, the microbiome may reduce the risk of both acute injuries and longer-term overtraining effects.

In summary, the gut microbiome can influence athletes via multiple interrelated pathways – by providing extra fuel, modulating inflammation and immunity, improving metabolic efficiency, and even affecting the mind.
These mechanisms are not mutually exclusive and often work in concert. Collectively, they form a strong rationale for why manipulating the gut microbiome (for example, through diet or probiotics) might yield **ergogenic** (performance-enhancing) effects.

In the next section, we examine the scientific evidence that supports this rationale, reviewing what studies have found about microbiome differences in athletes and the impacts of modifying the microbiome on performance outcomes.



4. EVIDENCE FROM SCIENTIFIC STUDIES ON MICROBIOME AND SPORT

4.1 Differences between athletes and sedentary individuals

Numerous studies have reported that athletes have a distinct gut microbiome profile compared to less active people [47] [18]. As mentioned, athletes often exhibit greater gut microbial diversity and a higher relative abundance of beneficial bacteria. For example, a study of professional rugby players found they had significantly more diverse gut microbiota than BMI-matched sedentary controls [20]. The rugby players also showed higher proportions of taxa associated with good health (like Akkermansia and Faecalibacterium) and produced more **fecal SCFAs** (acetate, propionate, butyrate) linked to enhanced muscle metabolism [21]. This contrasts with sedentary individuals, who on average tend to have less microbial diversity and fewer SCFA-producing microbes. Many other cross-sectional studies echo this pattern: athletes (especially endurance athletes) frequently have microbiomes enriched in species that help regulate metabolism and inflammation, whereas sedentary or obese individuals may harbor more pro-inflammatory microbiota profiles [48][49].

It is important to note that exercise itself can be a driving force behind these differences. Both animal and human studies show that regular physical activity independently alters the gut microbiota. In rodents, voluntary wheel running increases The abundance of butyrate-producing bacteria and overall diversity in the gut [50] [51]. In humans, even when controlling for diet, **higher cardio-respiratory fitness has been correlated with a more diverse microbiome and greater microbial functional capacity for producing beneficial metabolites** [52][53]. Thus, part of the "athlete microbiome" profile is likely a direct result of exercise training.

4.2 Effects of exercise and overtraining on the microbiome

The relationship between exercise and the microbiome appears to be dose-dependent. Moderate exercise is generally associated with beneficial shifts in the gut (increased diversity, more probiotic species), but extremely intense or prolonged exercise can have adverse effects on gut health [54]. For instance, high-mileage endurance athletes sometimes experience gastrointestinal disturbances during competition, presumably due to reduced blood flow to the gut and stress hormone spikes.
In one study of ultramarathon runners, **96%** of participants reported GI symptoms during the race, and about one-third had to withdraw primarily because of those symptoms [55].
This reflects how **severe physical stress can lead to a transient dysbiosis and increased gut permeability**.

After ultra-endurance events, studies have observed elevations in inflammatory gut microbes (like some Proteobacteria) and markers of endotoxin leakage into the blood. However, these detrimental changes are usually temporary. The key takeaway is that exercise benefits the microbiome up to a point, but overtraining or extreme exertion without adequate recovery may impair gut balance. Sports scientists describe a "J-curve" relationship where moderate training bolsters immunity (partly via a healthy microbiome), yet overtraining can suppress immunity and predispose athletes to illness [54][30]. This underscores the need for athletes to manage training load and maintain good nutrition to support their microbiome, especially during intense periods.

4.3 Notable performance-linked microbes

A landmark study in 2019 first identified a specific gut microbe associated with endurance performance – the Veillonella bacterium mentioned earlier [25]. Researchers found that Veillonella was enriched in marathon runners after the Boston Marathon relative to before the race and relative to non-runners[25]. This was among the first studies to directly link a gut microbe to improved exercise capacity. It raised the possibility of using "performance-enhancing" microbes from athletes as probiotics (a concept sometimes referred to as 'microbiome doping') [27][26]. Following this clue, the team isolated Veillonella from athletes and introduced it to mice, where it markedly improved the mice's treadmill run times (by 13% on average) [27]. The mechanism was traced to Veillonella's ability to consume lactate and produce propionate, helping the host dispose of fatigue-inducing lactate and generate additional energy [26]. This exciting finding suggests that certain microbes in athlete guts actively contribute to their hosts' endurance – essentially acting like microscopic "helpers" during exercise.

