



Contents lists available at [Journal ELORA](#)

JRTI (Jurnal Riset Tindakan Indonesia)

ISSN: 2502-079X (Print) ISSN: 2503-1619 (Electronic)

Journal homepage: <https://jrti.eloracenter.org/jrti>



From sensing to self-regulation: a systematic review of biofeedback and neurofeedback interventions for mental health and stress regulation in athletes

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Article Info

Article history:

Received Jul 10th, 2026

Revised Aug 17th, 2026

Accepted Sep 05th, 2026

Keyword:

Biofeedback,
Neurofeedback,
Heart rate variability,
Athlete mental health,
Psychophysiological self-regulation

ABSTRACT

Competitive sport puts a lot of stress on both the body and mind, and biofeedback and neurofeedback techniques are new ways to help with stress regulation and athlete mental health support by using sensors and tailoring a personal plan. This systematic review is summarizing the research evidence from these areas that show the impact on mental health aspects and psychophysiological stress regulation. Alongside modalities like HRV biofeedback and modalities of psychological indicators were also examined in the study. By applying the guidelines of a PRISMA systematic review, a Scopus database search 2015, 2026 revealed 629 records. Only one duplicate was removed, 628 titles and abstracts were checked, 31 full papers were critically reviewed, leading to 18 studies that were purely data based. The quality of those included studies was assessed by means of the Mixed Methods Appraisal Tool and their results were thematically combined. HRV biofeedback was the most commonly used technique (7 studies), followed by peripheral multi-modal biofeedback (6), combination HRV-EEG method (2), EEG/scpneurofeedback (2), and paced breathing (1). The most common positive changes were stress and cortisol levels (8), anxiety (5), attention/cognition (5), autonomic regulation (4), and recovery-stress balance (3). In general, the interventions demonstrated good results, such as the lowering of anxiety and perceived stress and the enhancement of autonomic flexibility. Nevertheless, the small number of participants, the different nature of the methods, and very few trials of this type with an active control make one cautious. Well-designed clinical trials with random allocation, appropriate sample sizes, and validated outcome measures are required.



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Introduction

The physical, mental, and autonomic aspects of sport are closely connected. In elite and sub-elite levels, the effects of prolonged training loads, competitive stress and inadequate recovery are manifested in overtraining, mental fatigue and disturbed emotionally states which are detrimental to both well-being and performance (Vigário, 2009). Changes between sympathetic and parasympathetic activity (autonomic balance) are commonly seen in conjunction with these conditions. In fact, competitive anxiety was found to influence heart autonomic regulation among athletes (Van Cutsem et al., 2017; Van Cutsem & Fortes, 2017). Therefore with the knowledge

provided by these previous studies it comes to a conclusion that there are more and more interests in the use of objective physiological methods for helping athletes who want to monitor and regulate their internal state actively without relying only on self-report, which usually is quite subjective.

Heart rate variability (HRV) the variations in the intervals between heart beats is now an important indication of one's autonomic control and a simple non-invasive technique for measuring recovery-stress level in sports activities (Shaffer & Goswick, 2019; Bosquet et al., 2008). The reason for the effectiveness of HRV in the context of biofeedback intervention is due to the fact that it is possible to change HRV by doing breathing at one's individual resonance frequency. Biofeedback teaches people how to do this in the present moment. Clinical evidence and practical applications show parasympathetic regulation can be improved along with emotion management in HRVbiofeedback (Hoskin, 2016; Paul et al., 2012; Leach & Gevirtz, 2004). Neurofeedback applies the operant concept to cortical activity derived from EEG and the combination of neurofeedback and biofeedback techniques have been proposed for therapy as well as to enhance sport performance context respectively (Linden, 2008; Tosti et al., 2024a; Tinello & Conder, 2014).

On the other side, the development of wearable or biosensing technology is quite fast, so now many physiological signals like HRV, EDA and cortical rhythms are no longer confined only to research laboratories setting. Seshadri & et.al., (2015) as an example, has shown how EDA and EEG can be captured by consumer grade sensors in the comfort of one's home. Nowadays, consumer-grade activity trackers and smartwatches allow continuous monitoring of HR and HRV as well as EDA along with providing user-friendly feedback, making them very suitable tools for a wide range of applications. Several of such applications have indeed helped the users of these devices to stay in a more balanced psychophysiological state (Peeters et al., 2013; Samsudin et. al, 2019). At this stage, machine learning analysis of physiological and cerebral signals is becoming a significant factor in monitoring and understanding of athletes. As a result, we have seen the use of such technologies in sports medicine, psychological state detection (Lan et al. 2012). In combination, these technological trends enable delivery of a sensor-driven, mentally healthy, personalized support from the physiological sensing level to the psychologisingself-regulation level.

