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The interplay of physical activity, psychological stress, and gut microbiota in adults: A systematic review

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ABSTRACT

Aging is associated with alterations in gut microbiota composition and diversity, which may influence physical, psychological, and metabolic health. Physical activity and psychological stress are key modulators of the gut–brain–body axis. However, the combined and independent effects on the gut microbiota remain unclear. This systematic review was conducted in accordance with PRISMA guidelines (PROSPERO CRD42024608619) and synthesizes evidence from 16 human studies examining associations between physical activity, psychological stress, and gut microbiota composition and diversity. Overall, moderate physical activity was consistently associated with beneficial microbial profiles, including an increased abundance of *Akkermansia*, *Faecalibacterium prausnitzii*, *Lachnospiraceae/Ruminococcaceae*, and *Bifidobacterium*. In contrast, high-intensity or prolonged exercise was associated with less favorable microbiota patterns, including dysbiosis. Psychological stress is associated with altered microbial composition, including increased *Escherichia*, *Shigella*, *Parabacteroides*, and *Blautia*. Furthermore, probiotic and symbiotic interventions, particularly strain-specific formulations, have been associated with improvements in perceived stress, psychological well-being, sleep quality, and microbial balance. Multifactorial interventions combining physical activity, diet, and stress management have shown broader benefits, although their individual effects cannot be isolated. Only one multifactorial study simultaneously addressed physical activity and stress-related factors, highlighting the limited evidence regarding their combined effects on gut microbiota outcomes. Overall, these findings suggest that lifestyle-based strategies may support gut microbiota health, although the heterogeneity and study limitations warrant cautious interpretation.

1. Introduction

Aging is often accompanied by a gradual decline in functional capacity and overall health, increasing the risk of developing non-communicable diseases, whether newly emerging, psychological, physiological, or exacerbating pre-existing chronic conditions.[1,2] One of the most significant physiological changes associated with aging is alteration in gut microbiota composition, which can influence nutrient absorption and overall health status. The gut microbiota consists of a diverse community of microorganisms that inhabit the gastrointestinal tract, increasing both in number and diversity from the stomach to the colon.[3,4] Alterations in this microbial ecosystem have been identified as contributing factors to the development of various pathologies, including immunological disorders, allergies, cardiovascular diseases, obesity, and certain cancers.[5,6] In recent years, there has been growing interest in understanding how the human microbiota interacts with other physiological systems and how these interactions influence health outcomes.[7,8] Although it is well established that the composition of the gut microbiota changes with age, its relationship with modifiable factors such as physical activity or stress remains an important area of research.[9,10] Understanding how physical activity and psychological stress interact with the gut–brain–body axis is relevant not only for aging populations, but also for the broader society, as it may inform the development of school-based physical education approaches that

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promote healthy behaviors and support long-term physical and mental health from early life.

Engaging in regular physical exercise offers numerous health benefits, including the prevention of chronic diseases and the enhancement of quality of life.[11–13] Scientific evidence indicates that physical activity among older adults reduces the risk of falls, mortality, and cardiovascular disease while also helping prevent certain cancers and improve mental health.[14] In addition, physical activity enhances quality of life in both healthy older adults and those with chronic conditions.[15,16] Physical activity programs have proven to be among the most effective strategies for maintaining functional capacity and overall health in later life.[17–19] Aging is also associated with structural and functional changes in the brain, as part of the central nervous system.[20] In this context, regular physical activity contributes to stress regulation and is positively associated with improved psychological well-being.[21,22] Conversely, elevated stress levels or depression may negatively impact participation in physical activity.[23] Therefore, it is important to examine the evidence regarding whether physical activity and stress influence the diversity and composition of gut microbiota.

Recent research has increasingly focused on the complex interplay between the gut microbiota, aging, and modifiable lifestyle factors, particularly in relation to inflammation and microbial alterations that influence health outcomes in older adults.[24,25] In this context, the role of physical activity in modulating gut microbiota has garnered increasing attention.[26,27] Emerging evidence suggests that the gut microbiota may also reflect biological aging processes. For instance, Torma et al.[28] demonstrated that increased gut microbial diversity is associated with epigenetic age acceleration and lower physical fitness levels, suggesting that microbiota alterations may reflect broader mechanisms of health decline beyond lifestyle-related factors alone. Cerdá et al.[3] proposed that exercise may alter gut microbial composition, potentially serving as a key mechanism through which physical activity promotes overall well-being, given the well-established link between the gut and systemic health. Moreover, physical activity has been shown to mitigate stress and reduce anxiety.[29,30] Evidence suggests that resistance training not only reduces stress but also improves cognitive performance in older adults.[31] Conversely, dysbiosis of gut microbiota has been associated with neuroinflammation and physiological changes that may impair cognitive performance.[32] Elevated stress levels and dysregulated cortisol secretion have also been implicated in adverse shifts in the gut microbial composition.[33] Physical activity may counteract these effects through multiple pathways, including the promotion of an anti-inflammatory state, improvement of neuromuscular function, and modulation of the hypothalamic–pituitary–adrenal (HPA) axis, thereby supporting gut health and overall well-being.[34] Understanding these interconnections is important for clarifying the mechanisms underlying age-related health outcomes and informing the development of integrative interventions aimed at fostering physical, mental, and gut health in older populations.[26] Despite prior investigations into the individual effects of physical activity and stress on gut health, no prior systematic review has examined the combined influence on gut microbiota. The present study aimed to synthesize human evidence on how physical activity, psychological stress, and related lifestyle or nutritional interventions interact to influence the gut microbiota composition and diversity in adult and aging populations.

2. Methods

2.1. Protocol and registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[35] The review protocol was registered in the PROSPERO database (registration number CRD4202460861).

2.2. Information sources and search strategy

A comprehensive electronic search was performed across four databases: Web of Science, MEDLINE, PubMed, and Scopus, covering all records available up to May 2026. The search strategy employed Boolean operators (AND/OR) and included the following terms:

[“microbiota” OR “microbiome”] AND [“adults” OR “older adults”] AND [“physical activity” OR “exercise”] AND [“stress” OR “psychological stress”].

The full search strategy is detailed in Supplementary Table S1.

2.3. Study selection criteria

The eligibility criteria were defined using the Population, Intervention, Comparison, and Outcome (PICO) framework (Table 1). Studies were included if they met the following criteria: (a) study design: cross-sectional, case-control, longitudinal, randomized controlled trials, clinical trials with parallel, crossover, cohort designs, or study pilot; (b) focus: examined associations between psychological stress and gut microbiota, or between physical activity and gut microbiota in humans; (c) stress: included psychological stress in the form of acute laboratory stress, chronic stress, stressful life events, management stress, or perceived stress; (d) physical activity, described gut microbiota responses to any form of exercise; (e) population: included adults with varying levels of physical activity, from sedentary individuals to athletes; (f) language and publication: published in English during the last 15 years as full-text articles in peer-reviewed journals.