Some studies have also reported that certain fiber-fermenting genera (e.g. Prevotella) tend to be more abundant in endurance athletes consuming plant-rich diets, although their direct role in performance remains to be clarified. Diet seems to play a role here: athletes on high-fiber diets often have more Prevotella, whereas those on Western diets do not, which hints that Prevotella might flourish under exercise plus diet conditions and potentially aid in carbohydrate utilization. Further research is needed to determine if supplementing such bacteria could confer benefits.

4.4 Probiotic intervention trials

Perhaps the most compelling evidence for the microbiome's role in sport comes from intervention studies where researchers alter the microbiome and measure effects on performance or health. A number of **randomized controlled trials (RCTs)** in recent years have tested probiotic supplements in athletes and active individuals. Overall, the results have been encouraging, especially for endurance-related outcomes [56][57]. For example, one trial in triathletes found that a 4-week probiotic regimen significantly improved 5 km run time compared to placebo[58], and another study in marathon runners reported better endurance test results and muscle oxygenation after 5 weeks on a probiotic mix [59]. Similarly, several RCTs on runners, cyclists, and swimmers have observed improvements in time-to-

exhaustion, time trial performance, or VO_2 max following a course of probiotics (typically multi-strain products containing **Lactobacillus** and **Bifidobacterium** species).

Though research in strength/power sports is more limited, one RCT found that adding probiotics to a protein regimen led to greater gains in leg press strength and vertical jump power than protein alone [37] [38]. This suggests **probiotics may enhance muscle recovery and adaptation, possibly by improving amino acid absorption and reducing exercise-induced damage**. Such findings extend the potential benefits of probiotics beyond endurance into the realm of anaerobic performance and strength development.

Probiotics have also demonstrated clear benefits for athlete health, which indirectly impact performance. As noted, intense training can leave athletes vulnerable to illnesses. Multiple studies have shown that daily probiotic supplementation can reduce the incidence and duration of upper respiratory tract infections (like the common cold) in athletes [32][31]. One trial found that 4 weeks of probiotics halved the frequency of URTI symptoms in endurance athletes vs. placebo [31]. Another RCT found significant reductions in URTI occurrence over a four-month winter training period in competitive cyclists taking a probiotic, compared to those on placebo [31][60]. Fewer sick days mean more consistent training, which can translate to better performance.
Probiotics have likewise been reported to decrease gastrointestinal infections or diarrhea episodes in endurance athletes [32].

> **The consistent theme is that a fortified microbiome (via probiotics) enhances an athlete's resilience to the stresses of heavy training, whether by boosting immune defenses or by maintaining gut integrity.**

In summary, the body of evidence—from observational comparisons to mechanistic mouse experiments to human trials—converges on the idea that the microbiome meaningfully affects athletic performance and well-being.
Athletes typically harbor microbiomes that look "optimized" for high physical output (diverse, metabolically flexible, anti-inflammatory), and **when scientists deliberately modulate the microbiome** (especially through probiotics), **they often observe improvements in endurance, exercise recovery, and reduced illness in athletes**. While there is still much to learn (e.g. identifying which specific strains or combinations are most effective for which sport), these studies firmly establish the microbiome as a new frontier in sports science.

5. MICROBIOME-TARGETED INTERVENTIONS FOR ATHLETES

Given the connections outlined above, it is natural to ask how athletes and coaches can leverage the microbiome to gain performance or health benefits. Broadly, interventions to modulate the microbiome fall into three categories:

dietary strategies

probiotic/prebiotic supplementation

lifestyle modifications

All three can work synergistically. Below, we discuss each approach and how it may be applied to support athletic performance.

5.1 Dietary strategies

Diet is one of the most powerful levers for shaping the gut microbiome. Athletes already pay close attention to nutrition for fueling and recovery; by making gut-friendly food choices, they can also foster a microbiome that works in their favor. In general, a diverse, **fiber-rich diet** supports a more diverse and beneficial gut microbiota [45]. High-fiber foods – vegetables, fruits, whole grains, legumes, nuts and seeds – provide the complex carbohydrates (prebiotics) that beneficial gut bacteria thrive on. These microbes ferment fiber to produce **SCFAs like butyrate and propionate**, **which**, as described, **fuel the body and reduce inflammation**. Athletes should ensure they get ample dietary fiber and a variety of plant-based foods daily to "feed" their microbiome.