Still there is much to uncover. For instance, what the literature specifically about athletes' health tells us is quite scarce and scattered. There is a trend in reviewing the literature on athletic performance but not on mental health issues, also some of the reviews have looked at athletes together with people who have been diagnosed clinically and non-athletes (Papadopoulos & Tsertanidis, 2022). Many of the psychological interventions directed at athlete' stress such as, for example, mind training through mindfulness and relaxation-based programs have shown to be very effective in stress-recovery balance (Holguín-Ramírez et. al., 2020; Nien et al., 2023; Pagani et al., 2023; Dallaway et al. 2022) but what is not well explained is how those two, biofeedback guided by physiological and the neurofeedback approach, interact or complement, each other. Even the most comprehensive studies on physiologicalpsychological interventions and techniques assisted by new technologies reveal the potential and variability of these tools, and, unfortunately, due to that same variety it is very difficult to come up with solid conclusions. (Hsu et al., 2013; Alkasasbeh et al., 2026; Liu et al., 2026).

This systematic review, therefore, pools together data of different interventions that have used biofeedback or neurofeedback in the form of the display of body signals such as respiratory rate, electrocardiogram, etc. or HRV-resonance paced breathing to treat or reduce athletes' mental health symptoms and stress-related psychophysiological problems. The three research questions served as a framework for the review. RQ1. How do biofeedback and neurofeedback interventions affect mental health and psychophysiological stress regulation in athletes?. RQ2. Which psychological and mental-health indicators (e.g., anxiety, stress, mood, recovery–stress balance, sleep, self-regulation, attention) are most frequently reported to change following these interventions?. RQ3. Which biofeedback/neurofeedback modalities and protocol characteristics appear most effective for improving athlete mental health?

Method

Protocol and reporting standard

The review was designed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021; Moher et al., 2009). The methodological framework followed established guidance for structured, reproducible reviews (Tranfield et al., 2003). Because the review synthesised heterogeneous intervention designs, findings were combined narratively and thematically rather than through meta-analysis (Thomas & Harden, 2008).

Eligibility criteria and PICOS framework

Eligibility was defined a priori using the PICOS framework (Table 1). Studies were included if they reported an empirical biofeedback or neurofeedback intervention delivered to an athletic population and measured at least one psychological or mental-health outcome alongside a psychophysiological index.

Table 1. PICOS framework defining the review scope.

Element	Definition applied in this review
Population (P)	Athletes across competitive levels (amateur to elite), adolescent and adult, in individual and team sports.
Intervention (I)	Biofeedback or neurofeedback using physiological-signal feedback (HRV, EEG, EMG, EDA/GSR, peripheral temperature, slow cortical potentials) or HRV-resonance paced-breathing protocols.
Comparison (C)	A control or comparison group, an alternative feedback modality, or a within-subject pre-post contrast.
Outcomes (O)	Mental-health and psychological outcomes (anxiety, stress, mood, well-being, recovery-stress balance, sleep, self-regulation, attention, resilience) reported with psychophysiological indices.
Study design (S)	Empirical intervention studies: randomised controlled trials, non-randomised controlled trials, pilot pre-post studies, single-case interventions and post-intervention qualitative studies.

Full inclusion and exclusion criteria are summarised in Table 2. Reviews and other secondary or conceptual publications were used only as background literature in the Introduction and Discussion and were not included in the synthesis of primary evidence.

Table 2. Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Population	Athletes (any competitive level, individual or team)	Non-athletes; support/management staff; general clinical populations
Intervention	Biofeedback / neurofeedback; HRV-resonance paced breathing	Non-feedback interventions (e.g., EMDR, transcranial electrical stimulation, pharmacology, generic information technology)
Outcome	≥1 psychological / mental-health outcome with a psychophysiological index	Studies reporting only physical, biomechanical or unrelated outcomes (e.g., oral health)
Design	Primary empirical intervention study	Reviews, meta-analyses, conceptual or perspective papers, protocols without data
Publication	Peer-reviewed journal article, 2015–2026, English-language metadata	Conference papers, book chapters, editorials, notes, errata; pre-2015

Information sources and search strategy

A systematic search of the Scopus database was conducted, and the exported records analysed here derive from that indexed source. The search combined terms for the population (athlete OR sport OR player), the intervention (biofeedback OR neurofeedback OR “heart rate variability”) and psychological outcomes (anxiety OR stress OR mood OR “mental health” OR wellbeing), restricted to 2015–2026 and to journal articles. Titles, abstracts and author keywords were used as the primary fields for screening.

