

The Gut-Brain Axis and Mental Health in Competitive Athletes: A Thematic Synthesis of Stress, Anxiety, Mood, Mental Fatigue, and Sleep

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Abstract

Background: High-performance competitive athletes face intense physiological, emotional, and environmental strain that impacts psychological well-being and sleep. The gut–brain axis, a bidirectional neurohumoral network linking the gastrointestinal tract, gut microbiota, and central nervous system represents an emerging target for supporting athletic mental health.

Objective: This thematic synthesis critically evaluates empirical evidence concerning gut microbiota composition and gut-directed interventions (psychobiotics, synbiotics, paraprobiotics) in relation to athlete mental health across five core domains: stress, anxiety, mood, mental/cognitive fatigue, and sleep.

Methods: Following thematic review methodology, 30 source documents representing 27 unique publications, including primary empirical studies and review articles, were synthesized using a qualitative thematic framework. Evidence was interpreted according to study design and methodological considerations, without quantitative meta-analysis or formal review procedures.

Thematic Findings: Controlled interventional trials suggest that specific psychobiotic strains (*Lactobacillus casei* Shirota, *Bifidobacterium animalis* subsp. *lactis* BB-12, *Lactobacillus gasseri* CP2305) and multi-strain synbiotics may attenuate subjective perceived stress, competitive state anxiety, and sleep latency in competitive athletes. Following extreme endurance exertion (marathons), multi-strain probiotics reduce systemic endotoxemia (serum lipopolysaccharide), preserve self-reported vigor, and prevent Total Mood Disturbance. Conversely, direct evidence for objective mental/cognitive fatigue remains limited to preliminary electroencephalographic reaction-time data, and sleep evaluations lack gold-standard polysomnography. Furthermore, gut microbial taxonomic correlations remain purely associative, and circulating HPA-axis hormones (cortisol, ACTH) generally do not change following probiotic intake.

Conclusion: Current evidence provides preliminary evidence that selected psychobiotic and synbiotic interventions may be useful as non-pharmacological adjuncts to attenuate perceived stress, competitive state anxiety, post-exertional mood collapse, and sleep latency in athletes. However, small sample sizes, female underrepresentation, and reliance on subjective self-reports mandate cautious interpretation. Gut-directed interventions should complement, rather than replace, established sports psychology, sleep hygiene, and clinical care.

Keywords: gut–brain axis; psychobiotics; competitive state anxiety; perceived stress; sports sleep outcomes; athletic mental fatigue; sports psychobiomics; synbiotics; endotoxemia

1. Introduction

Elite and competitive athletes operate in high-demand environments characterized by intense physical training, frequent competition, pre-race psychological pressure, rapid weight loss (RWL), travel fatigue, and strict dietary regimens (Aparicio-Mera et al., 2026; Clark & Mach, 2016; Marttinen et al., 2020). These multifaceted stressors can challenge physiological homeostasis and contribute to elevated perceived stress, competitive state anxiety, mood disturbance, mental fatigue, and sleep disruption (Fullagar et al., 2015; Salehi Asl et al., 2026). Between 20% and 60% of competitive athletes experience excessive training strain or inadequate recovery during their careers, emphasizing the need for evidence-based recovery strategies (Clark & Mach, 2016).

In recent years, exercise psychophysiology and sports nutrition have increasingly focused on the gut–brain axis, a dynamic, bidirectional communication system connecting the gastrointestinal tract, intestinal mucosal barrier, enteric nervous system (ENS), gut microbiota, and central nervous system (CNS) (Bongiovanni et al., 2025; Clark & Mach, 2016; Quero et al., 2021). Communication along this axis occurs through neuroendocrine pathways (hypothalamic–pituitary–adrenal [HPA] axis), autonomic/vagal afferent signaling, systemic immune/inflammatory cascades, and microbial-derived neuroactive metabolites, including short-chain fatty acids (SCFAs), gamma-aminobutyric acid (GABA), serotonin precursors, and catecholamines (Clark & Mach, 2016; Dalton et al., 2019; Shen et al., 2026).

Heavy physical exertion (>60% VO₂max) shunts blood flow away from the splanchnic circulation to active skeletal muscle, inducing transient intestinal hypoxia, epithelial tight-junction disruption, and mucosal hyperpermeability ('leaky gut') (Clark & Mach, 2016; Tavares-Silva et al., 2024). Translocation of luminal lipopolysaccharide (LPS) into systemic circulation activates Toll-like receptor 4 (TLR4) signalling, triggering pro-inflammatory cytokine release (IL-1 β , IL-6, TNF- α) that can cross the blood-brain barrier and induce central neuroinflammation and sickness behaviour's (Aquino-Lemos et al., 2025; Tavares-Silva et al., 2024).

Targeted nutritional strategies, specifically psychobiotics (live microorganisms that confer mental health benefits), synbiotics (probiotics combined with prebiotic substrates), and paraprobiotics (non-viable heat-killed bacteria) have been proposed to reinforce intestinal barrier integrity, suppress systemic endotoxemia, and modulate central neurohumoral signaling (Quero et al., 2021; Salehi Asl et al., 2026; Sawada et al., 2019). This thematic review synthesizes empirical evidence across 30 source documents representing 27 unique publications, including primary empirical studies and review articles to evaluate the impact of the gut–brain axis on stress, anxiety, mood, mental/cognitive fatigue, and sleep in competitive athletes.

2. Methods: Thematic Review Methodology

2.1 Review Approach

To synthesize the multifaceted relationship between the gut–brain axis, psychological states, and sleep in athletic populations, a qualitative thematic synthesis approach was adopted (Clark & Mach, 2016; Salehi Asl et al., 2026). A thematic review is particularly suited to complex, interdisciplinary domains in sports science where primary studies exhibit substantial heterogeneity in experimental designs, study populations, interventions, and outcome metrics (Aparicio-Mera et al., 2026; Marttinen et al., 2020).