Consistently consuming a wide range of plant fibers promotes **microbial diversity and metabolic capacity**, which can translate to better energy availability and recovery [45].

In addition to fiber, **fermented foods** are highly recommended for gut health. Products such as yogurt, kefir, fermented cottage cheese, kombucha, kimchi, sauerkraut, miso, and other fermented vegetables **naturally contain live probiotic bacteria and fermentation metabolites**. Regularly eating fermented foods can **increase the abundance of beneficial microbes in the gut**. Studies show that consistently including several servings of fermented foods per day can significantly boost microbiome diversity and lower inflammatory markers [45]. For athletes, fermented dairy (like yogurt, kefir) can serve as both a protein-rich recovery

snack and a probiotic source. Even simply adding kimchi or sauerkraut as condiments to meals, or drinking kombucha, can contribute helpful microbes. In one trial, 6 weeks of a diet high in fermented foods led to greater microbiota diversity and reduced cytokines in healthy adults [45] – changes likely to benefit anyone under physical stress.

Many athletes, particularly in strength and power sports, consume **high-protein diets** to support muscle building. Protein is crucial, but very high protein intake with low fiber **can sometimes alter the gut microbiome in unfavorable ways** (e.g. promoting protein-fermenting bacteria that produce ammonia or other potentially harmful metabolites). A practical tip is to **pair high protein intake with ample fiber from plant foods to maintain microbiome balance** [61].
The protein source may also have subtle effects: for example, diets rich in plant proteins or dairy protein (whey) might favor more beneficial gut bacteria compared to excessive red meat consumption [62]. Including plenty of fibrous veggies and whole grains alongside protein shakes or meat helps ensure that protein is effectively absorbed by the athlete's body while excess reaches the colon to be handled safely by microbes. Some evidence even suggests that whey protein could act as a prebiotic by stimulating certain gut bacteria when consumed with fiber [62].
The bottom line is that athletes should balance their macronutrient-focused diets with microbiome-supporting elements (fiber, polyphenols, fermented foods) to avoid unintended negative shifts in gut flora.

Interestingly, even low-carbohydrate performance diets can be made gut-friendly. For example, some endurance athletes experiment with ketogenic ("keto") diets for fat adaptation. A strict **keto diet** (very high fat, near-zero carbs) is typically low in fiber, which could starve gut bacteria. However, researchers have devised **modified keto regimens** that incorporate high fiber and plant-based foods.
One study on athletes using a **fiber-enriched keto diet actually saw improved endurance performance and an increase in beneficial SCFA-producing bacteria**, showing that performance diets can be formulated to support the microbiome [63][64]. The lesson is that whatever the chosen macro ratio – high carb, high protein, or high fat – athletes can include sufficient fiber (e.g. leafy greens, avocado, nuts, low-carb fibrous veggies in the case of keto) and fermented foods to keep their gut microbes happy.

Timing and practicality are also considerations. Athletes sometimes reduce fiber intake in the day or two before a major competition to minimize the risk of GI distress during the event (for example, distance runners might do a low-fiber "white diet" pre-marathon).
This short-term fiber restriction can reduce bowel activity on race day, but it shouldn't be a chronic practice because of fiber's importance.
Outside of competition windows, maintaining a fiber-rich, plant-heavy diet is recommended. Hydration is also key – drinking enough fluid supports healthy digestion and microbial metabolism.
Additionally, athletes should **avoid unnecessary antibiotics** and harsh anti-microbial supplements, as these can wipe out beneficial bacteria.
If an athlete must take antibiotics (due to injury or infection), using probiotic-rich foods or a probiotic supplement during and after the course may help restore the gut flora more quickly.

5.2 Probiotics and prebiotics

Targeted **probiotic** supplementation – consuming specific beneficial bacteria in high concentrations – is a direct way to influence the gut microbiome. As reviewed above, there is growing evidence that probiotics can confer performance and health benefits for athletes. The strains most commonly studied and used in products belong to the **Lactobacillus** and **Bifidobacterium** genera, which are normal residents of a healthy human gut. These probiotics are available in fermented foods and in capsule or powder form. For athletic purposes, researchers have used doses on the order of billions of colony-forming units (CFUs) per day **[56]**, often combining multiple strains to broaden the effects.