Exclusion criteria were as follows: (a) non-human studies; (b) studies focusing on any type of microbiota other than the gut microbiota will be excluded; (c) qualitative studies, case reports, editorials, protocols, meta-analyses, or reviews; (d) studies primarily involving individuals with active cancer or diabetes to minimize confounding effects related to disease-specific pathophysiology and treatments known to independently influence gut microbiota composition; (e) studies focused on adults in nursing homes or hospitals to avoid bias related to institutionalized care environments, which may influence lifestyle factors such as diet and physical activity.

2.4. Study selection process

Two independent reviewers conducted the literature search and applied inclusion and exclusion criteria. The search results were managed using EndNote v20.5 (Clarivate Analytics). After removing duplicates, the titles and abstracts were screened, followed by a full-text review of potentially eligible studies. Discrepancies were resolved through discussions and consensus.

Table 1
The PICO criteria for inclusion and exclusion of studies.

Parameter	Inclusion criteria	Exclusion criteria
Population	Healthy adults and older adults	Non-human studies; studies focusing exclusively on patients with major chronic diseases (e.g., cancer, diabetes)
Intervention	Studies assessing gut microbiota in relation to: (a) physical activity or exercise; (b) psychological stress; (c) lifestyle or nutritional interventions (e.g., probiotics, diet) influencing the gut microbiota–brain axis.	Studies examining microbiota in non-intestinal sites (e.g., oral microbiome)
Comparison	Control groups, baseline comparisons, or differing levels of exposure	-
Outcome	Studies reporting gut microbiota composition in relation to physical activity and/or stress	Studies not reporting microbiota outcomes related to physical activity or stress

2.5. Data collection process

Data extraction was performed by a single reviewer (R.A.M.) and verified by a second reviewer (S.M.C.). Extracted data included: (a) author (s) and year of publication; (b) study design; (c) participant characteristics (sample size, sex, and age); (d) intervention details (type, duration, control, and intervention group characteristics); and (e) main findings and conclusions.

2.6. Risk of bias in individual studies

To assess the risk of bias in the studies included in this systematic review, three different methodological tools were employed, selected according to the design of each study, with the aim of ensuring a rigorous and design-appropriate evaluation of the methodological quality.

RoB 2.0, the latest version of the Cochrane Risk of Bias tool, was used to evaluate the risk of bias for each randomized controlled trial included.[36] This tool is specifically designed for experimental studies and provides a structured assessment of bias across five key domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was assessed independently and contributed to an overall judgment of risk of bias, offering a detailed and transparent evaluation of the study's internal validity.[36]

For observational studies, including prospective cohorts and longitudinal and cross-sectional designs, the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was applied. This tool is designed to assess the risk of bias in studies that do not randomly assign interventions but aim to estimate causal effects. The ROBINS-I evaluates seven domains: bias due to confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result. Its structure allows for a comparison of the internal validity of these studies with that of a hypothetical ideal randomized trial.[37]

Finally, for quasi-experimental and pilot studies, the Joanna Briggs Institute (JBI) critical appraisal tool was used. This tool is tailored to non-randomized designs and includes a set of items to assess methodological quality, such as clarity of inclusion criteria, validity of measurements, baseline similarity between groups, management of confounding factors, and the appropriateness of statistical analysis. The JBI tool is particularly useful for exploratory studies or those with structural limitations inherent to non-experimental designs[38]

3. Results

3.1. Selection of studies

From 1157 articles identified and retrieved from the online database, 948 duplicates were discarded. The remaining 209 articles were further screened based on their titles, abstracts, and keywords, resulting in 166 exclusions. After thorough evaluation and full-text review, 29 articles were excluded as they did not evaluate the markers of interest. Consequently, 16 articles met the inclusion criteria and were included in the