The rationale for selecting thematic synthesis rather than quantitative meta-analysis stems from the methodological diversity present in the literature. Included studies span double-blind randomized controlled trials (RCTs), single-arm prospective pilot studies, cross-sectional observational cohorts, omics profiling, and narrative/evidence-synthesis reviews (Bongiovanni et al., 2025; Dong et al., 2021; Quero et al., 2021; Shen et al., 2026). Furthermore, interventions range from single-strain psychobiotics (e.g., *Lactobacillus casei* Shirota, *Bifidobacterium animalis* subsp. *lactis* BB-12) and multi-strain consortia to synbiotic ice cream, fermented milks, and paraprobiotics (Adikari et al., 2020; Sawada et al., 2019; Valle et al., 2021). Outcome measures encompass psychometric questionnaires, objective electroencephalographic (EEG) brain wave recordings, endocrine panels, and 16S rRNA/metagenomic sequencing (Adikari et al., 2020; Fu et al., 2024; Xie et al., 2026).

2.2 Source Corpus and Eligibility Considerations

The source corpus comprised 30 uploaded source PDF files representing 27 unique academic publications, including primary empirical studies and review articles. The difference arose because three duplicate file pairs were present in the uploaded repository; these duplicate records were consolidated so that each underlying publication was treated once in

the thematic synthesis. Eligibility considerations were applied to organize the evidence rather than to reproduce a formal systematic-review screening process. Secondary review sources in the uploaded corpus (e.g., Fullagar et al., 2015) were used as contextual/background attributions rather than treated as primary empirical athlete studies.

- Population: Competitive, elite, trained, or collegiate athletes across individual and team sports (soccer, rugby, diving, combat sports, badminton, running, shooting/archery). Highly active tactical/military cohorts were distinguished from competitive athlete cohorts.
- Interventions: Probiotic, prebiotic, synbiotic, or paraprobiotic supplementation, dietary modifications, or naturalistic pre-competition training/weight loss stress.
- Outcomes: Primary psychological or sleep constructs perceived stress, competitive state anxiety, mood disturbance, mental/cognitive fatigue, athlete burnout, or subjective/objective sleep metrics.

2.3 Evidence and Quality Considerations

Because this manuscript is a thematic review rather than a formal systematic review, study quality was considered qualitatively and in relation to study design. Randomized controlled trials were interpreted with attention to randomization, blinding, comparator use, sample size, and outcome measurement; prospective single-arm studies were considered more vulnerable to confounding and time-related effects; and cross-sectional or omics studies were interpreted as associative and hypothesis-generating. The study-level table therefore records design-specific methodological limitations and quality/risk-of-bias considerations. No single risk-of-bias instrument was applied uniformly across all study designs because the source corpus includes heterogeneous designs for which a single tool would not be appropriate. Formal RoB2 or AXIS-style judgments are not claimed where such assessments were not actually performed.

3. Study-Level Evidence

Primary human investigations evaluating the gut–brain axis in relation to psychological states, cognitive performance, or sleep in competitive athletes and physically active populations were extracted from the source corpus. The primary studies encompass randomized controlled trials (RCTs), non-randomized controlled trials, prospective single-arm pilot studies, paired pre–post observational cohorts, and cross-sectional omics analyses (Adikari et al., 2020; Aquino-Lemos et al., 2025; Bongiovanni et al., 2025; Dong et al., 2021; Fu et al., 2024; Harnett et al., 2021; Mei-hua et al., 2025; Quero et al., 2021; Shen et al., 2026; Valle et al., 2021; Wang et al., 2024; Wei et al., 2025; Wiącek et al., 2024; Xie et al., 2026; Zhu et al., 2023).

Table 1. Characteristics and empirical outcomes of primary human gut–brain studies in athletic and trained populations.

Study & Origin	Design & Sport	Intervention & Dose	Primary Outcomes	Key Findings & Significance	Risk of Bias / Quality Considerations
Adikari et al. (2020) [Malaysia]	Double-blind RCT Competitive collegiate soccer players (n=19)	L. casei Shirota (3×10 ¹⁰ CFU/day) vs. placebo (8 weeks)	EEG spectral power, sustained attention (Digit Vigilance Test)	Significantly higher absolute theta and delta EEG power at week 4; faster sustained attention reaction time (2.71±0.41 vs 3.24±0.59 min) [p < 0.05 (EEG); p = 0.037 (DVT)]	Double-blind RCT; small sample (n=19); comparator and blinding strengthen internal validity; objective EEG/DVT outcomes are a strength.
Salleh et al. (2021) [Malaysia]	Double-blind RCT Collegiate badminton players (n=30)	L. casei Shirota (3×10 ¹⁰ CFU/day) vs. placebo	Competitive state anxiety (CSAI-2R), perceived stress (PSS)	16% reduction in competitive anxiety (22.27±2.40 vs 26.33±2.50) and	Double-blind RCT; small sample (n=30); placebo comparator and

		placebo (6 weeks)		20% reduction in perceived stress (18.60 ± 1.40 vs 23.47 ± 2.20) [$p < 0.001$ (both)]	validated questionnaires strengthen inference; outcomes are largely subjective.
Quero et al. (2021) [Spain]	Triple-blind RCT Professional soccer players vs. sedentary controls (n=13 athletes, 14 controls)	Multi-strain synbiotic (Gasteel Plus®) (30 days)	ActiGraph sleep efficiency/latency, PSS stress, plasma neurochemicals	Significantly improved sleep efficiency % and reduced latency; lower PSS stress; selective elevation of plasma dopamine in athletes [$p < 0.05$ (sleep); $p < 0.01$ (PSS)]	Triple-blind randomized trial; very small athlete sample (n=13); objective ActiGraph sleep measures are a strength; limited power remains a concern.
Harnett et al. (2021) [Australia]	Double-blind RCT Elite rugby union players (n=19)	Multi-species probiotic (UltraBiotic 60™ + <i>S. boulardii</i>) (17-week season)	Perceptual wellness, muscle soreness, leg heaviness, sleep quality	Significantly reduced muscle soreness and leg heaviness; higher perceptual sleep quality strongly mediated by reduced muscle pain [$p < 0.001$ (soreness); $p < 0.0001$ (heaviness)]	Double-blind RCT; small sample (n=19); seasonal duration is a strength, but perceptual sleep and recovery outcomes are largely subjective.
Dong et al. (2021) [China]	Single-arm prospective proof-of-concept pilot; junior elite divers from Chongqing Sports Technical School (mean age 9.1 ± 1.8 yr; n=21; 100% male)	<i>B. animalis</i> subsp. <i>lactis</i> BB-12 (1×10^9 CFU/100 g yogurt), daily for 8 weeks	Cognitive state anxiety and somatic state anxiety (MRF-3); anxiety emotion (PHCSS); simulated competition diving performance	Cognitive state anxiety decreased by week 4 ($Z = -3.964$, $P < 0.001$); somatic state anxiety decreased by week 8 ($Z = -3.079$, $P = 0.003$); anxiety emotion decreased by week 8 ($Z = -2.973$, $P = 0.002$); performance under stress improved at week 8 ($\chi^2 = 7.88$, $P = 0.019$); fecal Bifidobacteriaceae abundance	Exploratory single-arm pilot with no parallel control/placebo; small, all-male, very young cohort; self-reported anxiety; dietary variation; possible habituation to repeated simulated stress; no physiological HPA-axis, inflammatory, vagal, metagenomic,