Evidence indicates these can improve aerobic capacity and even enhance training adaptations [56]. For instance, a multi-strain Lactobacillus/Bifidobacterium blend taken for several weeks significantly improved 5 km run times in recreational runners[58]. Similar benefits have been observed in cyclists' time trials, often with the added bonus of fewer GI complaints during heavy training.

Probiotics appear to work through several mechanisms simultaneously: improving gut barrier function (thus reducing exercise-induced endotoxemia) enhancing carbohydrate absorption and SCFA production for better energy supply, modulating immunity (e.g. higher salivary IgA levels), and possibly influencing redox status (antioxidant capacity).

For endurance athletes, probiotics can be thought of as another tool in the recovery and illness-prevention arsenal. Many athletes, especially those who travel or train in winter months, use probiotics to stave off colds and diarrhea that could disrupt their training.

A meta-analysis of studies on athletes found that probiotic supplementation significantly reduced the risk of upper respiratory illness and gastrointestinal distress during intensive training periods [32][31]. Athletes who are prone to antibiotic use (e.g. due to frequent infections or travel-related illness) may also use probiotics to help re-establish their gut flora.

In short, probiotics are increasingly seen as a component of **sports nutrition**, alongside protein powders and vitamins.

Strength/power athletes can potentially benefit as well. Some specific strains have been studied for muscle recovery – for example, Lactobacillus casei Shirota was found to lower levels of muscle damage markers after strenuous exercise, and Bacillus coagulans supplementation has been linked to less muscle soreness. Although research is early, these findings suggest probiotics might reduce exercise-induced muscle stress, thereby supporting training quality in the gym.

Prebiotic supplements are another strategy. Prebiotics are essentially "food" for beneficial microbes – typically fermentable fibers (like inulin, fructooligosaccharides, galactooligosaccharides) or certain resistant starches and polyphenols. By ingesting prebiotics, athletes can selectively promote the growth of good gut bacteria. For example, inulin and fructooligosaccharides increase Bifidobacterium counts in the colon. More Bifidobacteria can mean more SCFA production and stronger gut lining. Some companies even offer **synbiotic** products (combining probiotics with prebiotic fibers) to synergistically improve gut flora; in general population studies, such combos reduced infection rates by around one-third [32], a benefit likely relevant to athletes as well. Prebiotics are naturally found in foods like garlic, onions, bananas, asparagus, oats, and flaxseed – so athletes can get them from diet – but isolated prebiotic powders are convenient if higher doses are needed.

It's worth introducing prebiotics gradually, as a sudden large dose can cause bloating in some people until their microbiome adjusts.

5.3 Lifestyle and training factors

Finally, certain lifestyle choices and training practices can influence the microbiome. Regular **exercise itself** is beneficial – as repeatedly noted, moderate physical activity tends to increase microbial diversity and functional capacity. This creates a virtuous cycle: exercise improves the microbiome, which may further enhance exercise tolerance. On the other hand, athletes need to be wary of **overtraining** and chronic stress, which can negatively impact the gut. Adequate rest days, periodization of training intensity, and good sleep hygiene all help ensure that the microbiome isn't chronically disturbed by stress hormones or inflammation. Sleep is particularly important; poor sleep or travel-related sleep disruption (jet lag) can alter gut microbiota composition and promote inflammation, so athletes traveling for competitions may consider strategies to minimize jet lag and maintain regular eating schedules to keep their gut microbes in rhythm.

Stress management techniques (like mindfulness meditation, deep breathing, or yoga) might indirectly benefit the gut by lowering cortisol and sympathetic nervous system activity. Some preliminary research in non-athletes has shown stress reduction can lead to a more favorable gut bacterial balance. Given the high mental stress around competition for many athletes, incorporating relaxation practices could support their gut–brain axis and, by extension, performance.

Another practical consideration is environmental exposures. Athletes should practice good hygiene but not be overly antiseptic.
Excessive use of antibacterial mouthwashes or hand sanitizers might, in theory, reduce exposure to beneficial microbes. On the flip side, spending time in nature, interacting with pets, and eating a variety of natural foods all increase microbial exposure and diversity, which can help build a robust microbiome.

