

The Brain-Gut Muscle Connection: A New Paradigm for Physical Activity

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Abstract

One of the best ways to keep your body healthy is through physical education, which opens up several pathways. By engaging in physical exercise, one may preserve the functioning of every component and guarantee the creation of hormones inside. The current review integrates data from the brain and gut flora and show the effect of physical activity on it. The body's master organ, the gut flora, is now being investigated. The Vagus nerve, a vital transporter that carries information from the brain to the body, provides the information to the brain. The generation of neurotransmitters and the maintenance of neurons are significantly influenced by the gut flora & how exercise effect it. However, any type of imbalance in the gut flora causes a number of illnesses, including autoimmune disorders like SLE and RE, in brain it cause cognitive impairment, AD,PD and in stomach IBD etc. It is already proven that physical exercise provide a framework to the person physically, mentally and socially. Mentally Physical Exercise promote neurons stability, synaptic plasticity. Physically provide a framework & maintain the posture hence physical exercise promote overall well-being of a person.

Keywords: Systemic lupus erythematosus (SLE), rheumatoid arthritis (RA), Alzheimer's Diseases (PD) Parkinsons Diseases (PD) Inflammatory bowel disease (IBD) & Vagus nerve.

Introduction

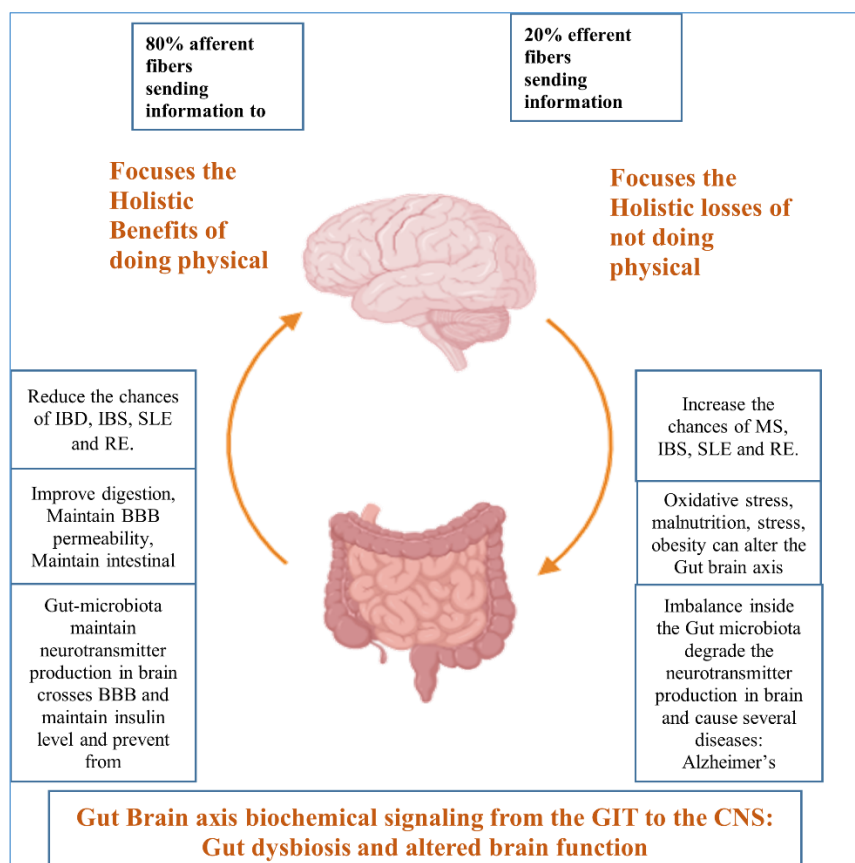
While advocating for the development of skills and healthy bodies, the traditional approach to physical education has mostly concentrated on the mechanical aspect of movement. Scientific data show that the growing body have more movement which shows the interaction of stomach, brain & muscles (Jarett et al., 2021). The mechanical characteristics of movement and skill development have been the main focus of traditional perspectives on physical education. Increasing scientific records improves the knowledge of the complex interaction between brain, stomach & muscles which provides better knowledge of human movement (Yang et al., 2024). In this review we will discuss that how gut microbiota affects the hormones, immunological function & neurotransmitters concerning with physical activity for example muscle endurance & muscle strength. Further connecting the data & information from the topic, physical education may joined with the new chapter & show its effect & also encourage individuals to participate in an exercise to framework the interrelationship of the stomach body & brain. Current lifestyle is the main cause of many diseases like neurodegenerative diseases, diabetes mellitus, inflammation etc (Dasso, 2019). There are several benefits of physical exercise by promoting physical as well as mental health. It is already proven that physical activity enhances mental health by preventing neurodegeneration, cognitive impairment & neural loss by reducing chronic inflammation and autoimmune diseases. Through the interplay of the immune

