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Wearable and Portable Psychophysiological Monitoring of Stress, Recovery, and Affective States in Competitive Athletes: A Systematic Literature Review of Evidence Published from 2021 to 2026

Rudyanto Rudyanto*), Mario Febrian, Kristian Burhan
Universitas Negeri Padang, Indonesia

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ABSTRACT

Wearable and monitoring can pair physiological signals with subjective reports, yet convergence between these channels remains unclear. This review synthesized evidence on (1) technologies paired with instruments; (2) convergence and divergence between physiological and subjective measures; and (3) interventions and strategies for optimizing athlete state. Following PRISMA 2020, Scopus was searched with TITLE-ABS-KEY strategy for studies during 2021 to 2026. After screening, 22 studies were included. Data used thematic synthesis and bibliometric analysis. Reporting quality was appraised using FICO, with retention at ≥12/16. No meta-analysis was conducted because designs, modalities, instruments, timing, and outcomes lacked an estimand. Four themes emerged: autonomic load, sleep and recovery, self-regulation, and individualized monitoring. HRV dominated. Physiological and subjective measures were often concordant but differed in magnitude and timing. Person-specific models were informative than group-level approaches. Dual-channel monitoring is more defensible. Future studies should use longer monitoring, standardized psychometrics, independent validation, and adequately powered interventions.

Corresponding Author:

Rudyanto Rudyanto,
Universitas Negeri padang,
Email: rudyanto@unp.ac.id

Introduction

Elite and sub-elite sport now happens inside an information-dense environment. Coaches are expected to quantify what athletes do, how their bodies respond, and how they feel, often every single day. The scientific case for this expansion rests on a straightforward premise: competitive performance emerges from the interaction between physical capacity and the regulatory systems that sustain it, and the autonomic nervous system provides an accessible window onto that regulation (Mosley & Laborde, 2024; Pruneti et al., 2024). The practical barrier to such measurement has fallen sharply over the last decade. Chest straps, wrist-worn optical sensors, sleep headbands and smartphone-linked recording systems now produce data of a quality once restricted to laboratories, and they do so during ordinary training weeks rather than in artificial testing sessions (Kusuma et al., 2026; Holzer et al., 2022). Consequently, the field's limiting factor has moved from data availability to interpretation. More precisely, it has moved to the question of what physiological signals mean about the psychological state of the person generating them.

The specific problem addressed here sits between two families of measurement that are routinely collected together yet rarely integrated conceptually. On one side are physiological indices, most prominently heart rate variability. These are objective, continuous, and immune to social desirability. On the other side are psychometric instruments: recovery-stress questionnaires, mood profiles, competitive anxiety inventories. They capture the athlete's own appraisal of their situation, but only if reporting is honest and consistent (Alfonso et al., 2025b; Machado et al., 2022). In applied monitoring, the two channels are increasingly collected together, but the evidence does not justify treating them as interchangeable. Prior syntheses have reported weak or inconsistent correspondence between subjective well-being and objective physiological indicators, supporting a complementary rather than substitutive interpretation of the two channels (Saw et al., 2016; Bellenger et al., 2016; Alfonso et al., 2025b). The central concern of the present review is therefore not whether one channel is a superior proxy, but when the two channels converge, when they diverge, and what contextual factors may explain the difference.

Existing research has laid the descriptive foundations of both channels. Autonomic responses to acute and chronic load have been characterised across a broad range of activities: exhaustive laboratory exercise (Wang et al., 2024), multi-day endurance competition (Swart & Constantinou, 2023), prolonged high-intensity track and field preparation (Georgieva-Tsaneva et al., 2025a), and structured team-sport retreats (Lucini et al., 2021). Parallel work has profiled athlete populations by body composition and autonomic indicators (Lucini et al., 2022) and has documented hormonal correlates of anaerobic effort (Kayacan et al., 2023). On the perceptual side, session ratings of perceived exertion remain the most widely used internal-load marker, benchmarked against external load in elite sprinters (Thome et al., 2024). Each literature is extensive in its own right. They have just grown up largely in parallel.

Recent years have also brought methodological and technological change. Slow-paced breathing and resonance-frequency protocols have been refined to the point where respiratory rate itself is treated as a dose parameter (You et al., 2024). Biofeedback has been trialled in school-age athletic populations (Firth et al., 2022). Electroencephalography has moved out of the laboratory and into applied assessment of psycho-emotional states during open-skill activity (Iammarino et al., 2026). Machine learning, meanwhile, has been used to classify alertness from heart rate variability in elite shooters (Lu et al., 2026) and to detect burnout from multimodal sensor streams (Smerdov et al., 2021; Gündoğdu et al., 2021). Non-linear dynamical approaches have even been proposed as early warning systems for injury using routine monitoring data (Neumann et al., 2024). All of this widens the analytical repertoire considerably. It also raises the evidentiary bar for any claim about what monitoring actually achieves.