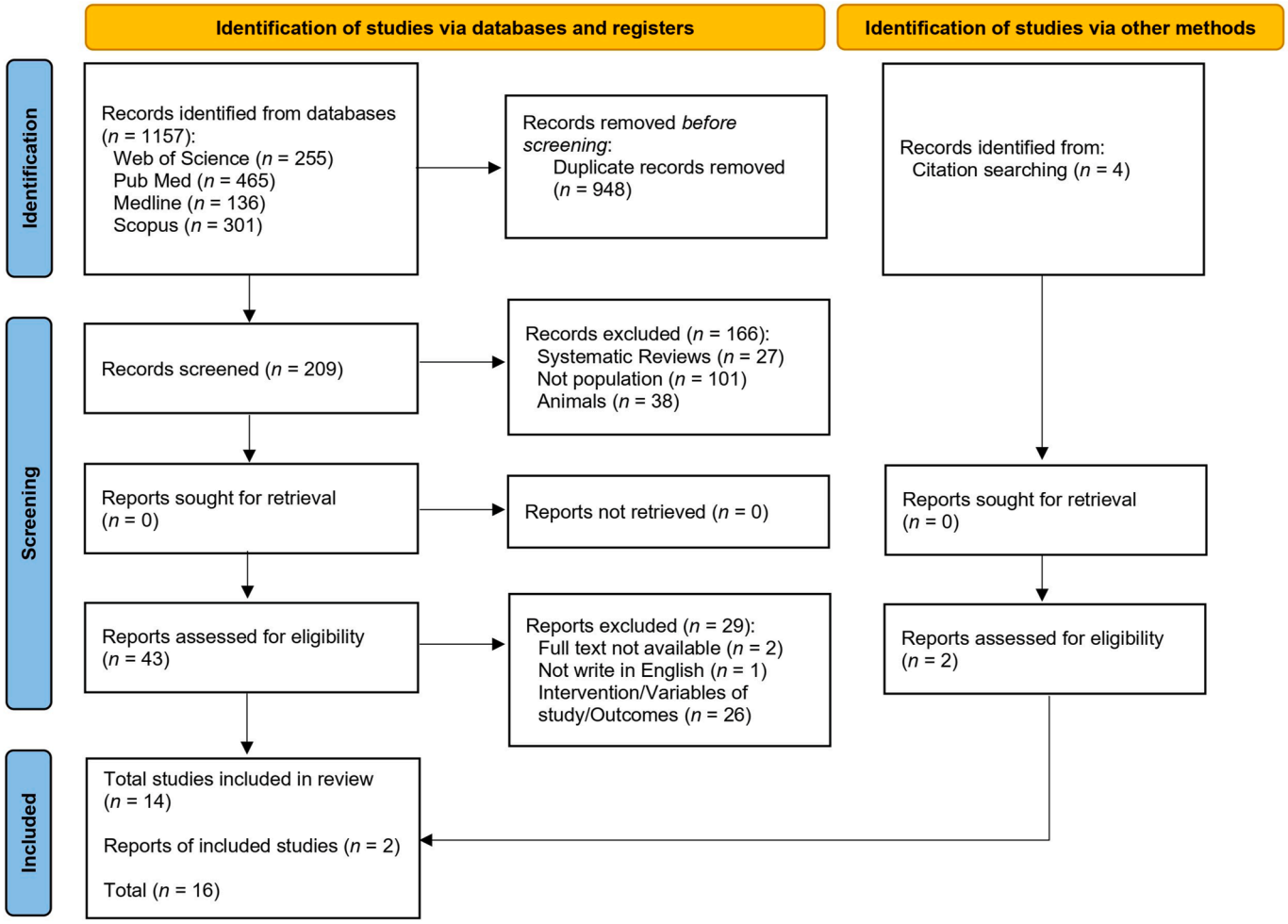

Fig. 1. PRISMA flow diagram of the study selection process.

systematic review. The study selection process is illustrated in Fig. 1.

3.2. Risk of bias within studies

The risk of bias assessment for the included studies is summarized in Figs. 2–4. The risk of bias assessment revealed several methodological limitations of the included studies. Randomized controlled trials frequently showed concerns related to the lack of blinding of participants and personnel and incomplete reporting of allocation procedures. Observational studies were commonly affected by a moderate to high risk of bias due to confounding factors such as diet, baseline physical activity levels, and lifestyle variability. Additionally, several studies were limited by small sample sizes, pilot designs, or the absence of control groups, which reduced the robustness of causal inferences. Overall, these limitations highlight the need for cautious interpretation of findings and underscore the necessity for more rigorous and standardized research in this field.

The risk of bias for the six included studies was assessed using Cochrane Collaboration's RoB 2.0, which evaluates five domains. An overall risk of bias judgment was assigned to each study (Fig. 2).

The risk of bias in the included studies was assessed using the Risk of Bias in Non-randomized Studies (ROBINS-I) tool, which is specifically designed for non-randomized observational studies. The results are shown in Fig. 3.

Finally, the risk of bias was assessed using the JBI Critical Appraisal Checklist for Quasi-Experimental Studies (nonrandomized experimental studies). The results are shown in Fig. 4.

3.3. Study characteristics

This systematic review included 16 research articles representing a variety of methodological designs. The main characteristics of the included studies are summarized in Table 2, and the main study outcomes are categorized by microbiota-related, clinical, and psychological variables in Table 3.

Given the heterogeneity of study designs and exposures, studies were

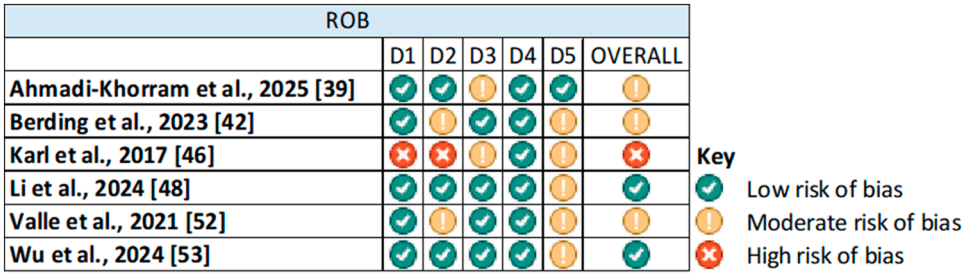

Fig. 2. Risk of bias overview of studies included I
D1, bias arising from the randomization process; D2: Bias due to deviations from intended interventions; D3: Bias due to missing outcome data; D4: Bias in measurement of the outcome; D5: Bias in selection of the reported result.

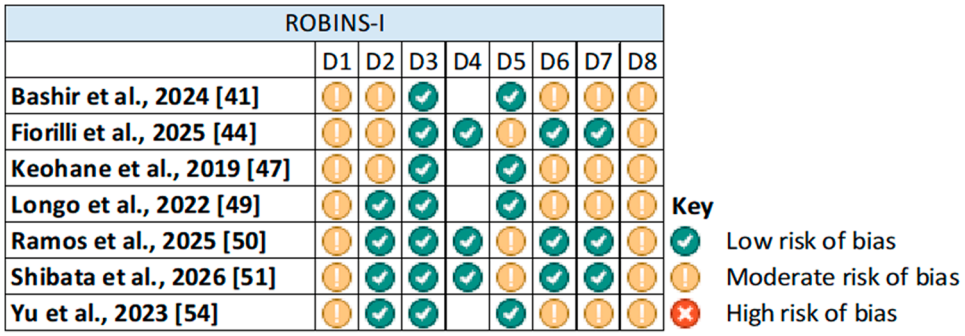

Fig. 3. Risk of bias overview of studies included II
D1: Bias due to confounding, D2: Bias in selection of participants, D3: Bias in classification of interventions/exposures, D4: Bias due to deviations from intended interventions, D5: Bias due to missing data, D6: Bias in measurement of outcomes, D7: Bias in selection of the reported result, D8: Overall risk of bias.

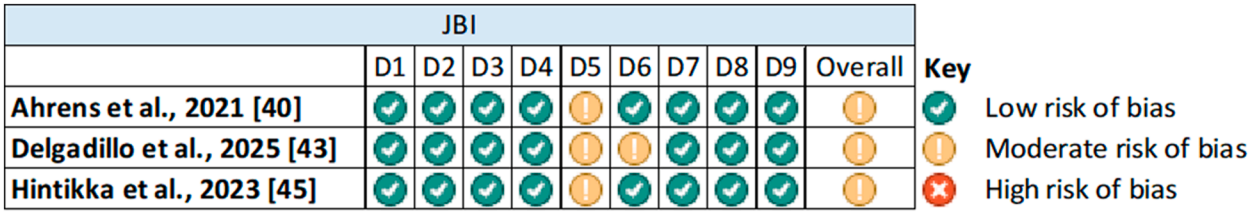

Fig. 4. Risk of bias overview of studies included III
D1: Is it clear in the study what is the 'cause' and what is the 'effect'? D2: Were the participants included in any comparison similar? D3: Were the participants included in any comparisons receiving similar treatment/care other than the exposure or intervention of interest? D4: Was there a control group? D5: Were there multiple measurements of the outcome, both pre- and post-intervention, or exposure? D6: Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed? D7: Were the outcomes of the participants included in any comparisons measured in the same way? D8: Were the outcomes measured reliably? D9: Was appropriate statistical analysis used.?.

Table 2
Summary of the main characteristics of the studies included in the review.