Selection process

The search returned 629 records. One duplicate record was removed, leaving 628 records for title-and-abstract screening. Screening excluded 597 records that did not address the target population, intervention or outcomes, yielding 31 full-text reports for eligibility assessment. Of these, 13 were excluded: one for a non-athlete population, three for non-biofeedback/neurofeedback interventions, six as secondary studies (reviews), two for off-target outcomes, and one conceptual paper without primary data. Eighteen studies met all criteria and were included in the qualitative synthesis. The full selection process is depicted in Figure 1.

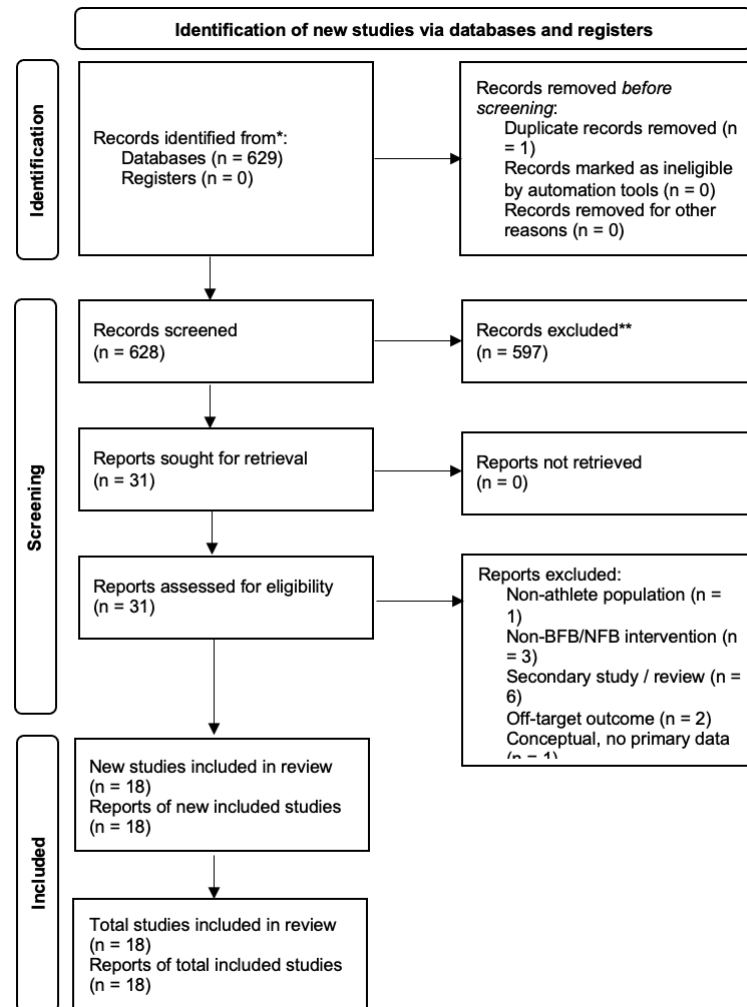


Figure 1. PRISMA 2020 flow diagram of the study selection process.

Data extraction

For each included study, the following were extracted: authors and year; full title; study design; biofeedback/neurofeedback modality; sample and sport; targeted psychological/mental-health outcomes; and principal findings. Country of study was recorded only where explicitly stated in the record; where affiliation data were not available in the export, country is reported as “not reported.”

Quality appraisal

Methodological quality was appraised with the Mixed Methods Appraisal Tool (MMAT), version 2018 (Hong et al., 2018), which accommodates the qualitative, randomised, non-randomised and quantitative-descriptive designs represented in the corpus. Because appraisal was based on the information available in indexed records and abstracts, ratings should be read as indicative rather than definitive. A summary appraisal is provided in Table 3.

Table 3. MMAT quality-appraisal summary of the 18 included studies.

Study	MMAT category	Rating	Appraisal note
Srilekha et al. (2015)	Quantitative RCT	Moderate-High	Randomised allocation and pre-post outcome measurement reported; small samples and infrequent blinding temper certainty.
Dziembowska et al. (2016)	Quantitative RCT	Moderate-High	Randomised allocation and pre-post outcome measurement reported; small samples and infrequent blinding temper certainty.
Rijken et al. (2016)	Quantitative randomised	non- Low-Moderate	Single-arm or two-cohort pre-post design without randomised control.