The first gap is one of synthesis. Reviews to date have concentrated either on heart rate variability as a psychological index (Mosley & Laborde, 2024; Pruneti et al., 2024) or on the association between self-reported variables and resting vagal activity (Alfonso et al., 2025b). Nobody has yet assembled a review organised around the combination itself. That would mean studies in which a wearable or portable physiological modality and a psychological instrument were deployed together in athletes and reported against one another. Without such a synthesis, it is hard to judge whether the two channels agree at all, let alone under what conditions they diverge.

The second gap is theoretical and methodological. Much of the applied literature still runs on a group-mean logic inherited from traditional performance-determinant research, in which population norms are used to classify individuals (Bais et al., 2023). Autonomic indices, though, are notoriously person-specific. The same absolute value can mean readiness in one athlete and strain in another. Studies of resilience-related vagal reactivity (Crameri et al., 2021) and of emotional arousal asymmetry during competition (Szekely et al., 2024) point the same way: meaningful signals reside in within-person deviation rather than between-person comparison. Whether the reviewed evidence has adopted this individualised logic, and with what success, remains unclear.

This is not just an academic question; it is a practical one. Monitoring systems are already embedded in professional and developmental programmes, and the numbers they produce influence decisions about training prescription, rest, and even selection (Jakowski, 2022; Çamiçi et al., 2025). If physiological and psychological indices are treated as interchangeable when they are not, athletes may be trained straight through states of psychological strain that the sensors never register. Or they may be rested unnecessarily on the strength of autonomic noise. With attention to athlete mental health and resilience inside performance environments growing (Suite et al., 2026; Reynoso-Sánchez & Hoyos-Flores, 2022), an evidence-based account of how these channels relate is timely.

Accordingly, the first objective of this review is descriptive and technological. Finding out which modalities and instruments have actually been paired in athlete populations shows where the evidence is concentrated and where it runs thin. It also exposes how heavily the field depends on a single measurement family. This yields the first research question.

RQ1: Which wearable or portable psychophysiological monitoring technologies have been combined with which psychological or subjective instruments in studies of competitive athletes published between 2021 and 2026?

The second objective is relational. Practitioners increasingly act on composite readiness scores, so it matters whether the physiological and perceptual components of those scores move together. Evidence from competitive settings suggests that they sometimes do (Zhao et al., 2024) and sometimes do not (Georgieva-Tsaneva et al., 2025b), yet the conditions distinguishing these outcomes have not been systematically compared. This yields the second research question.

RQ2: To what extent do wearable-derived physiological indices converge with concurrently measured psychological states in competitive athletes, and under what conditions do the two channels diverge?

The third objective is interventional and analytical. Monitoring is only valuable if it informs action, and a growing body of work has tested whether targeted protocols, whether biofeedback, paced breathing, sleep modification, or algorithmically individualised prescription, can shift psychophysiological state in a measurable and beneficial direction (Lizama et al., 2026; Wang et al., 2022). This yields the third research question. The novelty of this review lies in its organising principle. Instead of treating physiological and psychological monitoring as separate literatures, it selects only studies that measured both, then evaluates the field on the basis of what that pairing has actually demonstrated.

RQ3: Which interventions and analytical strategies have been shown to modify athlete psychophysiological state, and what methodological limitations constrain their translation into practice?

Method

Research Design and Framework

A systematic review was the right choice for this project. The research questions concern the state and consistency of an existing evidence base rather than the creation of new primary data. The methodological logic comes from Tranfield et al. (2003), where transparency, reproducibility, and explicit decision rules are what separate a systematic review from a narrative one. We also drew on the reporting conventions that Liberati et al. (2009) established for health-related syntheses.

Reporting followed the PRISMA 2020 statement (Page et al., 2021) and its explanation and elaboration document (Page et al., 2021). We picked PRISMA 2020 over earlier versions for a straightforward reason. Its flow diagram separates records removed before screening from those excluded during screening, and that distinction matters when database limiters remove a large portion of the initial yield. That was the situation here.

Search Strategy

We ran a single structured query across title, abstract, and keyword fields. Truncation let us capture morphological variants: athlet* retrieves athlete, athletes, and athletic; psycholog* retrieves psychology, psychological, and psychologically. The three conceptual blocks were combined with the AND operator, so every retrieved record had to address the athlete population, a sensing modality, and a psychological construct simultaneously. The search was conducted in Scopus in a single documented session and was restricted to English-language peer-reviewed journal articles published from 2021 through 2026. No supplementary hand-searching, citation chaining, grey-literature retrieval, or additional database searching was performed.