Finally, **monitoring and personalized feedback** is an emerging area: some elite programs have begun tracking aspects of athletes' gut health (like measuring inflammatory markers or even periodic microbiome sequencing) and adjusting nutrition if they notice adverse changes. Commercial gut-testing services are also now available to athletes and the general public, although translating those results into performance-enhancing advice remains an evolving science. Nonetheless, individualized approaches to microbiome care could become part of future athlete support programs. For example, if a particular athlete shows low levels of a certain beneficial bacterium, they might receive a customized probiotic containing that bacterium, or specific dietary guidance to foster it. This level of personalization is still in its infancy, but it represents the direction in which sports nutrition is heading: integrating data from each athlete's body (including their microbiome) to tailor interventions for maximum benefit.

6. MARKET TRENDS AND INVESTMENT LANDSCAPE

The convergence of microbiome science and sports performance has given rise to a nascent but rapidly growing market.

Both established nutraceutical companies and innovative startups are developing products and services at this intersection, and investors are taking note. Below is an overview of current market trends and the investment landscape.

Growing demand for gut health in sports nutrition

Across the broader supplements industry, gut health has become a major focus, and this trend is filtering into sports nutrition. Estimates put the global probiotics market at roughly **$80–90 billion** in 2023 and project it to surpass **$100 billion within the next few years**, reflecting robust consumer

interest [65].
Sports nutrition is a notable segment of this growth, as gut-health products are being incorporated into the athletic supplement category. Athletes today are not just buying protein powders and electrolytes; they're also interested in probiotic shots, fiber mixes, and gut-friendly protein bars. For instance, some protein powder brands now fortify their products with probiotic cultures or digestive enzymes, positioning them as easier on the gut. The idea of "train hard, recover harder" is expanding to include "and take care of your gut," recognizing that a healthy gut can mean fewer sick days and possibly better performance.

Startups pioneering athlete-focused probiotics

A particularly exciting area is the development of probiotics derived from elite athletes. One prominent startup, **FitBiomics**, was co-founded by researchers from Harvard's Wyss Institute and has garnered considerable attention [66][67]. FitBiomics has sequenced the gut microbiomes of top athletes (from marathoners to basketball players) to identify novel bacterial strains that could benefit endurance, recovery, or metabolic health.

They have since isolated other unique bacterial strains from athletes and launched a commercial probiotic product used by various professional and amateur athletes [68][69]. The concept of athlete-derived probiotics has gained enough traction that professional teams and events have begun partnering with such companies (e.g. a major marathon partnering to offer probiotics to participants) [69].
This indicates growing trust that microbiome interventions might confer a competitive edge or at least support athlete wellness.

Overall, the microbiome startup space has seen a surge of investment. In the past decade, **billions of dollars** of venture capital have flowed into microbiome-focused startups[70].
While much of this was initially aimed at medical therapeutics, there is now diversification toward wellness, nutrition, and sports performance. The microbiome startup ecosystem includes not just probiotic makers but also developers of novel prebiotics, **postbiotics** (direct microbial metabolites like butyrate), and gut health diagnostics. For example, one startup is developing a real-time microbiome sensor for daily gut tracking – technology that could appeal to elite sports programs looking to closely monitor athletes' gut status.

Major nutrition companies (e.g. IFF/DuPont, Nestlé, Danone) have also launched microbiome initiatives and partnerships to research probiotics for performance, immunity, and even cognitive benefits in athletes[71]. These efforts aim to discover new strains or combinations that can be patented and incorporated into next-generation sports nutrition products.

It's telling that DuPont (a leader in probiotic ingredients) created a dedicated "Microbiome Venture" and collaborated with academic institutes to study areas like the gut–brain axis in athletes[71][72].

Such corporate moves signal that industry sees long-term value in microbiome-based sports applications.

Key opportunities for growth

From an investment and market perspective, the junction of microbiomes and sport offers multiple avenues.

New performance supplements

Companies are formulating probiotics specifically marketed for endurance, strength, or recovery. We can expect to see sport-specific probiotic blends (for example, a mix aimed at runners vs. a different mix for strength athletes) based on emerging research about which strains confer which benefits. There is also interest in **postbiotic** supplements – providing athletes with the beneficial metabolites (like SCFAs or polyamines) directly, in a shelf-stable form, rather than the live bacteria.

Personalized nutrition and coaching

Startups are likely to offer personalized gut-health solutions for athletes. This could include at-home microbiome testing kits with AI-driven recommendations for diet and probiotic use tailored to the individual. For serious competitors, companies might provide consultations to interpret gut data and adjust training diets accordingly. Investors are already backing companies that combine wearables, biomarker tracking, and microbiome analysis to give athletes a more complete picture of their internal health and recovery status.