Study	MMAT category	Rating	Appraisal note
Gross et al. (2017)	Quantitative descriptive	Low–Moderate	Single-case intervention with detailed within-person data; limited generalisability.
Rusciano et al. (2017)	Quantitative non-randomised	Moderate	Concurrent control group with pre–post design; allocation not randomised.
Ferguson & Hall (2021)	Qualitative	Moderate	Coherent qualitative design with thematic analysis; small purposive sample.
Rose et al. (2021)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Cantón et al. (2022)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Makaracı et al. (2023)	Quantitative non-randomised	Low–Moderate	Single-arm or two-cohort pre–post design without randomised control.
Vacher et al. (2023)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Kim et al. (2024)	Quantitative descriptive	Low–Moderate	Single-case intervention with detailed within-person data; limited generalisability.
Li et al. (2024)	Quantitative RCT	Moderate	Randomised crossover with objective outcomes; small sample and carry-over risk.
Makaracı et al. (2024)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Merlin et al. (2024)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Lunhua (2025)	Quantitative RCT	Moderate–High	Randomised allocation and pre–post outcome measurement reported; small samples and infrequent blinding temper certainty.
Makaracı & Makaracı (2025)	Quantitative RCT	Moderate	Randomised pilot; adequate procedures but limited power.
Sentyabrev et al. (2025)	Quantitative non-randomised	Low–Moderate	Single-arm or two-cohort pre–post design without randomised control.
Lizama et al. (2026)	Quantitative RCT	Moderate	Randomised but exploratory, without an active sham control.

Synthesis approach

Given the heterogeneity of protocols and outcomes, a thematic synthesis was performed (Thomas & Harden, 2008). Studies were grouped by intervention modality and by targeted psychological outcome domain, and patterns of effect were examined across designs to address the three research questions.

Results and Discussions

Overview of included studies

The 18 included studies were published between 2015 and 2026, with a marked concentration in 2023–2026, which accounted for the majority of the corpus (Figure 2). This temporal clustering mirrors the recent diffusion of portable and wearable biofeedback devices into applied sport settings. Sample sizes were generally small, ranging from single-case designs to a smartwatch trial of 100 student-athletes, and populations spanned soccer, swimming, tennis, volleyball, shooting, golf, running and mixed varsity cohorts.

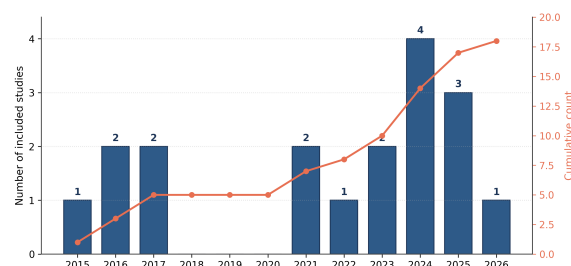


Figure 2. Temporal distribution of the included studies (2015–2026).

Table 4 summarises each included study with its full title, design, modality and principal findings.

Table 4. Summary of the 18 included studies (full titles and key findings).