TITLE-ABS-KEY (("athlete" OR "player*" OR "elite sport*" OR "competitive sport*") AND ("wearable*" OR "heart rate variability" OR "HRV" OR "biosensor*" OR "smartwatch" OR "electroencephalograph*" OR "actigraph*" OR "sensor*") AND ("psychological stress" OR "perceived stress" OR "anxiety" OR "mood" OR "mental fatigue" OR "recovery" OR "well-being" OR "psychophysiolog*")) AND PUBYEAR > 2020 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))*

At the search stage, the database interface carried a few limiters. Publication years were capped at 2021 to 2026, document type was set to journal articles only, and the language filter was English. Nothing else was locked down. Sport, sex, competitive level, and geographical region were all left open at that point, and the eligibility assessment took care of those dimensions later.

Database and Information Sources

Scopus was the only database used. Why that one? It indexes the sport science, sport psychology, biomedical engineering, and applied physiology outlets where this literature tends to be scattered, and its export format keeps the abstract and keyword fields intact, which we needed for screening and thematic coding. The search ran in a single session. The full metadata export then served as the authoritative record for every count, screen, and extraction step that followed.

We recognise that leaning on a single database is a limitation, and we come back to it in the limitations discussion. For study selection, we did not do any supplementary hand-searching, citation chaining, or grey-literature retrieval. That keeps the pathway fully reproducible from the exported record set.

Eligibility Criteria

Eligibility was framed around a PICOS structure adapted for observational and applied sport research; the full breakdown sits in Table 1. Population was limited to competitive or systematically trained human athletes. The exposure or intervention had to involve at least one wearable or portable physiological monitoring modality. Comparisons could be drawn between groups, conditions, or time points, or across a monitoring period within the same person. Outcomes needed at least one psychological or subjective measure reported alongside the physiological data. The study design had to be empirical.

Table 1. PICOS framework applied in this systematic literature review

Element	Specification applied in this review
P — Population	Competitive, elite, sub-elite or systematically trained human athletes of any age, sex or sport
I — Intervention / Exposure	At least one wearable or portable physiological monitoring modality (HRV recorder, chest strap, smartwatch or wristband biosensor, EEG headband, actigraphy, pulse oximetry, electrodermal sensor)
C — Comparison	Between-group, between-condition, between-time-point, or within-person comparison across a monitoring period; single-arm designs accepted where repeated measures were reported
O — Outcomes	At least one psychological or subjective outcome (perceived stress, anxiety, mood, mental fatigue, perceived recovery, subjective sleep quality, well-being) reported alongside the physiological data
S — Study design	Empirical study of any design: randomised or controlled trial, quasi-experimental, cohort, cross-sectional, case report, or qualitative

Table 2 lists the operational inclusion and exclusion criteria that came out of this framework. In practice, two criteria were doing almost all of the heavy lifting. First, we required a genuinely athletic population, which ruled out a large body of otherwise relevant research on general adult samples, clinical groups, and animal models. Second, we required a psychological outcome to be reported at the same time, which meant physiological studies got excluded if they only mentioned subjective state without actually measuring it.

Table 2. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Language	English	Any other language
Document type	Peer-reviewed journal article	Conference paper, book chapter, editorial, note, erratum
Publication period	2021–2026	Published before 2021
Population	Competitive or systematically trained human athletes	General population, clinical or rehabilitation samples, sedentary adults, animal models, non-sport occupational groups
Technology	Wearable or portable physiological monitoring modality	Laboratory-only invasive measurement without a wearable or portable component; no physiological monitoring
Outcome	At least one psychological or subjective measure reported with the physiological data	Physiological outcomes only; psychological state discussed but not measured
Study type	Empirical primary study	Systematic review, scoping review, narrative review, meta-analysis, study protocol, conceptual or theoretical paper
Accessibility	Abstract and bibliographic record complete in the database export	Record incomplete such that eligibility could not be determined

Study Selection Process

Selection ran in three sequential stages. Stage one was mostly a cleanup. Database limiters and deduplication went over the exported record set, stripping out duplicates and anything that fell short of the language, document-type, and publication-period criteria. The records that made it through were then screened in stage two on title, abstract, and author keywords against the population, technology, and outcome criteria. If a record clearly failed any one of those three, it was excluded without further argument.

The third stage assessed every retained report in full against the complete criterion set in Table 2. Each exclusion got a single primary reason, which kept the final count auditable. If a report met the population and technology criteria but reported psychological state only as an uncollected contextual comment, it was excluded under the outcome criterion, not the population one. Screening decisions were tied to the unique record identifier of each item in the export. Borderline cases were settled by re-reading the abstract against the criteria, again and again, until a consistent rule could be stated and applied to every comparable case. One reviewer completed title/abstract screening, full-text eligibility decisions, and data extraction. A second independent screening pass was not performed, so Cohen's kappa or another inter-rater statistic cannot be validly reported retrospectively. This point is treated explicitly as a methodological limitation rather than replaced by an invented reliability estimate.