system, GM, and neuroinflammation, the gut-brain axis serves as the foundation for preserving brain health. PE has been shown to have a beneficial effect on the diversity and richness of the gut microbiota, despite occasionally being disregarded (Versini et al., 2014). This beneficial effect on the GM may lessen neurological issues. Numerous neurological and neurodegenerative conditions, such as depression, dementia, and moderate cognitive impairment (MCI), have been demonstrated to benefit with PE intervention. Furthermore, it has been shown to reduce the risk of early death in depression and to postpone the rate of cognitive decline in severe forms of dementia, such as AD. The majority of autoimmune diseases, including systemic lupus erythematosus (SLE), rheumatoid arthritis (RA), multiple sclerosis (MS), and inflammatory bowel disease (IBD), have been proven to be safe when exercising (Sharif et al., 2018). What PE can accomplish for the human GM is unknown and the subject of much conjecture, while at least a few suggestions have been put forth: hormone synthesis during physical stress and HPA axis activation, inhibition of TLR4 signaling pathways, which would lower serum LPS; changes in the bile acid profile, possibly possessing antimicrobial qualities and thereby exerting selective pressure on specific bacterial strains; and the hormetic effect of stress that physical activity induced in the GIT, which can encourage advantageous intestinal barrier adaptations (Cataldi et al., 2022). The domain seems to have a significant impact on many aspects of human health, including the COVID-19 pandemic. According to a study, SARS-CoV-2 invasion of a host's organism may be facilitated by intestinal microbiota dysbiosis associated with compromised intestinal barrier integrity. This indicates that ACE2-positive cells from the target organs might get infected, increasing the likelihood of infections and the severity of symptoms. Furthermore, exercise and physical activity (PA/PE) may contribute to this relationship by preserving the gut microbiota, which is the flora and microbiome found inside our digestive tract (Zuo et al., 2020). Another study found that GM diversity in young, healthy persons is connected to aerobic fitness. However, this would appear to suggest that GM flexibility to the demands of greater physical fitness is tied to numerous functional cores rather than specific bacterial groups (Teaw et al., 2021). Furthermore, individuals with high cardiorespiratory fitness levels appear to have a microbial profile that promotes butyrate generation, most likely due to the presence of genera like Clostridiales, Roseburia, Lachnospiraceae, and Erysipelotrichaceae. In contrast, individuals with aerobic fitness is low have a higher level of Eubacterium rectale-Clostridium coccoides (EreC), which is linked to obesity and its associated metabolic conditions (Durk et al., 2019). Subjects with aerobic fitness is low exhibit higher amounts of Enterobacteria and Eubacterium rectale-Clostridium coccoides (EreC), which are connected to obesity and related metabolic issues, and lower levels of Bacteroides. Nevertheless, the correlation between EreC and VO₂ max disappeared when body fat % was taken into account, indicating that adiposity is skewing the results. Furthermore, there appears to be a relationship between VO₂ max and the Firmicutes: Bacteroidetes ratio, supporting previous research and suggesting that PE can favorably change the composition of the GM in healthy individuals. According to earlier findings, endurance exercise can marginally change the GM's composition and functionality without significantly changing the body composition of inactive, overweight people (Allen et al., 2018). Exercise has been associated with beneficial host effects by raising the population of the phylum Verrucomirobia and its genus Akkermansia because it encourages lipid oxidation. Similar

changes have been seen in previous research, however in this case, the genus *Akkermansia* grew independent of weight, body composition, or nutrition, suggesting that these species are exercise-sensitive.