Study	Full title	Design and modality	Key findings
Srilekha et al. (2015)	Impact of differential biofeedback interventions on autonomic habituation and fatigability in soccer players	RCT (parallel, 3-arm); Peripheral BFB (EMG/EDA)	EMG and skin-conductance biofeedback (12 wk) modulated autonomic indices of emotionality and improved bilateral shooting performance in national soccer players.
Dziembowska et al. (2016)	Effects of Heart Rate Variability Biofeedback on EEG Alpha Asymmetry and Anxiety Symptoms in Male Athletes: A Pilot Study	RCT (parallel); HRV biofeedback	Three-week HRV-BF significantly reduced self-reported anxiety and improved HRV, EEG alpha asymmetry and self-control versus no-intervention controls in young male athletes.
Rijken et al. (2016)	Increasing Performance of Professional Soccer Players and Elite Track and Field Athletes with Peak Performance Training and Biofeedback: A Pilot Study	Pilot, two-cohort pre-post; HRV-BF + EEG-NF	Mental coaching plus HRV biofeedback or EEG alpha-power neurofeedback raised HRV/alpha power and improved concentration, emotional scale and recovery in elite athletes.
Gross et al. (2017)	Resonant frequency training in elite sport: A case study example	Single-case intervention; HRV biofeedback (RFT)	Resonant-frequency HRV biofeedback enabled an elite shooter to sustain optimal performance and emotional regulation after disruptions; low-cost delivery options proposed.
Rusciano et al. (2017)	Neuroplus biofeedback improves attention, resilience, and injury prevention in elite soccer players	Controlled trial (pre-post); Multimodal BFB (autonomic)	Integrated 'Neuroplus' autonomic biofeedback enhanced physiological adaptability, post-stress recovery, visual selective attention and injury prevention in Serie-A soccer players.
Ferguson & Hall (2021)	A Voice Unheard: A Qualitative Exploration of Varsity Athletes' Perspective on the Use of Biofeedback Postintervention	Qualitative (thematic); Multimodal BFB	Varsity athletes perceived a 5-session multimodal biofeedback intervention as enhancing self-regulation, coping and preperformance routines transferable to academics.
Rose et al. (2021)	Efficacy of a Brief Biofeedback Intervention on Mood, Arousal, Mental Workload, Movement Time, and Biofeedback Device Preference	RCT (parallel, 3-group); HRV biofeedback	A brief HRV-BF protocol significantly improved perceived arousal but not mood, workload or movement time; device preference favoured desktop over portable units (N = 40).
Cantón et al. (2022)	Effect of Biofeedback on the Anxiety of Amateur Athletes	RCT (parallel); Multimodal BFB (temp/EDA/HR)	Amateur marathoners learned autonomic self-control after six sessions, lowering psychophysiological activation and skin conductance versus controls; STAI anxiety unchanged.
Makaracı et al. (2023)	A Pilot Study of the Biofeedback Training to Reduce Salivary Cortisol Level and Improve Mental Health in Highly-Trained Female Athletes	Pilot pre-post; HRV biofeedback	Seven-week HRV-BF lowered mid-day salivary cortisol and supported psychophysiological well-being in highly trained female volleyball players; CAR unchanged (n = 6).
Vacher et al. (2023)	Asynchronous Heart Rate Variability Biofeedback Protocol Effects on Adolescent Athletes' Cognitive Appraisals and Recovery-Stress States	RCT (parallel, longitudinal); HRV biofeedback (async)	An asynchronous 6-week HRV-BF protocol predicted lower biopsychosocial and cognitive stress in national adolescent swimmers, though recovery and perceived control were unaffected.
Kim et al. (2024)	Heart Rate Variability Biofeedback and Cognitive Restructuring for Self-Regulation: A Case Study	Single-case intervention; HRV-BF + cognitive restructuring	Ten sessions of HRV biofeedback combined with cognitive restructuring improved self-regulation and reappraisal in an elite national-team squash athlete.
Li et al. (2024)	A Comparison Between Pre-Sleep Heart Rate Variability Biofeedback and Electroencephalographic Biofeedback Training on Sleep	Randomised crossover; HRV-BF vs EEG-BF	Both HRV-BF and EEG-BF improved subjective sleep and mood; HRV-BF produced larger gains in objective sleep efficiency, sleep duration and reaction time in athletes with sleep disturbance.

Study	Full title	Design and modality	Key findings
Makaracı et al. (2024)	in National Level Athletes with Sleep Disturbances Effects of Ten Biofeedback Sessions on Athletes' Physiological, Psychological, and Cognitive Functioning: A Randomized Controlled Trial with International Tennis Players	RCT (parallel); Multimodal BFB (GSR/temp/HRV)	Ten multimodal biofeedback sessions reduced state anxiety and improved skin temperature and cognitive performance in international junior tennis players versus controls.
Merlin et al. (2024)	Psychophysiological Effects of Slow-Paced Breathing on Adolescent Swimmers' Subjective Performance, Recovery States, and Control Perception	RCT (parallel, longitudinal); Paced breathing (no BFB)	Slow-paced breathing without biofeedback improved recovery states, perceived control and subjective performance in adolescent swimmers but did not reduce stress markers.
Lunhua (2025)	The relationship between academic stress and educational anxiety in student athletes: exploring biofeedback technology as an intervention	RCT (parallel); Wearable HRV biofeedback	Smartwatch-based biofeedback significantly reduced perceived stress and state anxiety in Chinese student-athletes; no change occurred in the non-wearable control group (N = 100).
Makaracı & Makaracı (2025)	Enhancing autonomic regulation and attention through galvanic skin response and peripheral temperature biofeedback in female volleyball players: a randomized pilot trial	RCT (pilot); Multimodal BFB (GSR/temp)	A 5-week GSR- and temperature-focused biofeedback programme improved peripheral temperature and sustained-attention accuracy in national female volleyball players.
Sentyabrev et al. (2025)	NEUROBIOLOGICAL CONTROL OF CENTRAL CARDIOVASCULAR REGULATORY MECHANISMS; [НЕЙРОБИОУПРАВЛЕНИЕ СОСТОЯНИЕМ ЦЕНТРАЛЬНЫХ МЕХАНИЗМОВ РЕГУЛЯЦИИ СЕРДЕЧНО-СОСУДИСТОЙ СИСТЕМЫ]	Pre-post intervention; EEG neurofeedback	Personalised EEG neurofeedback over 3–4 sessions improved concentration and shifted athletes with adverse baseline cardiovascular regulation toward more favourable autonomic profiles.
Lizama et al. (2026)	Modulation of neuroendocrine and autonomic responses to competitive stress by slow cortical potentials training in golfers: An exploratory randomized controlled trial	RCT (exploratory); SCP neurofeedback	Eight-week slow-cortical-potential neurofeedback was associated with preserved autonomic modulation (higher HRV/RMSSD) under repeated competitive stress in golfers; putting performance unchanged.