Study	Country/ region	Study Design	*n*; sex (M/F)	Age (years) range, mean (± *SD*)	Type of Exercise	Duration, Frequency, Training Volume
Ahmadi-Khorram et al., 2025[39]	Iran	Randomized Controlled Trial	90 (47/43)	26.22 (±7.42)	This study does not involve a specific exercise intervention. It focuses on probiotic supplementation.	8 weeks; daily supplementation (multi-strain probiotic: *Lactobacillus acidophilus, L. casei, L. rhamnosus*; 3×10^9 CFU).
Ahrens et al., 2021[40]	United States	Trial - Pilot study	73 (37/36)	46.89 (± 12.38)	Cardiopulmonary exercise (relay races, kickball, and volleyball) and yoga classes (these were not required).	6 days, 5 h daily.
Bashir et al., 2024[41]	Denmark	Cross-sectional study (part of a cohort study)	160 healthy women	18 to 40 years	This study does not involve a specific exercise intervention. It focuses on the association between microbiota composition, neuroactive pathways, and symptoms of stress and depression.	NR
Berding et al., 2023[42]	Ireland	Randomized Controlled Trial	45 healthy adults Psychobiotic Diet Group: 24 (9/15) Control Diet Group: 21 (8/13)	18 to 59 years Psychobiotic Diet Group: 31.2 (± 1.6) Control Diet Group: 32.2 (± 2.2)	This study does not involve a specific exercise intervention. It focuses on the effects of a psychobiotic diet.	Dietary Intervention daily: 4 weeks. Psychobiotic diet group: high in prebiotic and fermented foods.
Delgadillo et al., 2025[43]		Observational study (cross-sectional analysis in two independent samples)	136 total Study 1: 62 (42/20; 68% female) Study 2: 74 (female only)	Study 1: 37.3 (mean) Study 2: 41.6 (mean)	This study does not involve a specific exercise intervention. It focuses on stress–microbiota associations.	NR (laboratory stress assessment; cross-sectional design).
Fiorilli et al., 2025[44]	Italy	Cross-sectional study		71-84	Long-term habitual physical activity (comparison: high-performance vs low-performance vs inactive).	Long-term physical activity exposure (48-month follow-up context; habitual levels).
Hintikka et al., 2023[45]	Finland	Randomized Controlled Trial	17 adult women	36.8 (± 3.9)	Aerobic exercise: cycling	12 weeks Control period: 6 weeks Exercise period: 6 weeks
Karl et al., 2017[46]	United States and Norway	Randomized controlled trial	73 (71/2)		Military-style cross-country skiing	The exercise was continuous over the 4-day period. Participants skied approximately 31 miles (51 km) while carrying 99-pound (45 kg) packs.
Keohane et al., 2019[47]	Ireland	prospective repeated measures study	4	26.5 (± 1.3)	Ultra-endurance rowing	The exercise lasted for 33 days. The participants rowed continuously, with shifts of 2 h rowing followed by 2 h rest. The total volume of training was approximately 12 h of rowing per day
Li et al., 2024[48]	China	Randomized Controlled Trial	120	18 to 35 years	This study does not involve a specific exercise intervention. It focuses on the effects of *Bifidobacterium breve* 207-1 on lifestyle behaviors and mental wellness.	The intervention lasted for 28 days. Participants followed the dietary intervention daily. Participants were divided into three groups: low-dose *B. breve* 207-1 (LD, $n = 40$), high-dose *B. breve* 207-1 (HD, $n = 40$), and placebo ($n = 40$).
Longo et al., 2022[49]	Brazil	Longitudinal observational study	15	66 (± 6.2)	This study does not involve a specific exercise intervention. It focuses on the effects of physical distancing due to the COVID-19 pandemic.	The study evaluated the impacts over a period of 6 months.
Ramos et al., 2025[50]	United Kingdom	Cross-sectional study	101	65–85	Physical activity (objective measurement: accelerometer; functional test: 6-min walk test)	7-day physical activity assessment (accelerometer); habitual PA levels (meeting vs not meeting WHO recommendations)
Shibata et al., 2026[51]	Japan	Cross-sectional study	73 (female only)	Older adults	Habitual daily physical activity (objectively measured via accelerometer; classification based on meeting WHO guidelines)	7-day monitoring (habitual PA; meeting vs not meeting WHO recommendations)
Valle et al., 2021[52]	Brazil	Randomized Controlled Trial	65	18 to 22	Military field training	The field training lasted for 5 days. The participants underwent continuous training over the 5-day period. Not specified in detail, but it involved strenuous physical activity typical of military field training.
Wu et al., 2024[53]	Taiwan, China	Randomized Controlled Trial	114 L-PS23 35 (25/10) HT-PS23 35 (25/10) Placebo 35 (25/10)	20 to 40 years	This study does not involve a specific exercise intervention. It focuses on the effects of Lacticaseibacillus paracasei PS23 supplementation.	The intervention lasted for 6 weeks. Participants took the supplement daily.
Yu et al., 2023[54]	China	Prospective cohort study	CC = 53 (15/38) HC = 31 (11/20)	CC: 45.89 (± 16.40) HC: 51.32 (± 13.61)		Physical activity (frequency of weekly exercise sessions for at least 30 min)

BDNF = brain-derived neurotrophic factor; **CDG** = Control Diet Group; **CMJ** = countermovement jump; **F** = female; **HD** = high-dose; **IMTP** = isometric mid-thigh pull; **LD** = low-dose; **M** = male; *n* = sample size; **NR** = not reported; **PDG** = Psychobiotic Diet Group; **± *SD*** = standard deviation.

Table 3
Result of study outcomes categorized by microbiota-related, clinical, and psychological variables.