1.2 The Mind-Gut Axis: A Brief Overview

Medical communities have tried to comprehend the historical relationship between a person's personality and his or her digestive habits, according to recent research in medical history. They investigated the potential indirect effects of emotions and the mind on the stomach, frequently connecting emotional behavior and identity with digestion (Allaband et al., 2019). The focus at the moment has been on all of the connections between the digestive system and the brain. Medical thought has occasionally focused on either the particular region of the gut or the relationship between the stomach and the mind (Miller, 2018). The autonomic nervous system facilitates a two-way information flow between the gut's bacteria, the gut, and the brain, which is known as the MGB axis. The vagus nerve is present in the brain, neck & abdomen which consist of two parts that is 80% of afferent which is responsible for sending the information to the brain and 20% of its area is covered with efferent nerve which sends information from the brain to the body (Heintz-Buschart & Wilmes, 2018). It facilitates the information exchange between gut bacteria and brain which is called as gut brain axis theory. The gut flora plays a crucial role to maintain the hormonal balance as well as maintain the functioning of body (Longo et al., 2023) (Nieman et al., 2019). However, stress negatively impacts the gut and microbiota via acting on the vagus nerve. This contributes to the development of gastrointestinal



Keywords: Lupus erythematosus (SLE), rheumatoid arthritis (RA), multiple sclerosis (MS), bowel disease (IBD), Blood Brain Barrier.

disorders such as IBD and irritable bowel syndrome IBS conditions that are often characterized by dysbiosis (Guccione et al., 2024). The majority of IBD and IBS patients have been shown to have low vagal tone, which would exacerbate peripheral inflammation. Stimulating the vagus nerve can help restore equilibrium in the GBM. VN stimulation's anti-inflammatory effects are one example of such an impact, which is advantageous for individuals with gastrointestinal disorders (Longo et al., 2023). Preganglionic neurons in the dorsal motor nucleus of the VN, pro-inflammatory M1 macrophages in the stomach that are linked to gastric inflammation and gastric ileus brought on by abdominal surgery, and M2 macrophages that have anti-inflammatory qualities and are closely linked to gastric cholinergic myenteric neurons are all known to be activated when the central vagal is activated with a hormone that releases thyrotropin analog (Bonaz et al., 2018)

2. The Mind-Gut Axis: A Deeper Dive

Gut microbiota is mainly made up of Firmicutes & Bacteroidetes, which is a group of good bacteria that maintain the human Gastrointestinal tract and operate a complex ecosystem inside the body. The digestion of food and other molecules is carried out by the microbiome present in stomach other than these bacteria are responsible for the breakdown of complex carbohydrates and maintain gut health among all these things it is also responsible for the production of neurotransmitter, neuromodulators which affects immunological response, neuronal function and BBB permeability. Exercise promotes BBB permeability by maintaining neuron stability, synaptic plasticity and reduce the chance of neuroinflammation because BBB act as a barrier in the brain which inhibits the entry of toxins inside the brain and also promotes the entry of rich oxidants and supply the high amount of oxygen (Dezfouli et al., 2024). Gut microbes and their hosts have developed an obligatory mutualistic interaction over the course of a lengthy evolutionary history. In addition to providing the host with nutrients and energy, the gut microbiota also undergoes fermentation of the host's food to satisfy its nutritional requirements. The concentration of pertinent neurotransmitters in the brain may be impacted by the production of certain neuroactive metabolites by the gut microbiota, such as neurotransmitters or their direct precursors. This implies that brain neuronal activity and cognitive functions may be impacted directly or indirectly by the gut's synthesis of neurotransmitters (Nichols et al., 2018). Neurotransmitters are essential to the brain's operation since they are the primary route of communication between different kinds of neurons and glial cells. Excitatory neurotransmitters like glutamate, acetylcholine, and dopamine, as well as inhibitory neurotransmitters like γ -aminobutyric acid (GABA), glycine, and serotonin, are among the neurotransmitters that actively support movement, emotion, learning, and memory (Jameson et al., 2020). The brain may produce more neurotransmitters if certain enzymes from various neuronal and glial cell types are present. Some of these same enzymes are known to be secreted by a variety of gut-dwelling bacterial species to promote the manufacture of neurotransmitters or neurotransmitter precursors, which may readily cross the BBB to act in neurotransmitter biosynthesis. Others can interact with the metabolites via influencing the

intestinal enteroendocrine cells' production of neurotransmitters. These cells either use the VN & transmit messages to the neurons or function locally on the CNS (Luqman et al., 2018). Neurotransmitter imbalances can lead to illnesses of the neurological system and cognitive impairment, including dementia, anxiety disorders, autism, PD & AD. Consequently, examining the imbalance in neurotransmitters in the CNS PNS may provide fresh understanding of the molecular origins of these disorders (Chen et al., 2021).