				increased, while overall α - and β -diversity did not significantly change.	or metabolomic measures; causal inference cannot be established.
Sawada et al. (2019) [Japan]	Double-blind RCT; male university Ekiden long-distance runners (n=49; n=24 CP2305, n=25 placebo)	Heat-killed <i>L. gasseri</i> CP2305 (1×10^{10} cells/day) vs. placebo (12 weeks)	Stress physical symptoms, STAI anxiety, PSQI sleep quality	Significantly alleviated stress-related physical complaints, reduced anxiety, and preserved PSQI sleep quality during heavy pre-competition volume [$p < 0.05$]	Double-blind RCT; small collegiate runner sample; placebo comparator strengthens inference, while several outcomes rely on self-report.
Tavares-Silva et al. (2024) [Brazil]	Double-blind RCT Experienced male marathon runners (n=14)	4-strain probiotic (<i>L. acidophilus</i> , <i>L. lactis</i> , <i>B. lactis</i> , <i>B. bifidum</i> ; 1×10^9 CFU/day) (30 days)	POMS vigor and TMD, serum LPS endotoxemia, cytokines	Placebo had severe post-race vigor collapse and TMD spike; probiotics preserved vigor, prevented TMD rise, and suppressed post-race LPS [$p = 0.05$ (vigor & TMD); $p < 0.02$ (IL-2/IL-4)]	Double-blind RCT; very small male-only sample (n=14); controlled design is a strength, but sex and sample-size limitations restrict generalizability.
Aquino-Lemos et al. (2025) [Brazil]	Double-blind RCT Experienced marathon runners (n=27)	<i>L. acidophilus</i> + <i>B. lactis</i> (2×10^{10} CFU/day) vs. placebo (30 days)	ActiGraph sleep latency, sleep efficiency, serum LPS 1h and 24h post-race	Prevented acute post-marathon sleep breakdown; preserved total sleep time and efficiency; significantly lower circulating endotoxin (LPS) [$p < 0.05$ (sleep metrics & LPS)]	Double-blind RCT; small sample (n=27); objective ActiGraph and LPS measures strengthen assessment, but replication is limited.
Shen et al. (2026) [China]	Double-blind RCT Competitive combat sport athletes (wrestling/judo/boxing) (n=32)	7-strain probiotic powder ($\geq 3 \times 10^{10}$ CFU/day) vs. placebo during RWL (4 weeks (RWL))	POMS fatigue, ABQ burnout, circulating GABA, gut microbiota	Nominal reduction in POMS fatigue and elevated GABA; lost statistical significance after Benjamini–Hochberg FDR correction; ABQ burnout unchanged [$p =$	Double-blind RCT; small sample (n=32); FDR correction attenuated some fatigue findings, indicating limited statistical robustness.

				0.002 (unadjusted fatigue); $q = 0.216 > 0.05$ (FDR)]	
Bongiovanni et al. (2025) [USA/Italy]	Single-arm crossover trial Professional soccer players (n=11)	Athlete-derived probiotic (Nella: 3-strain lactobacilli, 3.5×10^{10} CFU/day) (2 wk placebo + 2 wk probiotic)	Self-reported sleep quality, energy levels, D-ROMS oxidative stress	+69% improvement in sleep quality, +31% reported energy, +37% bowel frequency; significant reduction in reactive oxygen metabolites [$p < 0.0001$ (sleep); $p < 0.05$ (D-ROMS)]	Single-arm crossover design with a small sample (n=11); absence of a conventional parallel control and short intervention period limit causal inference.
Zhu et al. (2023) [China]	Controlled Trial / RCT Female collegiate taekwondo athletes (n=20)	B. animalis subsp. lactis BB-12 yogurt vs. control (8 weeks)	Athlete Burnout Questionnaire (ABQ: exhaustion, devaluation, accomplishment)	Significantly decreased total burnout, emotional exhaustion, sport devaluation, and perceived reduced athletic accomplishment [$p < 0.05$ across subscales]	Controlled/RC T design with small female collegiate sample (n=20); ABQ is validated for burnout but is not a direct measure of cognitive fatigue.
Fu et al. (2024) [China]	Cross-sectional metabolomic profiling Elite national wrestlers during pre-competition RWL (n=12)	Observational high vs. low athletic achievement cohorts (Pre-competition RWL)	CSAI-2 anxiety, fecal/urinary metabolomics, microbiome 16S	High-achievement athletes displayed higher self-confidence, lower failure anxiety, enriched Oscillospiraceae, and elevated GABA/ornithine metabolites [$p < 0.05$]	Cross-sectional metabolomic profiling; small sample (n=12); associations cannot establish directionality or causality.
Wei et al. (2025) [China]	Cross-sectional multi-cohort Elite shooting and archery national athletes (n=110)	Observational anxiety classification (GAD-7) (Cross-sectional)	GAD-7 anxiety, gut taxonomic sequencing, sex differences	Sex-dependent microbiome differences: Bacteroides and Clostridium correlated positively with anxiety; Streptococcus correlated negatively [$p < 0.05$]	Cross-sectional multi-cohort design; relatively larger sample (n=110), but taxonomic correlations remain associative and questionnaire-based anxiety

					limits causal interpretation.
Xie et al. (2026) [China]	Paired pre-post observational Elite taekwondo athletes preparing for World University Games (n=11)	8-week intensive pre-competition training camp (8 weeks)	CSAI-2 anxiety, 16S gut microbiota shifts	Competition stress elevated cognitive & somatic anxiety; Lactobacillaceae dropped significantly and correlated inversely with somatic anxiety [r = -0.689, p = 0.027]	Exploratory paired pre-post observational design with no randomized comparator; small sample (n=11); changes during training may reflect time, training load, or other confounding factors; causal inference cannot be established.