Study	Stress Variable Measured	Outcome
Ahmadi-Khorram et al., 2025[39]	PSS; inflammatory markers (ESR, CRP)	**Microbiota-related outcomes:**Evidence of microbiota modulation associated with probiotic supplementation (specific taxa not fully detailed) **Clinical/physiological outcomes:** ↓ inflammatory markers (ESR, CRP); ↑ body weight **Psychological outcomes:** ↓ perceived stress
Ahrens et al., 2021[40]	Stress management classes	**Microbiota-related outcomes:** ↑ *Faecalibacterium prausnitzii*, *Lachnospiraceae*, *Ruminococcaceae*; ↓ *Bacteroides*, *Phascolarctobacterium* **Clinical/physiological outcomes:** ↓ systolic and diastolic blood pressure; ↓ cholesterol and triglycerides; ↑ BMI (non-beneficial change) **Psychological outcomes:** Not clearly reported
Bashir et al., 2024[41]	PSS-10	**Microbiota-related outcomes:** ↑ *Escherichia*, *Shigella*, *Parabacteroides*, *Blautia* associated with higher perceived stress and depressive symptoms **Clinical/physiological outcomes:** Not reported **Psychological outcomes:** ↑ perceived stress and depressive symptoms associated with microbiota alterations
Berding et al., 2023[42]	PSS	**Microbiota-related outcomes:** Minor changes in microbial composition; no major taxonomic shifts; significant alterations in fecal lipid profiles **Clinical/physiological outcomes:** Not reported **Psychological outcomes:** ↓ perceived stress (greater reduction in intervention group vs control)
Delgadillo et al., 2025[43]	Perceived stress Stressful life events Biological stress: Respiratory Sinus Arrhythmia	**Microbiota-related outcomes:** ↓ alpha diversity associated with higher perceived stress; differences in beta diversity; ↑ *Escherichia/Shigella*; ↓ *Clostridium* **Clinical/physiological outcomes:** Not reported **Psychological outcomes:** Associations with perceived stress, stressful life events, and biological stress markers
Fiorilli et al., 2025[44]	Not directly measured	**Microbiota-related outcomes:** ↑ microbial diversity; enrichment of SCFA-producing taxa (*Phocaeicola, Dorea, Bacteroides, Alistipes, Blautia, Oscillibacter*) **Clinical/physiological outcomes:** Not directly reported **Psychological outcomes:** Not assessed
Hintikka et al., 2023[45]		**Microbiota-related outcomes:** ↑ *Alistipes*, *Parabacteroides*, *Ruminococcus gnavus*; ↓ *Faecalibacterium prausnitzii*, *Roseburia*, *Bifidobacterium* **Clinical/physiological outcomes:** ↑ intestinal permeability **Psychological outcomes:** Not directly assessed (physiological stress context)
Karl et al., 2017[46]		**Microbiota-related outcomes:** ↑ *Alistipes*, *Parabacteroides*, *Ruminococcus gnavus*; ↓ *Faecalibacterium prausnitzii*, *Roseburia*, *Bifidobacterium* **Clinical/physiological outcomes:** ↑ intestinal permeability **Psychological outcomes:** Not directly assessed (prolonged physiological stress context)
Keohane et al., 2019[47]	The study measured cortisol levels as a stress marker.	**Microbiota-related outcomes:** ↑ *Akkermansia*, *Bacteroides*, *Prevotella*; ↓ *Firmicutes*, *Faecalibacterium prausnitzii*, *Roseburia* **Clinical/physiological outcomes:** ↑ cortisol levels (physiological stress marker) **Psychological outcomes:** Not directly assessed
Li et al., 2024[48]	SDS and SAS	**Microbiota-related outcomes:** Improved gut microbiota composition (not strain-specific fully detailed) **Clinical/physiological outcomes:** Improved sleep quality **Psychological outcomes:** ↓ anxiety and depressive symptoms; ↑ mental well-being
Longo et al., 2022[49]	The study measured serum cortisol levels and brain-derived neurotrophic factor (BDNF) as stress markers.	**Microbiota-related outcomes:** ↑ *Blautia spp.* **Clinical/physiological outcomes:** ↑ BMI; ↓ physical activity **Psychological outcomes:** ↑ stress (inferred via cortisol changes)
Ramos et al., 2025[50]	Not directly measured	**Microbiota-related outcomes:** ↑ *Lactobacillus*, *Faecalibacterium prausnitzii*, *Roseburia intestinalis*; ↓ *Desulfovibrio piger*, *Enterobacterales* **Clinical/physiological outcomes:** Not directly reported **Psychological outcomes:** Not assessed
Shibata et al., 2026[51]	Not directly measured	**Microbiota-related outcomes:** ↑ alpha diversity; ↑ SCFA-producing *Ruminococcus*; differences in beta diversity **Clinical/physiological outcomes:** Not reported **Psychological outcomes:** Not assessed
Valle et al., 2021[52]	The study measured gastrointestinal symptoms as stress markers.	**Microbiota-related outcomes:** ↑ *Bifidobacterium*, *Faecalibacterium prausnitzii*; ↓ *Proteobacteria*, *Clostridium sensu stricto* **Clinical/physiological outcomes:** Not clearly reported **Psychological outcomes:** Improved subjective well-being (e.g., reduced tension and sleepiness)
Wu et al., 2024[53]	PSS	**Microbiota-related outcomes:** ↑ *Bifidobacterium*, *Akkermansia muciniphila*, *Lactobacillus*; ↓ *Proteobacteria*, *Clostridium sensu stricto* **Clinical/physiological outcomes:** Improved physical performance (CMJ, IMTP, Wingate) **Psychological outcomes:** ↓ perceived stress
Yu et al., 2023[54]	SAS and SDS	STC vs NTC: **Microbiota-related outcomes:** ↓ *Bacteroidaceae*; ↑ *Peptostreptococcaceae*, *Christensenellaceae*, *Clostridiaceae* **Clinical/physiological outcomes:** Not reported **Psychological outcomes:** ↑ anxiety and depression associated with microbiota alterations

BDNF = brain-derived neurotrophic factor; **ESR** = *Erythrocyte Sedimentation Rate*; **CRP** = *C-Reactive Protein*; **NR** = not reported; **PSS** = *Perceived Stress Scale*; **PSS-10** = 10-item *Perceived Stress Scale*; **SAS** = *Self-Rating Anxiety Scale*; **SDS** = *Self-Rating Depression Scale*; Arrows indicate the direction of the observed change: ↑ increase; ↓ decrease. Reported outcomes refer exclusively to variables related to stress, gut microbiota composition, or both.

grouped into three analytical categories to ensure conceptual clarity: (1) studies with prescribed physical activity or exercise interventions; (2) studies in which psychological stress was the primary exposure or outcome; and (3) studies with dietary, probiotic, or psychobiotic interventions targeting stress-related or lifestyle-associated microbiota alterations.