Quality Assessment: The FICO Framework

The eligible literature turned out to be a mixed bag: experimental trials, observational cohorts, case reports, and a single qualitative study. An appraisal framework had to work across all of those designs, and FICO fit the bill. Each study was evaluated on four dimensions. Focus, meaning the clarity and specificity of the research aim. Information, whether the sample description and measurement reporting were adequate. Context, the ecological validity of the setting and its relevance to competitive sport. And Outcome, the transparency and interpretability of the reported results. Because the corpus combined observational, controlled, case-report and qualitative designs, no single established design-specific risk-of-bias checklist was applicable without excluding eligible evidence. FICO was therefore used as a transparent internal appraisal rubric rather than as a validated risk-of-bias instrument. The rubric assesses the quality and interpretability of what each record reported; it should not be interpreted as proof of low risk of bias in study conduct.

Table 3. FICO quality appraisal framework and scoring

FICO dimension	Appraisal question	Rating scale
F — Focus	Is the research aim clearly stated and specific to athlete psychophysiological state?	1 (absent) to 4 (explicit and precise)
I — Information	Are the sample, instrumentation and measurement procedures adequately described?	1 (minimal) to 4 (fully specified)
C — Context	Is the setting ecologically relevant to competitive training or competition?	1 (artificial) to 4 (in situ competitive setting)
O — Outcome	Are results reported transparently and interpretably in relation to both channels?	1 (opaque) to 4 (transparent with effect estimates)
Threshold	Minimum total score required for retention in the synthesis	12 of a possible 16

Each dimension was scored on a scale of one to four, putting the maximum possible total at sixteen points. A study needed at least twelve points to be retained in the synthesis, which is equivalent to an average rating of three across the four dimensions. Every one of the 22 studies that satisfied the eligibility criteria also met this threshold, with scores ranging from 12 to 15. None was dropped purely on quality grounds. Instead, the scores were used to weight interpretive confidence during synthesis rather than to exclude evidence.

Data Extraction Procedure

Each included report was processed with the same standardised extraction template. From every record, the template captured the first author and publication year, the country or region the study team worked in, the study design, the sample and its competitive level, the physiological monitoring modality together with the specific indices reported, the psychological or subjective instruments administered, the principal findings that connected the two, and the FICO appraisal score.

Bibliographic fields were copied straight out of the database export without any modification. That way author names, titles, source titles, publication years and digital object identifiers line up exactly with the indexed record. Substantive fields, by contrast, were drawn from the abstract of each record. When a field could not be determined from the source record, that was recorded explicitly; nothing was inferred.

Bibliometric and Descriptive Analysis

A descriptive bibliometric analysis was applied to the included set to characterise its temporal, disciplinary and technological distribution. Publication years were tabulated to reveal how research activity had developed over time. Sport disciplines were grouped into seven categories according to the physiological and psychological demands of the activity, rather than by governing-body classification. Monitoring modalities, meanwhile, were counted non-exclusively, since many studies deployed more than one.

Author keyword and index keyword fields from the full exported record set were also tabulated, this time to map the terminological structure of the wider search yield and to inform how themes were labelled. Formal co-authorship and co-citation network analysis was deliberately not undertaken, since a set this size cannot support

JRTI (Jurnal Riset Tindakan Indonesia)
Vol. 11, No. 1, 2026, pp. 845-870

stable network estimation. These descriptive analyses, then, are best read as a characterisation of the evidence base rather than as bibliometric findings in their own right.

Data Analysis and Synthesis
Synthesis followed the three-stage procedure set out by Thomas and Harden (2008). First came line-by-line coding of the extracted findings, then the organisation of codes into descriptive themes, and finally the development of analytical themes that address the review questions. Coding was applied to the extracted findings statements rather than to full texts, which keeps every code traceable to a specific reported result.

Four descriptive themes emerged and were retained after confirming that each contained at least three studies and that no study was assigned to more than one primary theme. Analytical interpretation then mapped the themes onto the three research questions, with close attention paid to cases where studies disagreed. No meta-analytic pooling was attempted, since designs, instrumentation and outcome definitions varied substantially across the included studies. Effect-size synthesis is not reported either.

Reporting and Documentation
The review was conducted and reported in line with the PRISMA 2020 checklist (Page et al., 2021, BMJ, 372, n71). Figure 1 documents how records flowed through identification, screening, eligibility assessment and inclusion, and the numbers shown in the diagram match those stated in the abstract, Section 3 and Section 5.1 exactly. The protocol was not prospectively registered (e.g., PROSPERO), and this is reported explicitly as a limitation.

No protocol was prospectively registered, which is acknowledged here as a limitation. All numerical values in this review derive from the database export and the screening record. Nor has any bibliographic detail been supplied from another source.