Note: RCT = randomized controlled trial; CFU = colony-forming units; LPS = lipopolysaccharide; CSAI-2R = Competitive State Anxiety Inventory-2 Revised; PSS = Perceived Stress Scale; MRF-3 = Mental Readiness Form-3; ABQ = Athlete Burnout Questionnaire; DVT = Digit Vigilance Test.

Quality/risk-of-bias considerations in Table 1 are design-specific and qualitative; they are not formal RoB2 or AXIS scores.

4. Thematic Synthesis

4.1 Stress

Context and Physiological vs. Perceived Stress

Competitive athletes face chronic physical, physiological, and psychosocial strain that challenges systemic homeostasis (Clark & Mach, 2016). In sports science research, a fundamental distinction must be maintained between perceived/psychological stress (subjective cognitive appraisal of environmental demands exceeding coping resources) and physiological stress (HPA-axis neuroendocrine activation, exercise-induced muscle damage, splanchnic hypoperfusion, and systemic inflammation).

Controlled Intervention Evidence

Controlled trials suggest that psychobiotics and synbiotics may attenuate subjective perceived stress in competitive cohorts. Salleh et al. (2021) showed that 6 weeks of *L. casei* Shirota (3×10^{10} CFU/day) in collegiate badminton players significantly reduced Perceived Stress Scale (PSS) scores by 20% (18.60 ± 1.40 vs. 23.47 ± 2.20 , $p < 0.001$) compared to unchanged controls. Quero et al. (2021) observed a statistically significant reduction in PSS perceived stress following 30 days of multi-strain synbiotic (Gasteel Plus®) intake specifically in professional soccer players ($p < 0.01$), an effect absent in sedentary controls.

Longer-term supplementation trials corroborate these findings. Sawada et al. (2019) reported that 12 weeks of paraprobiotic *L. gasseri* CP2305 significantly reduced stress-related physical symptoms and fatigue in Ekiden distance runners during an intense pre-competition training block ($p < 0.05$). Carbuñ et al. (2018) demonstrated that 6 weeks of *B. longum* 35624 in Division I female swimmers resulted in significantly higher sport recovery scores on the RESTQ-Sport compared to placebo ($p < 0.05$). Objective electroencephalographic biofeedback by Adikari et al. (2020) revealed that 8 weeks of *L. casei* Shirota significantly increased absolute theta (4–8 Hz) and delta (0.5–4 Hz) EEG spectral power in collegiate soccer players at week 4 ($p < 0.05$), reflecting central mental relaxation and reduced arousal.

Neuroendocrine Discordance

Despite consistent improvements in subjective perceived stress questionnaires, psychobiotics generally do not significantly lower basal or post-exercise circulating cortisol, ACTH, or CRH concentrations in human athletes (Quero et al., 2021; Salleh et al., 2021; Sawada et al., 2019). In professional soccer players, Quero et al. (2021) observed that circulating CRH, ACTH, and cortisol remained statistically unchanged in athletes post-synbiotic intervention, although plasma dopamine elevated significantly. This pattern is consistent with, but does not establish, involvement of autonomic or vagal pathways in the attenuation of subjective stress.

4.2 Anxiety

Construct Distinction: Competitive State Anxiety vs. Generalized Anxiety

In sport psychology, competitive state anxiety is an acute, situation-specific emotional response characterized by cognitive worry, somatic physiological arousal, and fluctuating state self-confidence prior to competition. It must be rigorously distinguished from generalized anxiety disorder (GAD) or clinical trait anxiety (Dong et al., 2021; Fu et al., 2024; Wei et al., 2025). Primary athletic studies evaluated situational pre-competition anxiety via the Competitive State Anxiety Inventory-2 (CSAI-2, CSAI-2R) or Mental Readiness Form-3 (MRF-3), not clinical psychiatric disorders.

Intervention Evidence and Psychological Changes

Interventional RCTs and prospective pilot studies demonstrate that psychobiotics were associated with reductions in competitive state anxiety. Salleh et al. (2021) reported a statistically significant 16% reduction in CSAI-2R competitive anxiety in badminton players following 6 weeks of *L. casei* Shirota (22.27 ± 2.40 vs. 26.33 ± 2.50 , $p < 0.001$). In junior elite divers, Dong et al. (2021) demonstrated that 8 weeks of *B. animalis* subsp. *lactis* BB-12 yogurt significantly reduced cognitive state anxiety at week 4 ($p < 0.001$) and somatic anxiety at week 8 ($p = 0.003$) via MRF-3; PHCSS anxiety emotion also decreased at week 8 ($Z = -2.973$, $P = 0.002$), accompanied by improved diving performance under pressure ($p = 0.019$). Quero et al. (2021) reported significant reductions in STAI trait anxiety in professional soccer players following 30 days of synbiotic intake ($p < 0.05$), and Sawada et al. (2019) observed reduced STAI state anxiety in Ekiden runners following 12 weeks of paraprobiotic CP2305 ($p < 0.05$).