3.4. Studies with prescribed physical activity or exercise interventions

The eight studies included in this review investigated the relationship between physical activity and gut microbiota composition, showing generally consistent but context-dependent effects across different populations and exercise modalities. Moderate aerobic exercise is associated with beneficial microbial changes. In a randomized controlled trial, Hintikka et al.,[45] investigated overweight adult women and observed an increase in the abundance of the genus *Akkermansia* after six weeks of aerobic cycling training. Similarly, population-based and observational studies have reported that higher levels of habitual or leisure-time physical activity are associated with greater microbial diversity and enrichment of taxa linked to metabolic and gut health, including SCFA-producing bacteria.[50,51,54] In older adults, habitual long-term physical activity is associated with a more favorable microbiota composition and a higher abundance of beneficial taxa, suggesting a potential protective role against age-related dysbiosis.[44]

These findings are further supported by evidence from lifestyle-based interventions, although their multifactorial nature limits the causal interpretation. Among the included studies, only Ahrens et al.[40] simultaneously integrated physical activity and stress management within the same intervention. In this pilot study, 73 adults participated in a six-day lifestyle-based immersion program that combined physical activity (e.g., recreational games and yoga), stress management sessions, and healthy dietary practices. This intervention resulted in shifts in the gut microbiota composition, including changes in *Lachnospiraceae*, *Ruminococcaceae*, and *Faecalibacterium prausnitzii*, along with improvements in cardiovascular risk factors. This study also reported a decrease in *Bacteroides* and *Phascolarctobacterium*. However, because the intervention combined several lifestyle components, it was not possible to independently isolate the specific contribution of physical activity or stress management. Therefore, these findings should be interpreted as evidence of synergistic lifestyle effects rather than direct evidence of the isolated or combined effects of exercise and stress reduction on the gut microbiota composition. In contrast, high-intensity or prolonged exercise, such as military training or ultra-endurance activity, is associated with microbial alterations that are suggestive of dysbiosis. Karl et al.,[46] who studied adults undergoing four days of military skiing training, observed an increase in pro-inflammatory bacteria, including *Alistipes*, *Parabacteroides*, and *Ruminococcus gnavus*, along with reductions in beneficial bacteria, such as *Faecalibacterium prausnitzii*, *Roseburia*, and *Bifidobacterium*, as well as increased intestinal permeability. Similarly, Keohane et al.[47] reported that a 33-day ultra-endurance rowing expedition was associated with increases in *Akkermansia*, *Bacteroides*, and *Prevotella*, along with reductions in *Firmicutes*, *Faecalibacterium prausnitzii*, and *Roseburia*, accompanied by elevated cortisol levels. Overall, these findings suggest that moderate exercise promotes a balanced microbial profile, whereas extreme physical stress induces adverse microbial shifts and impairs intestinal homeostasis.

3.5. Studies in which psychological stress was the primary exposure or outcome

Although physical activity has been widely studied, psychological stress is another key factor influencing gut microbiota composition. Several studies have examined the association between psychological stress and gut microbiota composition, consistently showing that higher levels of perceived stress and depressive symptoms are associated with alterations in microbial profiles. In a cross-sectional study involving 160 healthy women aged 18–40 years, Bashir et al.[41] reported that higher stress and depressive symptom scores were significantly associated with an increased abundance of *Escherichia*, *Shigella*, *Parabacteroides*, and *Blautia*. Similarly, Delgadillo et al.[43] observed that biological, environmental, and psychological stressors are associated with distinct alterations in gut microbiota composition and functional pathways, including reductions in microbial diversity and shifts in neuroactive metabolic profiles.

Observational evidence also suggests that stress-related conditions may indirectly influence gut microbiota through behavioral and lifestyle changes. In a longitudinal study of older Brazilian women, Longo et al.[49] examined the effects of social isolation during the COVID-19 pandemic and reported increased cortisol levels and a higher abundance of *Blautia* spp. accompanied by reduced physical activity and increased body mass index. Overall, these findings suggest that psychological and physiological stress may contribute to gut microbiota dysbiosis, although specific microbial patterns appear to depend on the type, intensity, and duration of stress exposure.

3.6. Dietary, probiotic, or psychobiotic interventions targeting stress-related or lifestyle-associated microbiota alterations

A detailed analysis was performed to determine whether modulating the gut microbiota through probiotics, synbiotics, or dietary interventions could improve psychological well-being and stress-related outcomes. In a randomized clinical trial, Li et al.[48] evaluated the effects of *Bifidobacterium breve* 207-1 supplementation over 28 days in 120 healthy young adults, and observed significant improvements in mental well-being, sleep quality, and gut microbial composition, together with positive changes in anxiety and depressive symptom scores. Similarly, Wu et al.[53] conducted a randomized controlled study in 114 adults and found that six weeks of supplementation with *Lacticaseibacillus paracasei* PS23 reduced perceived stress levels and improved microbial diversity, increasing *Bifidobacterium*, *Akkermansia muciniphila*, and *Lactobacillus*, while reducing *Proteobacteria* and *Clostridium sensu stricto*.

In populations exposed to elevated physiological stress, microbiota-targeted interventions also appear to promote beneficial psychological and microbial effects. Valle et al.,[52] in a randomized clinical trial involving military personnel undergoing intense physical training, reported improvements in well-being indicators, including reduced tension and sleepiness, following synbiotic ice cream supplementation with *Lactobacillus acidophilus* LA-5, *Bifidobacterium animalis* BB-12, and inulin. The intervention was also associated with increases in *Bifidobacterium*, *Lactobacillus*, *Faecalibacterium*, and *Agathobacter*, along with reductions in potentially pro-inflammatory genera, such as *Parabacteroides*. Similarly, Berding et al.[42] demonstrated that a psychobiotic diet rich in fermented and prebiotic foods produced a greater reduction in perceived stress than a control diet after four weeks, although changes in microbiota composition were relatively subtle. Finally, Ahmadi-Khorram et al.[39] reported that probiotic supplementation in malnourished adults reduced stress and inflammatory markers by modulating gut microbiota composition, further supporting the role of microbiota-targeted interventions in stress regulation.

Overall, the findings of this review indicate that moderate physical activity is generally associated with more favorable gut microbiota profiles, including greater microbial diversity and enrichment of beneficial taxa, whereas high-intensity or prolonged exercise may induce less favorable microbial alterations associated with physiological stress and intestinal dysfunction. Psychological stress consistently appears to be associated with changes in microbiota composition, particularly those involving increases in potentially pro-inflammatory taxa. Additionally, dietary, probiotic, and psychobiotic interventions may positively influence both the microbial composition and stress-related outcomes, although the reported effects remain heterogeneous across populations and intervention protocols. Collectively, these observations highlight the complex, bidirectional, and context-dependent interactions among

physical activity, stress, and gut microbiota composition.