PRISMA 2020 Flow Diagram

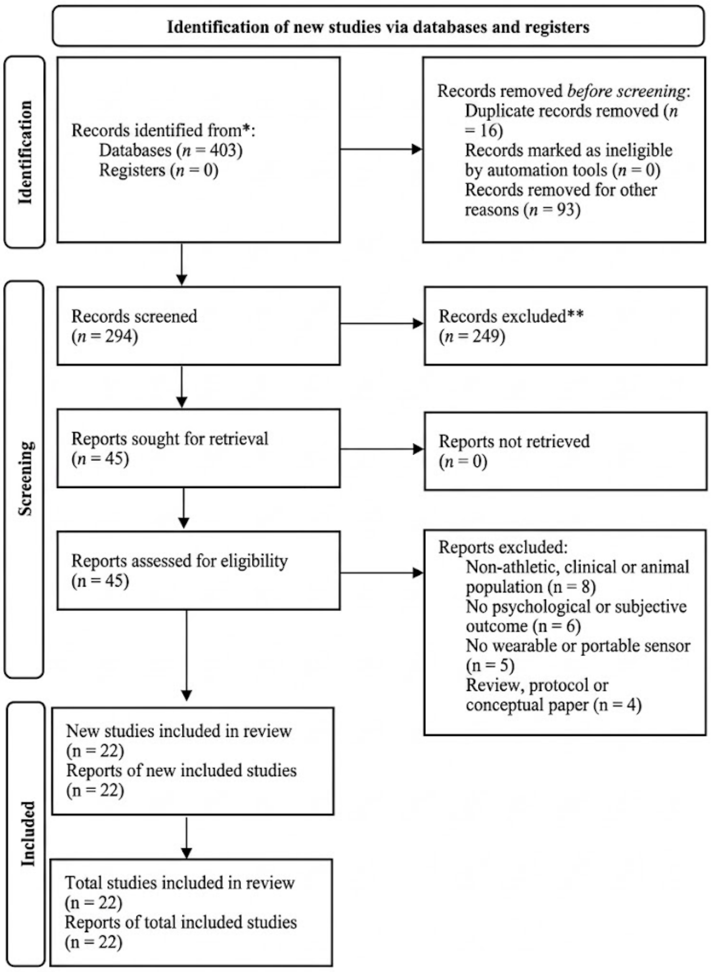

Figure 1. PRISMA 2020 flow diagram of the identification, screening, eligibility assessment and inclusion of studies.

Figure 1 presents the flow of records through the review, starting with identification in Scopus and ending with inclusion in the qualitative synthesis. Every value in the diagram derives from the database export and the screening record. Reporting follows the PRISMA 2020 statement (Page et al., 2021).

Results and Discussions

Study Selection Results

The structured search in Scopus returned 403 records. Before screening could begin, 16 duplicates were taken out, and the language, document-type and publication-period limiters removed a further 93. That left 294 records to check on title and abstract. Of those, 249 were excluded during screening for not addressing the review question. Most commonly, the sample was not athletic, no psychological or subjective outcome was reported, or no wearable or portable physiological modality was involved.

Forty-five reports were sought for retrieval, and all 45 were obtained, so nothing was lost at this stage. Full-text assessment excluded 23 reports, each for one recorded primary reason. Eight involved a non-athletic, clinical or animal population; six reported no psychological or subjective outcome alongside the physiological data; five used no wearable or portable physiological sensor; and four were reviews, protocols or conceptual papers. Ultimately, 22 studies entered the qualitative synthesis. Figure 1 presents the complete flow of records.

Descriptive Characteristics of the Included Studies

Table 4 summarises the 22 included studies, giving the full title, authorship, year, country or region of the study team, design, sample, monitoring modality and principal finding of each. Table 5 classifies the same studies by theme, psychological instrumentation and FICO appraisal score. Figures 2 to 4 characterise the set by publication year, sport category and monitoring modality respectively.

Table 4. Summary of the 22 included studies

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
Ramadan intermittent fasting alters cardiac autonomic modulation, neuromuscular performance, and recovery in adolescent tennis players: a within-subject repeated-measures design	Lakhdar et al. (2026)	Tunisia	Within-subject repeated-measures field study; 16 male ITF junior tennis players	HRV (lnRMSSD, LF/HF); countermovement jump; blood glucose and hydration markers	Match play lowered lnRMSSD and raised LF/HF, indicating sympathetic dominance. During Ramadan, parasympathetic activity and jump performance were reduced, while sleepiness, fatigue and perceived recovery were significantly impaired.
Psychophysiological Stress Markers During Preseason Among Elite Female Soccer Players	Botelho et al. (2022)	Brazil	Longitudinal observational study across a 7-week preseason; 24 elite female soccer players	HRV; salivary testosterone and cortisol; blood creatine kinase; internal training load	Negative mood scales, total mood disturbance, cortisol, testosterone and creatine kinase all increased after preseason. Cortisol correlated positively with tension and confusion and negatively with the LF/HF index of HRV.
Comprehensive assessment of heart rate variability, blood pressure, sleep quality, and	Ataman et al. (2025)	Ukraine	Cross-sectional case-control comparison; 52 track and field athletes (11 with	Short-term HRV recording (Cardio+ monitor); arterial blood pressure	Athletes with fatigue lasting more than two weeks showed lower well-being,