Intervention modalities (RQ3)

Heart rate variability biofeedback was the most common modality, applied as the primary intervention in seven studies (Dziembowska et al., 2016; Gross et al., 2017; Rose et al., 2021; Makaracı et al., 2023; Vacher et al., 2023; Kim et al., 2024; Lunhua, 2025). Multimodal peripheral biofeedback combining electromyographic, electrodermal, temperature and cardiovascular channels featured in six studies (Srilekha et al., 2015; Rusciano et al., 2017; Ferguson & Hall, 2021; Cantón et al., 2022; Makaracı et al., 2024; Makaracı & Makaracı, 2025). Two studies compared or combined HRV biofeedback with EEG feedback (Rijken et al., 2016; Li et al., 2024), two applied EEG or slow-cortical-potential neurofeedback (Sentyabrev et al., 2025; Lizama et al., 2026), and one delivered slow-paced breathing without device feedback (Merlin et al., 2024). This distribution is summarised in Figure 3.

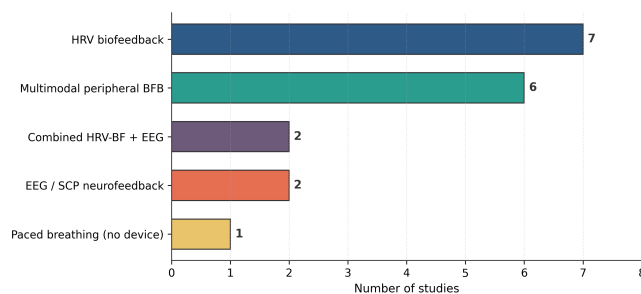


Figure 3. Distribution of included studies by biofeedback/neurofeedback modality.

Targeted psychological outcomes (RQ2)

Across the corpus, stress and cortisol regulation was the most frequently targeted domain (eight studies), followed by anxiety, attention/cognition and performance (five each), autonomic regulation (four), and recovery–stress balance, mood/affect and self-regulation (three each); sleep, self-esteem/well-being and resilience were addressed less often (Figure 4). Author-keyword frequencies reinforced this profile, with biofeedback, heart rate variability, athletes, stress and skin conductance dominating the corpus (Figure 5).

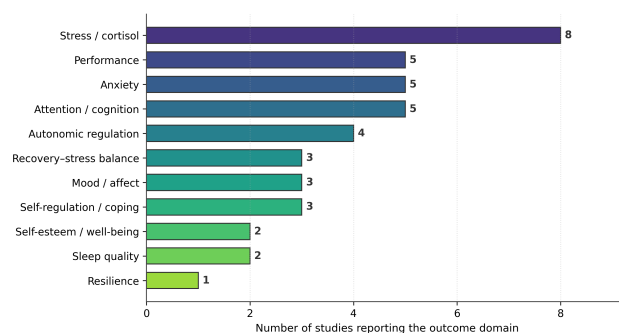


Figure 4. Frequency of targeted psychological and mental-health outcome domains.

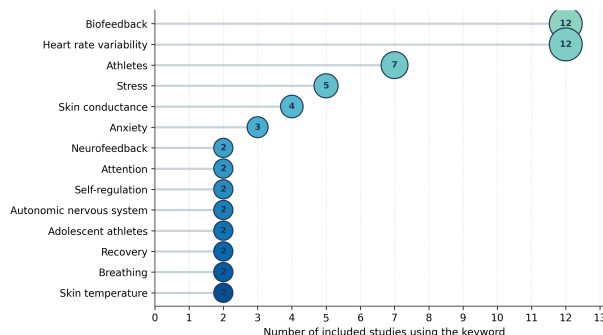


Figure 5. Author-keyword frequency across the included corpus (keywords in ≥ 2 studies).