Observational Taxonomic Correlates

Cross-sectional profiling in national wrestlers undergoing pre-competition RWL revealed that high-achievement wrestlers had higher state self-confidence, lower failure anxiety, and enriched Oscillospiraceae and Paraprevotella abundance, which correlated with stress-resilience metabolites (ornithine, L- α -aminobutyric acid) (Fu et al., 2024). In 110 precision athletes, Wei et al. (2025) found that *Bacteroides* and *Clostridium* correlated positively with GAD-7 anxiety, whereas *Streptococcus* correlated negatively ($p < 0.05$). In elite taekwondo athletes, Xie et al. (2026) showed that pre-competition situational stress increased CSAI-2 cognitive and somatic anxiety, while Lactobacillaceae abundance decreased and correlated inversely with somatic anxiety ($r = -0.689$, $p = 0.027$). These taxonomic correlations are associative and hypothesis-generating.

4.3 Mood

Constructs and Operational Measurement

Mood in athletes represents a dynamic, multidimensional spectrum of transient affective states evaluated via the Profile of Mood States (POMS) or Brunel Mood Scale (BRUMS) across negative subscales (tension, anger, depression, fatigue, confusion), positive affect (vigor), and composite Total Mood Disturbance (TMD) (Shen et al., 2026; Tavares-Silva et al., 2024). Subclinical mood shifts in athletes must be distinguished from clinical depression, perceived stress, and athlete burnout.

Protection Against Post-Exercise Affective Collapse

Primary interventional evidence suggests that multi-strain probiotics may protect against post-exercise mood collapse following severe endurance exertion. Tavares-Silva et al. (2024) evaluated experienced male marathon runners ($n = 14$) receiving 30 days of multi-strain probiotics (*L. acidophilus*, *L. lactis*, *B. lactis*, *B. bifidum*, 1×10^9 CFU/day) or placebo prior to a marathon. Placebo runners suffered a post-marathon vigor collapse (12.2 ± 2.71 to 5.50 ± 2.88 , $p = 0.05$) and TMD spike (-4.83 ± 7.28 to 4.83 ± 4.67 , $p = 0.05$). Probiotic supplementation preserved post-marathon vigor (11.0 ± 4.73 to

8.14 ± 4.06 , $p > 0.05$) and prevented TMD elevation (-2.57 ± 5.86 to 3.71 ± 10.00 , $p > 0.05$). This affective protection was accompanied by significant suppression of post-race serum LPS ($p = 0.05$) and an improved IL-2/IL-4 cytokine ratio ($p < 0.02$).

In contrast, during rapid weight loss in combat athletes, Shen et al. (2026) observed that initial unadjusted POMS fatigue interaction effects ($p = 0.002$) lost statistical significance after Benjamini–Hochberg False Discovery Rate (FDR) correction ($q = 0.216 > 0.05$), and overall TMD did not differ between groups. Similarly, Salleh et al. (2021) found no significant changes in BRUMS baseline mood scores in badminton players, indicating that psychobiotics may protect against acute stress-related mood worsening rather than altering basal mood in non-stressed settings.

4.4 Mental and Cognitive Fatigue

Conceptual Differentiation Across Fatigue Constructs

Scientific rigor requires strict differentiation between distinct fatigue domains:

- **Mental Fatigue:** A psychobiological state induced by prolonged cognitive exertion, characterized by subjective tiredness, lack of energy, and elevated perception of effort (Adikari et al., 2020).

- **Cognitive Fatigue:** Objective decrement in cognitive performance processing speed, sustained attention, executive control, or reaction time resulting from sustained mental load (Adikari et al., 2020).
- **Physical Fatigue:** Transient reduction in maximal muscle force-generating capacity driven by peripheral metabolic strain (creatine kinase [CK], lactate, muscle damage) (Clark & Mach, 2016; Mei-hua et al., 2025). Physical performance metrics and RPE do not represent direct measures of cognitive fatigue.

- **Athlete Burnout:** Multidimensional psychological syndrome resulting from chronic sport stress, characterized by emotional/physical exhaustion, reduced accomplishment, and sport devaluation on the Athlete Burnout Questionnaire (ABQ) (Shen et al., 2026; Zhu et al., 2023).

Direct Evidence and Evidence Gap

Direct evidence for objective cognitive fatigue under gut microbial modulation is limited to a single double-blind RCT. Adikari et al. (2020) reported that 8 weeks of *L. casei* Shirota in collegiate soccer players significantly improved sustained attention reaction time on the Digit Vigilance Test (DVT) at week 8 ($p = 0.037$) and increased absolute theta and delta EEG brain wave power at week 4 ($p < 0.05$).

Other studies evaluated subjective POMS fatigue subscales or sport burnout. Zhu et al. (2023) demonstrated that 8 weeks of *B. animalis* subsp. *lactis* BB-12 yogurt in female taekwondo athletes significantly reduced ABQ total burnout, reduced accomplishment, emotional exhaustion, and sport devaluation scores ($p < 0.05$). However, the ABQ measures chronic sport burnout, not acute cognitive fatigue. High-density objective cognitive testing batteries remain a major research gap in sports psychobiomics.

4.5 Sleep

Subjective Questionnaires vs. Objective Modalities

Sleep disruption is highly prevalent in elite athletes due to training overloads, muscle soreness, pre-competition anxiety, travel jet lag, and high nocturnal core body temperature (Harnett et al., 2021; Salehi Asl et al., 2026). Evaluation requires distinguishing subjective self-reports (PSQI, ESS, Likert sleep logs) from objective modalities (24-hour ActiGraph accelerometry, EEG spectral power) (Quero et al., 2021; Wiącek et al., 2024). No primary athletic trial in the source corpus used polysomnography (PSG); sleep evidence therefore relies on PSQI/self-report measures and ActiGraph accelerometry rather than PSG-measured sleep-stage restoration.

Controlled Intervention Evidence

Primary RCTs suggest that multi-strain probiotics and synbiotics may preserve sleep parameters following extreme physical exertion and during competitive seasons. In experienced marathon runners ($n = 27$), Aquino-Lemos et al. (2025) reported that 30 days of *L. acidophilus* + *B. lactis* (2×10^{10} CFU/day) preserved post-marathon sleep latency, total sleep time, and sleep efficiency 24h post-race compared to severe sleep breakdown in placebo ($p < 0.05$), accompanied by significantly lower serum LPS at 1h and 24h post-race ($p < 0.05$).