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
anxiety in athletes with persistent fatigue			persistent fatigue)		more sleep disturbance and higher anxiety. Fatigue correlated very strongly with reduced well-being and moderately with insomnia and daytime sleepiness, but not with anxiety.
Training Stress, Sleep Behaviour, and Recovery Self-Regulation in Elite Female Boxers: A Behavioural Pattern Analysis Using Data-Driven Methods	Rattanasateankij et al. (2025)	Thailand	Observational study with machine-learning classification of readiness; Elite female boxers during the pre-competition phase (5,200 labelled boxing actions)	Wearable-derived sleep duration and efficiency; quantified training load	Integrating training load, wearable sleep metrics, recovery regulation and psychological dimensions into a dimensionality-reduced classification framework produced readiness patterns that separate movement analysis alone cannot capture.
Integration of wearable technologies in monitoring physical performance and psychological stress in tennis players	Wang (2025)	China	Controlled intervention study with intervention and comparison groups; 100 professional Chinese tennis players (54 male, 46 female)	Smartwatches, biosensor wristbands, GPS trackers, electromyographic sensors; HR, HRV, HRR	Athletes using wearable devices showed significantly faster post-exertion recovery, a more favourable autonomic balance with greater parasympathetic activity, and lower perceived stress than those who did not.
Psychophysiological Effects of Slow-Paced Breathing on Adolescent Swimmers' Subjective Performance, Recovery States, and Control Perception	Merlin et al. (2024)	France	Randomised two-group ecological trial with multilevel modelling (7 weekly waves); 13 national-level adolescent swimmers	HR and HRV from a weekly submaximal 5'-5' test (MeanRR, RMSSD, LFnu, HFnu, LF/HF); HR recovery	A seven-week slow-paced breathing protocol without biofeedback significantly predicted biopsychosocial recovery states, perception of control and subjective training performance, although effects on HRV indices were not uniformly significant.
Reprogramming the Psychology of Success: The Reflections of Wearable	Camici et al. (2025)	Turkiye	Qualitative interview study with thematic analysis; Professional	Athlete-worn wearable devices (self-reported use)	Wearables function beyond data capture, supporting self-awareness, self-

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
Technologies in Athletes' Emotional and Motivational Dynamics			athletes from various disciplines		discipline, self-esteem and intrinsic motivation, while risks of technology dependence, privacy loss and over-quantification of self-perception were poorly recognised by athletes.
Autonomic Nervous System Control in Male and Female Elite Soccer Players: Importance of Different Training Routines and Perceived Stress	Oggionni et al. (2025)	Italy and Portugal	Cross-sectional observational study across three first-division clubs; 117 elite soccer players (74 male, 43 female)	HRV-derived Autonomic Nervous System Index (ANSI) from multivariate statistical modelling	ANSI was higher in males and, among them, in midfielders and defenders who sustain the greatest external load. Female players instead reported significantly higher somatic symptoms and perceived stress, which was highest in midfielders and forwards.
Effects of "Living High-Training Low and High" on Sleep, Heart Rate Variability, and Psychological Responses in Elite Female Cyclists	Pirlot et al. (2025)	France	Exploratory repeated-measures study across three 19-day monitoring periods; 10 elite/international female cyclists (17.3 +/- 1.2 years)	Chest-strap resting HRV; electroencephalography sleep headband for sleep architecture	Early hypoxic acclimatisation increased perceived sleep disturbance and altered HRV and sleep architecture without changing total sleep time. Sleep became restorative during middle acclimatisation while HRV remained altered, showing dissociation between subjective and autonomic recovery.
Relationship between state anxiety, heart rate variability, and shooting performance in adolescent shooters	Zhao et al. (2024)	China	Cross-sectional comparative study in a real competition setting; 45 adolescent shooters of two competitive grades	Inter-competition HRV (RMSSD, total power, HFn, LFn)	Higher-graded athletes reported lower cognitive and somatic state anxiety and higher confidence, and simultaneously showed higher RMSSD, total power and HFn with lower LFn, linking vagal capacity to anxiety regulation and shooting outcome.