Integration into team programs

On the professional sports side, there's a growing willingness to integrate microbiome considerations into athlete management. For example, some European football (soccer) clubs and Olympic training centers have begun educational seminars on gut health for their athletes [73].

In the near future, it wouldn't be surprising if professional teams routinely provide microbiome tests and gut-boosting protocols as part of their sports science programs. This could open the door for B2B services: companies working with sports teams to supply testing kits, customized probiotics (perhaps even using strains sourced from the team's top players), and expert guidance.

Digital health platforms

Given the tech-savvy nature of the younger athletic population, digital platforms and mobile apps focusing on gut health for fitness are an area of opportunity. Imagine an app that logs your diet and training, syncs with a gut sensor or uses periodic microbiome tests, and then gives you daily recommendations (e.g. "increase your fiber today" or "take X probiotic before your long run"). Such personalized, interactive tools could engage a broad user base from weekend warriors to professional athletes. Investors are keen on these tech-enabled solutions; sports tech accelerators are already scouting for microbiome-related startups to support.

Sports tech accelerators and venture funds (for example, Seventure's new **Sport & Performance Capital fund**) are actively seeking innovations that give athletes an edge in a scientifically sound way [74].

Microbiome-based solutions, with their dual appeal to health and performance enhancement, are a prime example. The fact that these interventions are generally legal and fall under "nutritional supplements" makes them especially attractive – there is little regulatory barrier compared to pharmaceuticals. Notably, sports regulatory bodies do not restrict probiotics or microbiome tweaks – they are treated as nutritional measures, not banned substances.

This makes market entry relatively straightforward, though companies must be careful to market these products with realistic claims (e.g. "supports performance/recovery" rather than making any unsubstantiated promises).

In summary, the microbiome-sport interface is transitioning from lab discovery to real-world application. The market is still young, but all signs point to robust growth ahead. Athletes are increasingly aware of gut health, consumers are interested in holistic wellness (bridging performance and health), and investors see the potential for high returns in this space.

We can expect continued innovation in products (probiotics, synbiotics, etc.), more scientific validation of specific formulations, and the integration of microbiome strategies into mainstream sports nutrition and training. What was once a fringe idea – that your gut bugs might influence your 10K race time – is rapidly becoming a part of the vocabulary of sports science and the business of performance enhancement.

7. CONCLUSION

The relationship between the human microbiome and athletic performance exemplifies a new paradigm in sports science, wherein the microscopic organisms in our gut can have macroscopic effects on exercise capacity, recovery, and overall athlete health. This report has surveyed the scientific evidence that the gut microbiome influences key aspects of performance – from energy production and inflammation control to immune resilience and even mental focus. We have also discussed interventions that can shape this relationship, such as diets rich in fiber and fermented foods, probiotic supplementation, and lifestyle strategies to support gut health.

For scientists, the microbiome provides fertile ground for further research: unraveling the gut–muscle and gut–brain signaling pathways, pinpointing which microbial strains or metabolites yield the greatest ergogenic effects, and exploring how microbiome modulation can be personalized to individual athletes. These investigations will deepen our understanding of human physiology and could lead to novel approaches in training and recovery protocols.

For investors and the sports industry, the insights into microbiome-performance links have already spurred innovation and investment.
We are witnessing the emergence of microbiome-focused products and services aimed at competitive athletes and fitness enthusiasts alike. This trend aligns with the broader movement in health and wellness toward personalization and preventative care. In the coming years, it is conceivable that assessing and optimizing one's gut microbiome will become as routine as tracking heart rate or VO_2 max in the pursuit of athletic excellence.

In conclusion, **the microbiome represents both a frontier of scientific discovery and a practical lever for enhancing sports performance**. The adage "you are what you eat" can be extended to "you perform as your microbes help you to" – underscoring that caring for our trillions of microbial partners is an integral part of caring for our bodies. By integrating microbiome science with training, nutrition, and sports medicine, we have an opportunity to unlock new levels of performance and resilience in athletes, while also promoting long-term health. This convergence of science and sport is a win-win proposition, benefiting athletes on the field (or track, or pool) today, and paving the way for a new generation of performance innovations tomorrow.

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