3. Relationships Between Gut Microbiota and Physical Activity at the Biomolecular Level

Numerous advantages of exercise are associated with gut flora, and exercise is essential for preventing a number of chronic disorders. Physical exercise promotes balance and regulates energy, which affects the makeup of gut microorganisms (Malm, 2004). But it's crucial to take into account certain changes based on the kind of exercise, such as intensity, frequency, and modality. Additionally, there are significant distinctions between aerobic exercise and strength training. Additionally, competitive athletes may have different benefits and drawbacks than leisure players. The main distinctions between normal, non-competitive physical exercise and sports training will be discussed in the section that follows (Wegierska et al., 2022).

3.1 Frequent Training and Exercise and an Active Lifestyle

Exercise is linked to a decrease in intestinal inflammation and an enhancement in the integrity and shape of the intestines, even when consuming a high-fat diet. When paired with a sedentary lifestyle, a high-fat diet can lead to an increase in plasmacytoid and lymphocyte infiltrates, which can cause the intestinal villi to enlarge. Regular exercise may help prevent some of these changes by reducing the production of cyclooxygenase-2 (Cox-2) in both the proximal and distal intestines (Monda et al., 2017). By lowering Cox-2 expression in these areas, regular exercise could help avoid some of these alterations. However, it has also been shown that resistance training can lead to a temporary decrease in splanchnic blood flow, dropping by up to 80% of baseline values. This reduction may result in changes to the physiology and morphology of the intestinal tissues (Monda et al., 2017). Regular exercise may help prevent some of these changes by reducing the expression of cyclooxygenase 2 (Cox-2) in the proximal and distal intestines. Nonetheless, it has been demonstrated that resistance training results in a transient decrease in splanchnic blood flow (up to 80% of baseline values), which might be followed by changes in the intestinal tissues' physiology and morphology. This decrease relies on the increased arterial resistance in the splanchnic vascular bed, which is caused by heightened activity of the sympathetic nervous system. Consequently, prolonged physical activity may lead to increased intestinal permeability, potentially allowing bacteria to move out of the colon and elevating the risk of gastrointestinal issues (Clauss et al., 2021). It's crucial to remember that butyrate may prevent histone deacetylases from working. Numerous processes, such as immunological modulation, gene regulation, oxidative stress reduction, carcinogenesis suppression, and cell differentiation, may be impacted by this inhibition. Butyrate regulates intestinal motility, visceral sensitivity, and the intestinal barrier, among other physiological processes (Nieman & Wentz, 2019). The text highlights how physical activity can prevent obesity and alter the major phyla composition in obese mice that are on a high-fat diet. In this animal model, there is a negative correlation between the total distance traveled by the mice and the ratio of the phyla Bacteroidota to Bacillota. When mice participated in moderate,