4. Discussion

Overall, this review synthesizes evidence from 16 studies that synthesize human evidence on how physical activity, psychological stress, and related lifestyle or nutritional interventions interact to influence the gut microbiota composition and diversity in adult and aging populations. Only one multifactorial intervention combining physical activity, diet, and stress management was identified; therefore, the evidence for the combined effects remains preliminary. The included studies had a range of methodological designs, including randomized controlled trials, cross-sectional studies, observational cohort studies, longitudinal designs, and pilot interventions. While several studies have reported associations among physical activity, stress regulation, and beneficial microbial profiles, the evidence remains heterogeneous and is often limited by small sample sizes, variation in study design, and differences in the measurement of both physical activity and stress. The reviewed studies identified beneficial bacteria such as *Faecalibacterium prausnitzii*, *Lachnospiraceae*, *Ruminococcaceae*, *Akkermansia muciniphila*, and *Bifidobacterium* which are promoted by physical activity and stress reduction. These microbial shifts were observed in interventions involving aerobic exercise, military-style training, and ultra-endurance activities and were often accompanied by improvements in stress markers such as cortisol levels and perceived stress scores. Collectively, these studies suggest that both psychological and physiological stress induced by extreme exercise can alter the diversity and abundance of specific bacterial families. In contrast, moderate physical activity[50,55] and probiotic and synbiotic interventions[39] are associated with improvements in psychological and microbiota-related outcomes in some studies. However, these effects are heterogeneous and remain subject to ongoing debate, with evidence suggesting that the benefits may be strain-specific and context-dependent.[55] Thus, the findings underscore the potential of moderate physical activity and targeted nutritional strategies to positively modulate gut microbiota, enhance resilience to stress, and contribute to overall mental and physiological well-being. These insights support the integration of lifestyle-based interventions in stress management programs and highlight gut microbiota as a promising biomarker and therapeutic target in the context of exercise and psychological health.

To better contextualize these findings, it is important to consider the biological mechanisms that may underlie the interaction between physical activity, psychological stress, and gut microbiota composition. Multiple interconnected pathways may explain how physical activity modulates the intestinal microbial ecosystems. Exercise has been shown to influence gut motility, intestinal transit time, and splanchnic blood flow, thereby altering substrate availability and luminal oxygen gradients, which in turn may favor the growth of specific microbial taxa.[56] Moderate physical activity has also been associated with reduced systemic inflammation, enhanced immune surveillance, and a shift toward anti-inflammatory cytokine profiles. In addition, skeletal muscle contraction may influence the release of myokines, such as interleukin-6 (IL-6), which can exert immunomodulatory effects beyond the muscle tissue and contribute to the maintenance of gut barrier integrity.[57] Neuroendocrine pathways also play a relevant role, as regular physical activity modulates autonomic balance and attenuates HPA axis activation, thereby reducing stress-related perturbations in gut permeability and microbial ecology.[56] Conversely, psychological stress influences gut microbiota through complementary neuroendocrine and immunological mechanisms. Activation of the HPA axis and sympathetic–adrenal–medullary system leads to increased levels of cortisol and catecholamines, which can impair intestinal barrier function and modulate immune responses.[58] Chronic exposure to stress has also been associated with increased gut permeability and low-grade systemic inflammation, further reinforcing dysbiosis of the microbiota. Collectively, these mechanisms provide a plausible biological framework linking perceived stress with alterations in microbial diversity and downstream metabolic and neurobehavioral consequences.[59]

The studies included in this review indicated that physical activity can induce significant changes in the gut microbiota composition. However, the observed effects are heterogeneous and appear to depend on exercise intensity, duration, and modality as well as the characteristics of the populations studied. For instance, moderate aerobic exercise (e.g., cycling) has been associated with an increase in *Akkermansia*, a bacterium linked to improved gut barrier function and insulin sensitivity.[45] In addition, it is important to highlight that the reviewed studies showed a divergent response of *Akkermansia* to different exercise programs. While moderate aerobic exercise is associated with increased *Akkermansia* abundance, ultra-endurance exercise under extreme physiological stress also results in increased *Akkermansia* levels.[47] Rather than representing a true contradiction, this pattern may reflect a nonlinear or hormetic response, in which moderate exercise promotes adaptive microbial remodeling, whereas extreme physical stress may influence compensatory or stress-related microbial shifts. Differences in baseline fitness, dietary intake, energy balance, and timing of sample collection may further contribute to these observations, highlighting the importance of interpreting microbiota responses within their physiological and contextual frameworks. Moreover, moderate physical activity appears to promote a healthy microbial profile.[60–62] In contrast, studies evaluating high-intensity or prolonged exercise reported increased levels of pro-inflammatory bacteria (*Alistipes*, *Parabacteroides*, *Ruminococcus gnavus*) and a decrease in beneficial species such as *Faecalibacterium prausnitzii*, *Roseburia*, and *Bifidobacterium*.[46,47] In this context, Yu et al.[54] reinforced the association between an active lifestyle and healthier gut microbiota. In this cohort, a higher frequency of physical activity correlated with a greater abundance of bacterial families, such as *Peptostreptococcaceae*, *Christensenellaceae* and *Clostridiaceae*, and lower levels of *Bacteroidaceae*, which may reflect a favorable microbial adaptation to regular exercise. These results are further supported by recent studies in adult and older populations, which consistently reported associations between habitual physical activity, increased microbial diversity, and enrichment of SCFA-producing taxa, particularly in aging populations.[44,50,51] These findings also align with emerging evidence suggesting that alterations in gut microbiota may reflect broader biological aging processes. Torma et al.,[28] reported associations between gut microbial diversity, epigenetic age acceleration, and physical fitness, reinforcing the idea that the gut microbiome may act as an integrative marker of physiological function. This perspective supports the notion that microbiota-related changes observed in response to physical activity and stress may be part of a more complex systemic aging mechanism.

Regarding stress management, the studies included in this review are consistent with those of Moloney et al.,[63] who described how psychological stress disrupts gut microbial balance and how stress-reducing strategies can support the restoration of microbiota homeostasis. Their synthesis in the literature highlights that reducing stress may promote the abundance of beneficial bacteria such as *Lactobacillus spp.*, *Bifidobacterium spp.*, and *Faecalibacterium prausnitzii*. Moreover, Moloney et al.[63] discussed how interventions aimed at lowering stress levels, such as dietary approaches, probiotics, and behavioral therapies, may contribute to improvements in both mental and physical health. Additionally, studies by Bashir et al.[41] and Longo et al.[49] showed that high levels of perceived stress, anxiety, and social isolation were associated with an increase in potentially pro-inflammatory bacteria such as *Escherichia*, *Shigella*, *Parabacteroides* and *Blautia*. These findings are consistent with the current evidence indicating that chronic stress may induce gut dysbiosis, characterized by reduced microbial diversity, increased intestinal permeability, and expansion of bacteria linked to adverse inflammatory and metabolic processes.[64] Moreover, the fact that these effects were observed in both young women and older adults strengthens the hypothesis that stress, regardless of age, can negatively