In professional soccer players, Quero et al. (2021) reported that 30 days of multi-strain synbiotic (Gasteel Plus®) significantly improved objective ActiGraph sleep efficiency percentage and reduced sleep latency exclusively in athletes

($p < 0.05$). Bongiovanni et al. (2025) reported a 69% improvement in self-reported sleep quality in professional soccer players receiving an athlete-derived probiotic (Nella) for 2 weeks ($p < 0.0001$), accompanied by reduced oxidative stress (D-ROMS, $p < 0.05$). Harnett et al. (2021) showed that multi-species probiotics in elite rugby players significantly reduced muscle soreness and leg heaviness ($p < 0.0001$), explaining higher perceptual sleep quality across a 17-week season. Sawada et al. (2019) reported preserved PSQI sleep quality in Ekiden runners receiving paraprobiotic CP2305 for 12 weeks ($p < 0.05$).

5. Cross-Cutting Mechanistic Interpretation

5.1 Gut Barrier Homeostasis & Endotoxemia

Strenuous exertion ($>60\%$ VO₂max) can cause splanchnic hypoperfusion, mucosal hypoxia, and epithelial tight-junction disruption (ZO-1, occludin breakdown), elevating circulating intestinal fatty acid-binding protein (I-FABP) and zonulin (Clark & Mach, 2016; Marttinen et al., 2020). Translocation of luminal lipopolysaccharide (LPS) into systemic circulation activates CD14/TLR4 receptors on immune cells, triggering pro-inflammatory cytokines (IL-1 β , IL-6, TNF- α) (Aquino-Lemos et al., 2025; Tavares-Silva et al., 2024). Human athlete RCTs provide evidence that 30-day probiotic supplementation significantly suppresses post-marathon serum LPS, lowers fecal zonulin, and reduces systemic inflammatory markers (Aquino-Lemos et al., 2025; Tavares-Silva et al., 2024). Direct upregulation of tight-junction gene expression remains a proposed mechanism derived from rodent exercise models.

5.2 HPA Axis, Autonomic & Vagal Signaling

Acute physical and emotional stress stimulates the SAM axis (catecholamines) and HPA axis (CRH $\rightarrow$ ACTH $\rightarrow$ cortisol) (Clark & Mach, 2016). Vagal sensory afferents can convey gut-derived signals to the nucleus of the solitary tract (NTS) and related brain regions (Clark & Mach, 2016; Dalton et al., 2019). In human athletes, psychobiotics attenuate subjective perceived stress and competitive anxiety without lowering basal cortisol or ACTH, a pattern that is consistent with mechanisms involving autonomic or vagal signaling rather than direct adrenal glucocorticoid suppression (Adikari et al., 2020; Quero et al., 2021; Salleh et al., 2021). [P] Preclinical Hypothesis: subdiaphragmatic vagotomy evidence comes from rodent models and has not been demonstrated in human athletes.

5.3 Neuroinflammation & Microglial Activation

[P] Preclinical Hypothesis: circulating pro-inflammatory cytokines and translocated LPS may influence the CNS through blood-brain barrier or circumventricular pathways and may contribute to microglial activation; this mechanistic inference is not directly demonstrated in human athletes (Bongiovanni et al., 2025; Tavares-Silva et al., 2024). [P] Preclinical Hypothesis: microglial activation has been proposed to alter monoaminergic neurotransmission and contribute to sickness-related behaviors (lethargy, mood collapse, loss of vigor, sleep fragmentation). Probiotic-induced suppression of peripheral endotoxemia and cytokine generation is consistent with preservation of post-race vigor and sleep outcomes in human athletes (Aquino-Lemos et al., 2025; Tavares-Silva et al., 2024).

5.4 Microbial Metabolites & Neuroactive Compounds

Commensal bacteria ferment dietary fibers into short-chain fatty acids (SCFAs: acetate, propionate, butyrate) and can contribute to the production or modulation of neuroactive compounds (GABA, dopamine, serotonin precursors, menaquinone) (Bongiovanni et al., 2025; Clark & Mach, 2016; Shen et al., 2026). In combat athletes, probiotics were associated with significantly elevated circulating GABA levels (Shen et al., 2026). In national wrestlers, high self-confidence correlated with SCFA-producing taxa (Oscillospiraceae, Ruminococcaceae) and stress-resilience metabolites (ornithine, L- α -aminobutyric acid) (Fu et al., 2024). Athlete-derived probiotics upregulated menaquinone (vitamin K₂) biosynthesis pathways, reducing oxidative stress (D-ROMS) and improving sleep quality (Bongiovanni et al., 2025). [P] Preclinical Hypothesis: striatal dopamine release via TRPV1 endocannabinoid afferents remains a proposed rodent model and has not been demonstrated as a causal pathway in human athletes (Wang et al., 2024).

6. Evidence Strength and Interpretation

Evidence across the five core themes was interpreted according to study design and methodological strength. Controlled intervention evidence from RCTs was considered separately from prospective uncontrolled evidence, observational

associations, and mechanistic/preclinical evidence. These categories are used to support a qualitative interpretation of evidence strength rather than a formal evidence-grading system.

Table 2. Qualitative interpretation of empirical evidence across the five athlete gut–brain domains.