JRTI (Jurnal Riset Tindakan Indonesia)
Vol. 11, No. 1, 2026, pp. 845-870

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
Psychophysiological profiling of elite cricket athletes	Joseph et al. (2025)	United States	Repeated-measures experimental study with machine-learning modelling (144 observations); 36 elite fast bowlers	HRV (RMSSD) recorded before and after accuracy tasks; self-selected sensory interventions	A support vector regression model weighting each athlete's deviation from a personally optimal RMSSD outperformed group-level approaches, and explanatory analysis identified RMSSD distance and affect features as the primary predictors of bowling accuracy.
Effect of Biofeedback on the Anxiety of Amateur Athletes	Canton et al. (2022)	Spain and Italy	Randomised controlled experimental design (six sessions over two weeks); 16 amateur marathon athletes	Peripheral temperature, skin conductance and heart rate biofeedback	Athletes receiving biofeedback achieved significantly lower psychophysiological activation than controls, with significant interaction effects for peripheral temperature and skin conductance, indicating learned voluntary control of autonomic responses.
An Investigation of Psychological and Physiological Factors Affecting Performance in Adolescent Judokas	Stepanyan et al. (2023)	Armenia	Cross-sectional correlational study; 23 male adolescent judokas aged 10-16 years	HRV via Varikard 2.51 (IRSA, LF, total power)	Participants reported high well-being, activity and positive mood, yet the index of activity of regulatory systems, LF and total power exceeded normative ranges, revealing autonomic regulatory tension that self-report alone did not disclose.
Effects of a Modular Sleep System on Subjective Sleep Quality and Physiological Stability in Elite Athletes	Marshall et al. (2026)	Germany	Applied intervention study with objective and subjective sleep monitoring; Elite athletes in a high-performance training environment	Objective sleep metrics, circadian timing and nocturnal autonomic physiology	An individually adjustable modular sleep system improved perceived sleep quality in athletes whose sleep duration was already near optimal, without disrupting circadian timing or nocturnal autonomic regulation.

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
Comparative Characteristics of Psychophysiological and Shooting Performance Between Intermediate and Elite Compound Archers	Salleh et al. (2023)	Malaysia	Cross-sectional comparative study; 20 compound archers aged 13-21 years (intermediate and elite)	Polar heart rate monitor; digital finger pulse oximeter (blood oxygen percentage)	Elite archers showed a descriptive pattern of lower cognitive anxiety, somatic anxiety and heart rate, with significant between-group differences for blood oxygen percentage and shooting performance, while self-confidence was associated with performance.
Maximizing sleep quality and well-being in female athletes: the role of the menstrual cycle and whole-body cryostimulation	Messaoudene et al. (2025)	France	Randomised controlled cross-over trial over two menstrual cycles; 17 naturally menstruating young female athletes	Objective sleep quality, core temperature and HRV; whole-body cryostimulation at -110 degrees C	The mid-luteal phase reduced objective sleep quality and raised fatigue, core temperature and sympathetic activity without changing subjective sleep quality; cryostimulation improved objective sleep and perceived fatigue but did not normalise sympathetic activity.
Application of Vagal-Mediated Heart Rate Variability and Subjective Markers to Optimise Training Prescription: An Olympic Athlete Case Report	Chiron et al. (2024)	France	Longitudinal single-athlete case report across a pre-Olympic season; One world-class female 3000 m steeplechase runner	Supine and orthostatic HRV (LnRMSSDsu, HRsu) recorded four times weekly	LnRMSSDsu correlated negatively with RPE-based training load and sleep quality, while supine heart rate correlated positively with perceived exertion, sleep quality, stress, soreness and fatigue, supporting combined objective-subjective prescription.
Heart rate variability, recovery and stress analysis of an elite rally driver and co-driver during a competition period	Di Credico et al. (2024)	Italy	Observational case series across a four-day competition period; One elite rally driver and one co-driver (Italian National	HRV parameters including mean RR, RMSSD, SDNN, stress index, Poincare plots and power spectral density	Race days produced sharp reductions in mean RR, RMSSD and SDNN with an inverse rise in the stress index; questionnaire-based recovery and

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
			Rally Championship)		stress differed significantly for the driver but not the co-driver despite similar physiological trends.
One-Week Home-Based HRV Biofeedback with Supervised Sessions Versus Passive Relaxation: Effects on Autonomic, Sensorimotor Functions and Kata Performance in Eastern Martial Arts Athletes	Toloraya et al. (2026)	Russian Federation	Two-group controlled intervention trial; 40 high-level martial arts athletes aged 17-27 years	Hybrid HRV biofeedback: supervised resonance-frequency breathing plus smartphone-guided home practice at six breaths per minute	One week of hybrid HRV biofeedback significantly improved movement oscillation frequency and associated sensorimotor indices relative to passive relaxation, indicating that brief, low-cost self-regulation training can be embedded in routine practice.
Effects of Sprint Interval Training on Brain Fatigue Resistance in Competitive Skateboarders: Evidence from EEG, HRV, and VAS Measures	Yang et al. (2026)	China	Single-group repeated-measures preliminary intervention study (6 weeks); 12 elite skateboarders	EEG and HRV recorded after a standardised 60-minute Stroop task at three time points	Six weeks of sprint interval training was associated with higher central nervous system activation, more flexible autonomic regulation and stable mental fatigue ratings alongside increased mental exertion and motivation and reduced physical fatigue.
Individual training prescribed by heart rate variability, heart rate and well-being scores in experienced cyclists	Alfonso et al. (2025)	Spain and Canada	Three-arm controlled trial over 40 days with daily monitoring; 28 experienced male cyclists	Daily vagally mediated HRV, resting heart rate and customised training prescription	All groups improved cycling performance, but the group guided by HRV, well-being and resting heart rate combined improved most; autocorrelation analysis showed perceived stress had the highest day-to-day consistency of the subjective measures.
Improving the functional status of young boxers in the preparatory period of training with biofeedback	Kubiyeva et al. (2025)	Kazakhstan	Controlled intervention trial in the preparatory training period; 50 male boxers aged 15-16 years	HRV biofeedback combined with breathing and emotional regulation exercises; stress index and regulatory-system reactivity	The HRV biofeedback group showed very large improvements in attention and working memory and a moderate