Classification by modality and outcome

Of the 18 included studies, most used heart rate variability (HRV) biofeedback. It was the most common modality in the sample, with seven studies published between 2016 (Dziembowska et al.) and 2025 (Lunhua). A few practical factors likely explain this. HRV biofeedback is easy to apply, its breathing-based training protocols are well established, and the required equipment has become more affordable. The fact that these studies span nearly a decade also points to steady interest in the method.

Multimodal peripheral biofeedback, which combines EMG, EDA, and temperature signals, was the second most common approach, accounting for six studies. Work such as Srilekha et al. (2015) and Cantón et al. (2022) tracked several physiological signals at once rather than relying on a single measure. Methods based on brain activity were far less common. Two studies paired HRV-BF with EEG (Rijken et al., 2016; Li et al., 2024), and two others used EEG- or slow cortical potential-based neurofeedback (Sentyabrev et al., 2025; Lizama et al., 2026).

Only one study used paced breathing without device feedback (Merlin et al., 2024). Overall, these numbers show a field still centred on peripheral measures, chiefly HRV and other autonomic signals, while brain-signal

methods and device-free interventions remain rare. Both are underrepresented in the current literature and are worth exploring in future work.

Table 5. Classification of the included studies by modality and principal outcome focus.

Modality category	Included studies	n
HRV biofeedback	Dziembowska et al., 2016; Gross et al., 2017; Rose et al., 2021; Makaracı et al., 2023; Vacher et al., 2023; Kim et al., 2024; Lunhua, 2025	7
Multimodal peripheral BFB (EMG/EDA/temp)	Srilekha et al., 2015; Rusciano et al., 2017; Ferguson & Hall, 2021; Cantón et al., 2022; Makaracı et al., 2024; Makaracı & Makaracı, 2025	6
Combined HRV-BF + EEG	Rijken et al., 2016; Li et al., 2024	2
EEG / SCP neurofeedback	Sentyabrev et al., 2025; Lizama et al., 2026	2
Paced breathing (no device feedback)	Merlin et al., 2024	1

Synthesis by research question

RQ1 (effects on mental health and stress regulation). Across designs, biofeedback and neurofeedback were associated with improved psychophysiological regulation and reduced psychological distress. HRV biofeedback reduced self-reported anxiety and improved autonomic indices in young male athletes (Dziembowska et al. (2016)), lowered mid-day salivary cortisol in elite female athletes (Makaracı et al. (2023)), reduced perceived stress and state anxiety in student-athletes using smartwatch feedback (Lunhua (2025)), and lowered biopsychosocial and cognitive stress in adolescent swimmers (Vacher et al. (2023)). Multimodal biofeedback reduced psychophysiological activation in amateur marathoners (Cantón et al. (2022)) and reduced state anxiety while improving cognition in junior tennis players (Makaracı et al. (2024)). Neurofeedback approaches shifted athletes toward more favourable autonomic profiles (Sentyabrev et al. (2025)) and were associated with preserved autonomic modulation under competitive stress (Lizama et al. (2026)).

RQ2 (indicators most frequently changed). Reductions in anxiety and perceived stress were the most consistent findings, reported across HRV, multimodal and wearable protocols (Dziembowska et al. (2016); Cantón et al. (2022); Makaracı et al. (2024); Lunhua (2025)). Improvements in autonomic regulation and attention were also recurrent (Rusciano et al. (2017); Makaracı & Makaracı (2025)), as were gains in self-regulation and coping (Ferguson & Hall (2021); Kim et al. (2024)). Effects on sleep and mood were positive but less consistent (Li et al. (2024)), and several studies reported selective effects — for example, improved recovery and perceived control without changes in stress markers following paced breathing (Merlin et al. (2024)), or improved arousal without mood or workload changes after a brief protocol (Rose et al. (2021)).

RQ3 (most effective modalities and protocols). HRV biofeedback delivered over multiple sessions produced the most reproducible reductions in stress and anxiety, and outperformed EEG biofeedback on objective sleep efficiency in athletes with sleep disturbance (Li et al. (2024)). Multi-session multimodal protocols (10–21 sessions) were associated with broader cognitive and autonomic benefits (Makaracı et al. (2024); Makaracı & Makaracı (2025); Makaracı et al. (2023)), whereas very brief protocols yielded narrower effects (Rose et al. (2021)). Integrated autonomic training linking cardiovascular and cortical regulation showed benefits for attention and resilience (Rusciano et al. (2017); Rijken et al. (2016)). Overall, dose (number of sessions), individualisation to resonance frequency, and multimodal signal coverage emerged as the protocol features most associated with favourable outcomes.