prolonged activity, their intestine produce IgA was higher & their B and T-CD4 cell counts were lower than those of sedentary mice (Pant et al., 2020). Short-chain fatty acid (SCFA) profile alterations brought on by exercise provide credence to the link between exercise & the muscle-microbiota axis. The microbiota produces SCFAs that can activate AMPK, a crucial regulator of ATP consumption in muscles. The leptin FFar2 pathway, which affects several facets of muscle glucose, cholesterol, and lipid metabolism, is one method that these SCFAs might indirectly activate AMPK or directly activate it by raising the AMP/ATP ratio. Furthermore, peptide (PYY) is a hormone that increases insulin-related glucose absorption in adipose tissue & muscle induces satiety. SCFAs produced in the colon can raise plasma levels of PYY. Additionally, they activate the FFar2 and FFar3 receptors (Lustgarten, 2019). Muscles have TLR4 & TLR5 receptors, which can be triggered by circulating lipopolysaccharides. The amount of LPS that activates these receptors varies depending on the gut microbiota's makeup. TLR4 receptor activation has been connected to muscle atrophy in experiments using mice given LPS injections (Lamichhane et al., 2018). The lipopolysaccharides from certain bacterial species activate Toll-like receptors, which, in turn, trigger the production of inflammatory cytokines in the muscles by activating NF- κ B. Notably, both acute and long-term exercise can significantly reduce TLR4-mediated signaling pathways in the liver, muscle, and adipose tissue of rats on a high-fat diet. This reduction is associated with decreased serum LPS levels and improved insulin signaling and sensitivity in metabolic target tissues (Ortiz-Alvarez et al., 2020). Regular exercise causes muscle fibers to create cytokines and other peptides called myokines, which have paracrine and endocrine effects. Physical activity cause muscle cells to create more InterLukin-6, which raises blood levels of the cytokine and contributes to its anti-inflammatory and metabolic advantages (Selleri et al., 2022). By triggering the production of anti-inflammatory cytokines including interleukin-10, IL-1ra, and TNF-R, IL-6 protects against chronic diseases linked to low-grade inflammation. Furthermore, via phosphorylating AMPK, IL-6 increases glucose absorption and encourages fat burning. Therefore, regular exercise may help shield the microbiome from alterations caused by inflammatory conditions including inflammatory bowel disease and type 2 diabetes (Allen et al., 2018). The hypothalamic pituitary adrenal (HPA) axis has a major influence on the gut/brain axis, which is the reciprocal modulation between the gut and brain. This two-way communication may cause changes in some bacterial populations, and the hormones that are produced may subsequently change host behavior (Saboo et al., 2022). It is well known that the activation of the HPA axis during physical and psychological stress, which generates a number of chemicals, including corticotropin, cortisol, noradrenaline, adrenaline, and dopamine, may have an impact on gut microbial dysbiosis. Microorganisms that live in the gut are impacted by changes in stomach acid production, gastrointestinal motility, and mucus formation brought on by the release of corticotropin-releasing factor. Similarly, elevated noradrenaline plasma levels during stressful situations impact the gut microbiota and enhance the pathogenicity of intestinal (Nieman & Wentz, 2019). Exercise may lead to weight loss, and weight loss may change the framework of the gut microbiota, as was briefly mentioned above. This component is particularly interesting as the microbiota composition of obese and no nobese individuals varies (Cerdá et al., 2016). Sports and physical activity have many positive effects on the host, especially when it comes to metabolic benefits and immunological protection. Both qualitative

and quantitative changes in the makeup of gut bacteria are responsible for these advantages (Tyler et al., 2014). The intestinal tract's equilibrium and physiology depend on a varied, stable, and enriched microbial population. Additionally, these gut bacteria are essential for promoting communication between the gut and other organs including the liver and lungs, as well as along the brain-gut axis. Exercise encourages the growth of good bacteria, which can improve barrier functions, boost mucosal immunity, and create substances that guard against colon cancer and gastrointestinal disorders. Consequently, exercise promotes and enhances the variety of gut microbiota (Grosicki et al., 2019). More thorough investigation of the precise alterations in microbiota composition brought on by exercise may help develop novel treatment approaches for inflammatory and metabolic diseases in which the microbiota is essential (Ding et al., 2021). On the other hand, irregular and rigorous training, especially for professional athletes, can cause intestinal microbiota dysbiosis, which can have detrimental consequences that affect how other organs and tissues are modulated through the gut and eventually affect athletic performance. Combining probiotics and prebiotics with other supplements has been proposed as a way to prevent or treat this dysbiosis and aid in athletes' recuperation (Santacroce et al., 2019).

Sr.No.	Gut Bacteria	Action	References
1	<i>Bacteroides vulgatus</i>	Formation of short-chain fatty acids, which are essential for gut health, and the breakdown of complex carbohydrates.	(Zafar & Saier, 2021)
2	<i>Roseburia intestinalis</i>	A genus of bacteria called Roseburia is involved in the synthesis of butyrate, which may improve gut health.	(Nie et al., 2021)
3	Bacteroidota	They are known to breakdown proteins, carbohydrates, and compounds derived from carbs.	(Pan et al., 2023)
4	Akkermansia	Number of human disorders by enhancing many metabolic pathways.	(Pellegrino et al., 2023)
5	Lachnospiraceae	Lachnospiraceae are a family of spore-forming, obligatorily anaerobic bacteria that digest a variety of plant polysaccharides to short-chain fatty acids.	(Vacca et al., 2020)