Neuropsychological Domain	Qualitative Evidence Interpretation	Target Constructs & Key Strains	Key Mechanistic Markers	Primary Methodological Caveats
1. Perceived Stress	Relatively consistent human intervention evidence	PSS scores, RESTQ-Sport recovery, EEG theta/delta power • <i>L. casei</i> Shirota, <i>B. longum</i> 35624, Paraprobiotic <i>L. gasseri</i> CP2305, Gasteel Plus® synbiotic	Increased theta/delta brain wave power (Adikari et al., 2020); unchanged circulating cortisol/ACTH (Quero et al., 2021; Salleh et al., 2021)	Small sample sizes; absence of direct adrenal endocrine attenuation; relies on subjective self-report
2. Competitive Anxiety	Relatively consistent human intervention evidence	CSAI-2R cognitive/somatic anxiety, MRF-3, STAI state anxiety • <i>L. casei</i> Shirota (3×10^{10} CFU), <i>B. animalis</i> BB-12 (1×10^9 CFU), <i>L. gasseri</i> CP2305	Vagal nerve sensory tone; inverse correlation with Lactobacillaceae abundance ($r = -0.689$, $p = 0.027$)	Evaluates situational pre-competition anxiety, not generalized psychiatric disorders; taxonomy remains associative
3. Mood Disturbances	Preliminary human intervention evidence	POMS Vigor, Tension, Total Mood Disturbance (TMD), BRUMS • 4-strain probiotic (<i>L. acidophilus</i> , <i>L. lactis</i> , <i>B. lactis</i> , <i>B. bifidum</i>)	Suppression of post-marathon endotoxemia (serum LPS); improved IL-2/IL-4 ratio (Tavares-Silva et al., 2024)	Protective only during severe exertion/stress; nominal POMS changes in combat RWL lost significance after FDR correction
4. Mental & Cognitive Fatigue	Limited human evidence	Digit Vigilance Test reaction time, EEG spectral density, ABQ burnout • <i>L. casei</i> Shirota (DVT reaction time); <i>B. animalis</i> BB-12 (ABQ burnout)	DVT sustained attention speedup ($p = 0.037$); central dopamine modulation	Major research gap: only 1 study tested objective cognitive performance; burnout scales measure chronic sport exhaustion, not cognitive load
5. Sleep Outcomes	Preliminary human intervention evidence	Sleep efficiency %, sleep latency, PSQI quality, post-race sleep breakdown • Gasteel Plus® synbiotic, <i>L. acidophilus</i> + <i>B. lactis</i> , CP2305, Nella athlete-derived	Reduced serum LPS 1h & 24h post-marathon (Aquino-Lemos et al., 2025); reduced muscle soreness (Harnett et al., 2021); lowered D-ROMS	ActiGraph accelerometry used in only two small trials; complete absence of gold-standard Polysomnography (PSG)

Note: Evidence labels reflect the consistency and design of available human athletic studies and are qualitative, not formal GRADE ratings. They should be interpreted alongside the methodological caveats shown in the table.

Methodological Limitations

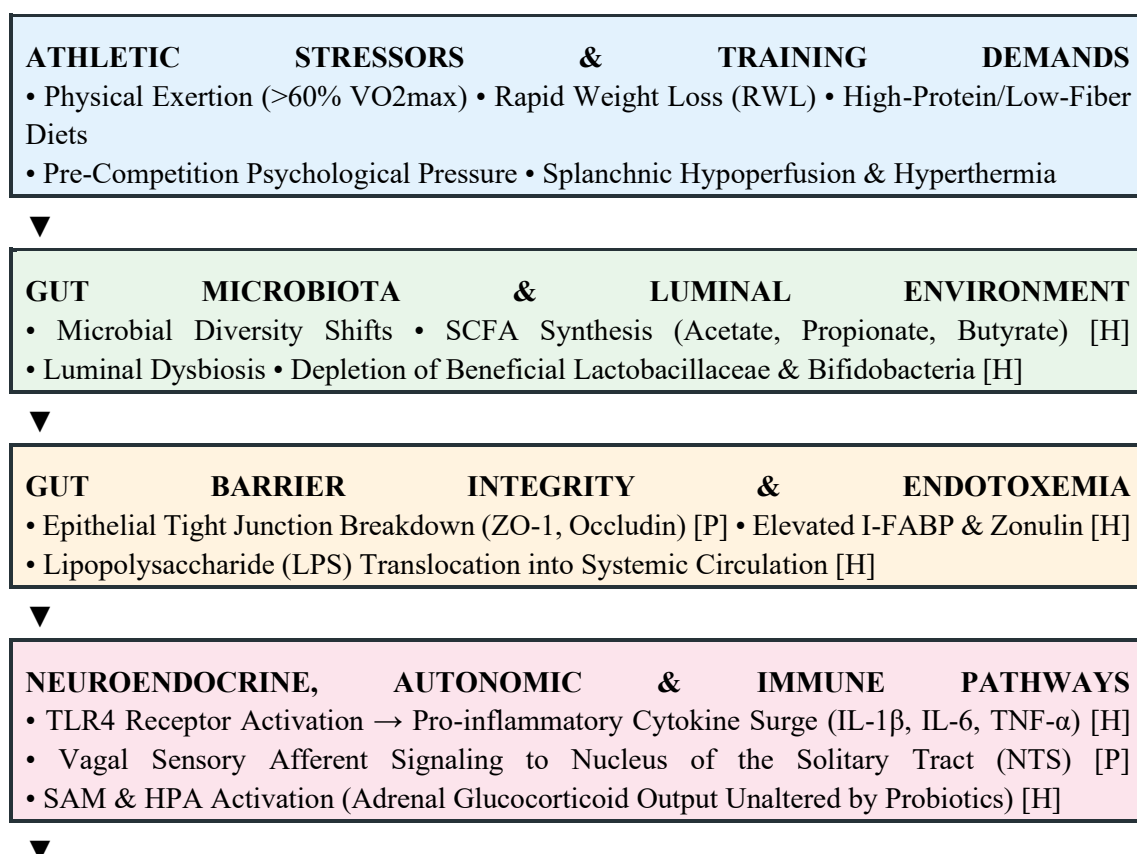
Critical examination of the 30 source documents reveals several major methodological constraints across current sports psychobiomics:

- **Small Sample Sizes:** Primary athletic RCTs enroll 32 participants per trial, leading to underpowered statistical interaction effects (e.g., Shen et al., 2026 losing significance after FDR adjustment).
- **Severe Sex Representation Imbalance:** Out of 12 interventional human RCTs, 8 were conducted exclusively in male athletes, despite supported sex-dependent differences in gut microbial diversity and psychological stress pathways (Wei et al., 2025).
- **Broad Intervention Heterogeneity:** Investigated formulations range from single-strain bacteria to 7-strain consortia, with dosages spanning 1×10^9 to 3.5×10^{10} CFU/day, delivered via capsules, powders, yogurts, or ice creams across durations of 2 to 17 weeks.
- **Dietary Fiber & Training Load Confounders:** Few studies rigorously tracked background dietary fiber or used continuous heart rate/GPS telemetry, leaving ambient lifestyle variations unaddressed.
- **Subjective Questionnaire Reliance:** Psychological evaluations are predominantly based on self-report questionnaires (CSAI-2, PSS, POMS), with rare utilization of objective cognitive testing batteries or gold-standard polysomnography.