Discussion

This review synthesised 18 empirical studies applying biofeedback or neurofeedback to athlete mental health and stress regulation. Three conclusions emerge. First, the evidence is broadly convergent: across heterogeneous designs, populations and modalities, interventions were repeatedly associated with reduced anxiety and perceived stress and with improved autonomic flexibility. This coherence aligns with mechanistic accounts of HRV biofeedback, in which resonance-frequency breathing strengthens baroreflex gain and vagal regulation (Lehrer & Gevirtz, 2014; Shaffer & Ginsberg, 2017), and with prior applied work linking HRV biofeedback to improved performance psychology (Paul et al., 2012; Prinsloo et al., 2014).

Second, HRV biofeedback dominates the field, but the corpus is diversifying toward multimodal peripheral training, EEG and slow-cortical-potential neurofeedback, and wearable-delivered protocols. The appearance of smartwatch-based feedback in a large student-athlete sample (Lunhua, 2025) illustrates how consumer biosensing can extend these interventions beyond the laboratory, consistent with the broader trajectory of wearable sensing in sport (Seshadri et al., 2019; Ferguson et al., 2022; Ajami & Teimouri, 2015) and with machine-learning-based physiological analysis (Bellfield et al., 2022; Palermi et al., 2024; Jiang et al., 2023).

This trajectory supports a genuinely personalised pathway from physiological sensing to psychological self-regulation.

Third, biofeedback and neurofeedback should be read as complementary to, rather than in competition with, other psychological interventions for athletes. Mindfulness- and relaxation-based programmes improve the stress–recovery balance (Holguín-Ramírez et al., 2020; Nien et al., 2023; Pagani et al., 2023), and integrative frameworks explicitly combine cognitive-behavioural, mindfulness and psychophysiological strategies (Alkasasbeh et al., 2026; Lopez Blanco et al., 2025). Studies that paired HRV biofeedback with cognitive restructuring (Kim et al., 2024) point to the value of such hybrid designs.

Gaps and limitations of the evidence base

Several gaps qualify these conclusions. (1) Statistical power: most studies used small samples and pilot or single-case designs, limiting precision and generalisability. (2) Control conditions: active sham or attention-matched controls were rare, so expectancy effects cannot be excluded, as the authors of an exploratory neurofeedback trial explicitly cautioned (Lizama et al., 2026). (3) Outcome heterogeneity: anxiety, stress, mood, recovery and self-regulation were measured with diverse instruments, precluding meta-analysis and complicating cross-study comparison (Nagy et al., 2024; Tosti et al., 2024b). (4) Protocol standardisation: session number, duration and individualisation varied widely, and dose–response relationships remain underspecified. (5) Follow-up: durability of effects was seldom assessed beyond the intervention period.

Limitations of this review

This review has limitations of its own. The synthesis analysed records from a single indexed database export (Scopus); incorporating additional databases could identify further eligible studies and would alter the identification and de-duplication counts in the PRISMA flow. Restricting eligibility to English-language journal articles may introduce language and publication bias. Country of study could not be extracted for many records because affiliation fields were unavailable in the export, so a geographic synthesis was not attempted. Finally, quality appraisal relied on information available in indexed records and abstracts and is therefore indicative.

Future directions

Future research should prioritise adequately powered randomised controlled trials with active control conditions and standardised, validated mental-health outcomes; direct comparisons of modalities (e.g., HRV versus EEG feedback) and of dose; ecologically valid, wearable-delivered protocols with longer follow-up; and hybrid interventions that integrate biofeedback with cognitive or mindfulness-based components. Consistent reporting of population, protocol and effect sizes would enable future meta-analysis.

Conclusions

Biofeedback and neurofeedback interventions show consistent, if preliminary, benefits for stress regulation and mental health in athletes, with the most reproducible effects on anxiety, perceived stress and autonomic flexibility. Heart rate variability biofeedback is the best-established modality, while multimodal, neurofeedback and wearable-delivered approaches are expanding the field toward personalised, sensor-driven support. Realising this promise will require larger, actively controlled trials with standardised outcomes and clearer dose–response evidence, so that the pathway from physiological sensing to psychological self-regulation can be translated into dependable practice.

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