4. Implications for Physical Education

Diet and physical exercise have a major impact on the gut microbiota composition of both athletes and non-athletes. Carbohydrate consumption appears to have an anti-inflammatory impact both during and after exercise. Probiotic pills also seem to help with recuperation after exercise, especially with restoring a balanced population of gut bacteria (Allaband et al., 2019). The microbiome of physically active individuals, regardless of their fitness level, contains higher quantities of SCFAs & produces by organisms (Cerdá et al., 2016). In comparison to sedentary persons, these people also show higher levels of "health-promoting gut species" and alpha diversity. To see these positive impacts, exercise programs should preferably persist longer than eight weeks. Immunity is significantly impacted by the GM reaction to physical activity. A brief immune alteration linked to alterations in the microbiome occurs after extended high-intensity exercise (Miranda-Comas et al., 2022). Studies have compared athletes and non-athletes to examine the impact of brief exercise bursts (less than 60 minutes) on gut flora. Nutrition is a common confounding element in these experiments. The measurement of SCFAs & evaluations of gut microbiome diversity are the two main techniques used to examine the impact of exercise on GM. Alpha diversity & beta diversity are two categories of gut microbiota diversity. "Alpha diversity" describes the range of bacteria found in a single sample or person, whereas "beta diversity" describes the range of bacteria found in several samples or people. Certain gut microbes are commonly shown to be advantageous or health-promoting across a variety of research. Despite the varying results from different studies, they feature *Faecalibacterium prausnitzii*, *Roseburia hominis*, *Akkermansia muciniphila*, and various species of *Prevotella* (Jäger et al., 2017) greater frequency of the bacteria that make short chain fatty acid and/or greater amounts of SCFA are associated with better levels of physical fitness. There have been two systematic reviews (Mohr et al., 2020) (Ortiz-Alvarez et al., 2020) have collated the findings of human research and discovered that the influence of physical activity on the GM is not well supported by high-quality data. Humans who exercise or engage in physical activity increase the chances of health-promoting species in their GM and a greater diversity of species (alpha diversity), according to the scant information that is currently available (Jäger et al., 2019). Analyses that used exercise programs and those that were physically active showed a substantial difference. Exercise treatments that lasted less than eight weeks showed little to no effect on the variety of bacteria's alpha and beta (Karl et al., 2017). The effects of some diets on the microbiome's makeup appear to be amplified by exercise. Compared to those on a diet high in carbohydrates, elite race walkers who underwent a hard three-week course of study while following a less-carb, increase-fat diet showed the most alterations on GI flora. However, their exercise economy decreased as a result of these microbiome changes (Yu et al., 2018). Higher protein consumption, whether from supplements or animal food, resulted in a greater variety of species. When comparing bodybuilders, distance runners, and control groups, research showed that the athletes' diets and the type of exercise training they received affected the microbiota composition at the genus and species levels. Every one of these groups adhered to a unique diet tailored to their sport (Bressa et al., 2017). According to research, distance runners who eat differently from bodybuilders, who often eat a diet rich in protein, low in carbs, and low in fiber, have fewer microbiome make SCFAs. Long periods of high-intensity exercise can cause transient immunological dysfunction, while

regular exercise is shown to improve immune function over the long run. Furthermore, research employing animal models has shown that exercise causes pro-inflammatory alterations in the colonic flora, which might be related to dysregulation of the GM (O'Donovan et al., 2020). It shows that the "normal" microbiota does not fully revert to its baseline after 72 hours. This implies that taking probiotics before to prolonged exercise may aid in the gut flora's ability to repair. Nonetheless, the tissue's antipathogen activity can be increased by even a short, intensive bout of moderate-to-intense exercise that lasts less than an hour. The health of the gut microbiota is influenced by the increased circulation of neutrophils, natural killer cells, cytotoxic T cells, immunoglobulins, anti-inflammatory cytokines, and immature B cells (Morita et al., 2019).

4.1 Effect of Exercise on the body

The guidelines established by the International Conference on Frailty and Sarcopenia Research Working Group recommend that both healthy and ill individuals engage in a variety of physical activities. For adults, participating in strength training, aerobic exercise & balance training can help prevent or reduce the impact of chronic conditions and syndromes such as sarcopenia, falls, & cognitive impairment (Izquierdo et al., 2021). Exercises that involve holding or working muscles against an applied force or weight are referred to as resistance exercises, weight training, strength training, or resistance training.