7. Proposed Bidirectional Gut–Brain–Mental Health Framework

To unify the empirical findings, a comprehensive bidirectional framework is proposed. This model delineates the forward cascade through which high-intensity training, environmental stress, and pre-competition pressure may influence the gut microbiota, gut-barrier function, systemic endotoxemia, and downstream neuroimmune signaling, alongside the reverse feedback loop, whereby psychological stress and sleep disruption may influence gastrointestinal motility and microbial composition.

Figure 7.1. Structural Bidirectional Gut–Brain–Mental Health Framework in Competitive Athletes.



CENTRAL NERVOUS SYSTEM & NEUROINFLAMMATION

- Blood-Brain Barrier Hyperpermeability [P] • Microglial Activation & Sickness Behavior [P]
- Central Monoamine Turnover • Altered Theta/Delta EEG Power Spectral Density [H]



PSYCHOLOGICAL & SLEEP OUTCOMES IN ATHLETES

- Attenuated Perceived Stress (PSS) [H] • Reduced Competitive State Anxiety (CSAI-2R) [H]
- Preserved Post-Race Vigor & Total Mood Disturbance (POMS) [H]
- Sustained Attention Reaction Time (DVT) [H] & Decreased Athlete Burnout (ABQ) [H]
- Preserved Sleep Latency, Sleep Efficiency % & Total Sleep Time [H]

===== REVERSE CENTRAL FEEDBACK LOOP =====

PSYCHOLOGICAL DISTRESS & SLEEP DISRUPTION

- Chronic Anxiety • Insomnia / Reduced REM Sleep • Emotional Exhaustion
- Central Autonomic Dysregulation → Sympathetic Overactivity



GASTROINTESTINAL & MICROBIAL SECONDARY SHIFTS

- Subepithelial Mast Cell Degranulation [P] • Altered Gastric Emptying & Splanchnic Tone [H]
- Further Depletion of Beneficial Commensals • Exacerbated Barrier Hyperpermeability [H]

Legend: [H] = directly supported by human athlete or active-population evidence; [P] = proposed or hypothesized mechanism derived mainly from preclinical or general models. Arrows represent evidence-informed or proposed associations and should not be interpreted as demonstrating direct causal relationships across all pathway components. The figure illustrates interconnected top-down and bottom-up neuroimmune pathways.

8. Research Gaps and Future Directions

To advance sports psychobiomics beyond exploratory associations toward better-supported clinical and performance applications, five critical research directions must be prioritized:

1. Adequately Powered, Sex-Stratified RCTs: Multi-center RCTs using formal statistical power calculations to recruit sufficient sample sizes, incorporating balanced female athlete cohorts to evaluate sex-dependent gut-brain signaling (Wei et al., 2025).
2. Confounder Control Protocols: Implement weighed dietary intake tracking, objective training load monitoring (via heart rate/GPS), and controlled sleep hygiene parameters to isolate psychobiotic effects from environmental noise (Harnett et al., 2021; Salehi Asl et al., 2026).
3. Objective Sleep and Cognitive Batteries: Combine psychometric scales with objective measurement tools, including 24-hour ActiGraph accelerometry, polysomnography (PSG), high-density EEG, and validated cognitive batteries (Stroop, psychomotor vigilance tasks) (Adikari et al., 2020; Salehi Asl et al., 2026).
4. Multi-Omics Profiling: Utilize high-throughput metagenomic shotgun sequencing paired with targeted/untargeted LC-MS metabolomics to map strain-level microbial dynamics, SCFA flux, GABA synthesis, and tryptophan-kynurenine activity alongside circulating gut barrier (I-FABP, LPS) and neuroinflammatory biomarkers (Bongiovanni et al., 2025; Fu et al., 2024).
5. Longitudinal Seasonal Tracking: Follow competitive athletes across full macrocycles (pre-season, peak competition, rapid weight loss, off-season) to evaluate longitudinal gut microbiota stability and long-term psychoneuroendocrine adaptations.

9. Practical Considerations

Practitioners sports dietitians, team physicians, coaches, and sport psychologists may consider gut-directed interventions as complementary strategies where evidence exists, while recognizing that strain-specific effects and the limited size of the evidence base preclude universal recommendations.

However, gut microbial manipulation should not replace established sports psychology, clinical care, sleep hygiene, or evidence-based sports nutrition. Effects appear to be strain- and context-specific, and the available studies do not establish a universal supplementation protocol.

The interventions represented in the available literature have generally been studied over periods ranging from approximately 2 to 17 weeks. Accordingly, the optimal duration for individual athletes remains uncertain, and supplementation should not be interpreted as having a universally established minimum duration.

10. Conclusion

This thematic synthesis demonstrates that gut-directed strategies (psychobiotics, synbiotics, paraprobiotics) offer a promising non-pharmacological approach to support mental health and sleep in competitive athletes. Controlled interventional evidence suggests potential benefits for subjective perceived stress, competitive state anxiety, post-marathon vigor, and sleep latency. However, direct evidence for objective cognitive fatigue remains limited, sleep evaluations lack gold-standard polysomnography, and taxonomic correlations remain associative. Small sample sizes, female underrepresentation, and reliance on self-report questionnaires mandate cautious interpretation. Gut-directed strategies should complement, rather than replace, established sports psychology, sleep hygiene, and clinical care.

Declarations

Ethics Approval and Consent to Participate: Not applicable (thematic literature synthesis).

Consent for Publication: All contributing authors have reviewed and approved the final submitted manuscript.

Availability of Data and Materials: All synthesized data and study characteristics are fully detailed within the manuscript tables and source references.

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