affect the microbial balance and contribute to a systemic pro-inflammatory state. Nevertheless, studies that evaluated probiotic supplementation support the potential of probiotics and symbiotics as modulators of the gut–brain axis, particularly in the context of physical or psychological stress.[65–67] For instance, in the clinical trials by Li et al.[48] and Wu et al.,[53] the administration of specific strains, such as *Bifidobacterium breve* 207-1 and *Lacticaseibacillus paracasei* PS23, was associated with significant improvements in psychological well-being, sleep quality, and gut microbiota composition. These interventions also resulted in a reduction in perceived stress levels and an increase in beneficial bacterial genera such as *Bifidobacterium*, *Akkermansia muciniphila* and *Lactobacillus*, along with a decrease in potentially pro-inflammatory taxa such as *Proteobacteria* and *Clostridium sensu stricto*. These findings are consistent with previous research that highlighted the bidirectional relationship between stress and the gut microbiota.[68,69] For instance, systematic reviews by Cooke et al.[70] and Ma et al.[71] showed that psychological stress is linked to decreased microbial diversity and increased harmful taxa. Chronic stress has been shown to disrupt the microbial balance, reduce beneficial bacteria, and promoting pro-inflammatory species.[72] Moreover, different domains of stress (psychological, environmental, and biological) are associated with distinct alterations in the gut microbiota composition and diversity.[43] These results reinforce the idea that interventions such as probiotics and stress-reduction strategies can help restore microbial balance and potentially improve mental and physical health.

In addition, Valle et al.[52] provide evidence of the effect of a symbiotic intervention in the context of high physical and psychological demands, such as military training. Although no significant changes were observed in gastrointestinal symptoms, improvements in well-being indicators, such as reduced tension and sleepiness, following training have been reported. These findings align with broader evidence highlighting the bidirectional communication between the gut microbiota and brain, through which dietary or probiotic interventions can modulate stress-related responses.[73] Furthermore, favorable modulation of the gut microbiota was noted, with increases in *Bifidobacterium*, *Lactobacillus*, *Faecalibacterium* and *Agathobacter*, and a reduction in potentially pro-inflammatory genera such as *Parabacteroides*.[52] These findings align with previous research demonstrating that psychobiotics can reduce cortisol levels, improve stress responses, and promote the production of short-chain fatty acids, such as butyrate, which exert anti-inflammatory and neuroprotective effects.[74] Thus, the combined use of probiotics and prebiotics may enhance these effects by supporting the survival and metabolic activity of the administered strains, as observed in both in vitro and clinical studies.

Finally, a particularly notable finding was the implementation of a multifactorial intervention combining physical activity, stress management, and lifestyle changes.[40] However, as this is a multifactorial intervention, causal attribution to individual components remains limited. This approach was associated with improvements in both clinical parameters and gut microbiota composition, with an increase in butyrate-producing bacteria (*Faecalibacterium prausnitzii*, *Lachnospiraceae*, *Ruminococcaceae*) as well as a reduction in potentially harmful genera. This combination appears to be especially effective because each component targets different yet interconnected pathways of the gut–brain axis. Physical activity has been shown to enhance microbial diversity and increase the abundance of beneficial bacterial taxa, whereas stress management techniques, including mindfulness and relaxation strategies, may reduce HPA axis hyperactivation, thereby reducing cortisol levels that otherwise disrupt gut permeability and microbial balance.[26] Therefore, by simultaneously targeting multiple determinants of gut health, multifactorial interventions may exert synergistic effects, leading to more robust and sustained improvements in both the microbiota composition and mental well-being. This integrated approach strengthens the notion that combined lifestyle and behavioral interventions are likely to have a greater impact on gut health than strategies focused on a single factor.

5. Conclusion

This review suggests that moderate physical activity and stress management strategies, with or without targeted probiotic or synbiotic supplementation, are associated with favorable shifts in gut microbiota profiles in adult and aging populations. These changes include an increased abundance of taxa such as *Akkermansia, Faecalibacterium prausnitzii, Lachnospiraceae/Ruminococcaceae, and Bifidobacterium*, along with improvements in stress-related outcomes. Conversely, chronic psychological stress and prolonged or extreme exercise appear to be associated with dysbiosis, which is characterized by reduced microbial diversity and enrichment of potentially proinflammatory taxa. These findings highlight the dual role of both psychological and physiological stressors in shaping the gut microbiota composition. Overall, the evidence supports the potential of multimodal lifestyle approaches, combining moderate physical activity, structured stress reduction strategies, and targeted nutritional interventions, as promising tools to promote gut–brain–body health. However, given the heterogeneity and methodological limitations of the available studies, the conclusions should be interpreted with caution. Further high-quality, well-controlled studies are required to establish causal relationships and to provide evidence-based recommendations.

6. Limitations

This review has several limitations that should be considered when interpreting the findings. First, the included studies exhibited substantial methodological heterogeneity, including differences in the study design, intervention duration and intensity, microbial sequencing methods, and stress assessment tools. This variability limits the comparability across studies and precludes quantitative synthesis. Second, many studies are characterized by small sample sizes, short follow-up periods, and under-representation of older adults, limiting the strength and generalizability of the findings. The exclusion of populations with conditions such as diabetes or cancer, while intended to reduce confounding related to disease-specific treatments, may further restrict generalizability to clinical aging populations in which these conditions are highly prevalent. Third, potential confounding factors such as diet, medication use, sleep patterns, antibiotic exposure, and the physiological stress associated with high-intensity exercise were not consistently controlled across studies, making it difficult to attribute observed microbiota changes solely to physical activity or stress-related variables. Fourth, although appropriate risk-of-bias tools were applied according to the study design, several studies presented methodological limitations, including a lack of blinding, incomplete outcome reporting, and inconsistent handling of missing data. These issues reduce the confidence in causal inferences. Future research should prioritize larger, longitudinal, and well-controlled studies with standardized methods for assessing physical activity, psychological stress, and microbial composition. Improved control of lifestyle and clinical confounders is essential to clarify the underlying mechanisms and support the development of robust, evidence-based recommendations.

6.1. Practical applications

The findings of this review suggest that moderate physical activity, stress management strategies, and targeted probiotic or synbiotic supplementation can be integrated into practical lifestyle interventions to support gut health in adults and aging populations. Moderate exercise appears to promote beneficial bacterial taxa and reduce stress-related physiological load, whereas psychological stress reduction techniques may help restore microbial balance. Additionally, strain-specific probiotic approaches, particularly those shown to improve well-being and gut composition in clinical trials, may serve as useful adjuncts in the context of physical or psychological demands. Together, these strategies offer feasible, non-invasive tools that practitioners can incorporate into

preventive and therapeutic programs aimed at enhancing gut–brain–body resilience.

CRediT authorship contribution statement

Raquel Aparicio-Mera: Conceptualization, Data curation, Funding acquisition, Methodology, Writing – original draft. **Samuel Manzano-Carrasco:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Antonio Hernandez-Martin:** Supervision, Writing – original draft. **Ricardo Cuevas:** Writing – review & editing. **Jorge Garcia-Unanue:** Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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