4.2 Resistance Exercises:

Resistance training is one of the most essential types of exercise because it increases both strength and muscle mass (Hurst et al., 2022). When performing appropriate exercise, it is commonly recommended to concentrate on the eight to ten major muscle groups involved in upper and lower body function and mobility. Do resistance training two or three times a week, working your way up to two or three sets of eight to twelve repetitions from one to two sets (Lange et al., 2019). Start with 30% to 40% of your maximum strength in one repetition and increase it to 70% to 80%, taking a one to three minute pause b/w every set Recommended workouts include squats, bench presses, knee flexions and extensions, as well as unilateral and bilateral exercises that involve modifying hand and foot positions, grip strength, and body posture. Resistance training has been shown to help treat and prevent both rheumatoid arthritis (RA) and osteoporosis by increasing muscle mass and size in various muscle groups (Kon et al., 2021).

4.3 Cardiorespiratory Fitness

Cardiorespiratory training is linked to enhance aerobic capacity, better CVS function, and improved metabolic management. It serves as a valuable indicator of cardiorespiratory fitness in older adults. Typically, older individuals engage in aerobic training three to seven times a week, dedicating 20 to 60 minutes for each session, as it offers numerous health benefits for their bodies (Hwang et al., 2018). Walking, stair climbing, and ball sports are exercises that can help older adults improve their aerobic and metabolic capacity. Adults should keep their exercise intensity between 55% and 70% of their highest heart rate depending on their

tolerance. According to Veronica Guadagni and colleagues, aerobic exercise enhances memory and cognitive performance (Guadagni et al., 2020).

Brain Endurance Training:

The popularity of endurance events has grown dramatically in the new century, and they are now popular diversions worldwide. These tournaments have grown in popularity both locally and abroad. According to recent research, older people's cognitive and physical performance has increased when they use BET (Brain Endurance Training), a combination of cognitive and exercise training (Dallaway et al., 2023). These improvements were noticeable. These improvements were shown in resistance and endurance training, as well as cognitive processes linked to executive function and attention. Crucially, the abilities enhanced by BET were compared to both conventional exercise training and no training. Furthermore, we reexamined the connection between perceived effort and exercise, indicating that BET improves resilience to mental fatigue. Large-scale studies on cognitive processes linked to executive function and attention, as well as resistance and endurance training, are required to validate and generalize these findings across various populations. Crucially, the abilities enhanced by BET were compared to both conventional exercise training and no training. Furthermore, we reexamined the connection between perceived effort and exercise, indicating that BET improves resilience to mental fatigue. Large-scale research studies are required to confirm and extrapolate these findings to other populations (Díaz-García et al., 2025). The subject of endurance nutrition is always evolving, and doctors need to stay up to date on both new commercial supplements and research discoveries. Pro athletes often search for small advantages that might change the outcome of a match. An abundance of carbs It may not be as well known how crucial protein is for maintaining muscle growth, recovering from injuries, and preventing muscle damage, even though diets are still recommended for endurance athletes. Even while "training low" and eating a lot of fat may not necessarily lead to improved performance, fats are growing in popularity, particularly among athletes who engage in ultra-endurance. To minimize the risk of exercise-associated hyponatremia, current hydration recommendations emphasize individualized fluid intake based on thirst and sweat rates (Ghosh & Chatterjee, 2024). Water and carbohydrate intake guidelines have remained largely consistent over time. However, historically, endurance athletes have given less attention to how much fat and protein they eat. Probiotics, caffeine, antioxidants, and nitrates are only a handful of the several supplements available on the market that have been shown to have potential for endurance workouts. Main suggestion for endurance athletes focus on three key areas: macronutrients, hydration, and supplements (Ghosh & Chatterjee, 2024).

5. Conclusion

A person's microbiome may be influenced by a number of variables, which are linked to characteristics that are frequently observed in athletes. Exercise and food modifications may combine to affect the microbiome's makeup, which might improve immunological and athletic performance. By controlling the amount and variety of microbiota as well as the produce secondary metabolites, the MGB plays crucial role in preserving optimum health, as this review emphasizes. Clarifying the underlying processes and filling up current knowledge gaps may be made easier by comprehending the mechanisms underlying these interactions. Future studies

might concentrate on delving further into these pathways, creating more efficient therapy programs that include physical activity, and assessing the accessibility and clinical effectiveness of such treatments. The basic underpinnings and processes of the MGB axis are still largely unknown. Apart from problems related to the gastrointestinal tract, metabolism, and immune system, gut microbiota also seems to be involved in some mental health disorders.

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