Full title of the study	Author(s) (Year)	Country/ region	Design and sample	Monitoring modality	Key findings
					reduction in physiological stress compared with controls, alongside improved neurovegetative balance.

Note. All bibliographic details are transcribed directly from the Scopus export. Country/region denotes the location of the study team as reported in the source record. Full source titles and digital object identifiers are given in the reference list.

Table 5. Classification of included studies by theme, psychological instrumentation and quality appraisal

Author(s)	Year	Country/ region	Research design	Theme / focus	Psychological or subjective instrument	FICO (/16)
Lakhdar et al.	2026	Tunisia	Within-subject repeated-measures field study	T1. Autonomic load and competitive stress	Sleepiness, chronotype, fatigue and perceived recovery questionnaires; RPE	15
Botelho et al.	2022	Brazil	Longitudinal observational study across a 7-week preseason	T1. Autonomic load and competitive stress	Profile of mood states (negative subscales and total mood score)	14
Ataman et al.	2025	Ukraine	Cross-sectional case-control comparison	T2. Sleep, recovery and subjective well-being	Fatigue Assessment Scale; WHO-5; Athens Insomnia Scale; Epworth Sleepiness Scale; HADS	13
Rattanasateankij et al.	2025	Thailand	Observational study with machine-learning classification of readiness	T4. Individualised and data-driven monitoring	Standardised recovery questionnaires; competitive anxiety, self-confidence, team cohesion, perception of opponents	12
Wang	2025	China	Controlled intervention study with intervention and comparison groups	T4. Individualised and data-driven monitoring	Perceived Stress Scale (PSS-10)	13
Merlin et al.	2024	France	Randomised two-group ecological trial with multilevel modelling (7 weekly waves)	T3. Self-regulation interventions	RESTQ-36-R-Sport; cognitive perceived stress and control; subjective performance and internal load	15
Camici et al.	2025	Turkiye	Qualitative interview study with thematic analysis	T4. Individualised and data-driven monitoring	Semi-structured interviews on motivation, self-confidence, self-regulation and technology dependence	12
Oggionni et al.	2025	Italy and Portugal	Cross-sectional observational study across three first-division clubs	T1. Autonomic load and competitive stress	Questionnaires of perceived stress and somatic symptoms	15
Pirlot et al.	2025	France	Exploratory repeated-measures study across three 19-day monitoring periods	T2. Sleep, recovery and subjective well-being	Psychological stress and sleep disturbance questionnaires	15
Zhao et al.	2024	China	Cross-sectional comparative study in a real competition setting	T1. Autonomic load and competitive stress	Pre-competition state anxiety and state self-confidence (cognitive and somatic subscales)	15
Joseph et al.	2025	United States	Repeated-measures experimental study with machine-	T4. Individualised	Self-Assessment Manikin ratings of affective state	15

Author(s)	Year	Country/ region	Research design	Theme / focus	Psychological or subjective instrument	FICO (/16)
			learning modelling (144 observations)	and data-driven monitoring		
Canton et al.	2022	Spain and Italy	Randomised controlled experimental design (six sessions over two weeks)	T3. Self-regulation interventions	State-Trait Anxiety Inventory (STAI); subjective activation scale	13
Stepanyan et al.	2023	Armenia	Cross-sectional correlational study	T1. Autonomic load and competitive stress	Well-being, Activity and Mood (WAM) questionnaire	12
Marshall et al.	2026	Germany	Applied intervention study with objective and subjective sleep monitoring	T2. Sleep, recovery and subjective well-being	Subjective sleep quality and recovery perception ratings	13
Salleh et al.	2023	Malaysia	Cross-sectional comparative study	T1. Autonomic load and competitive stress	Revised Competitive State Anxiety Inventory-2 (CSAI-2R)	12
Messaoudene et al.	2025	France	Randomised controlled cross-over trial over two menstrual cycles	T2. Sleep, recovery and subjective well-being	Subjective sleep quality and perceived fatigue ratings	15
Chiron et al.	2024	France	Longitudinal single-athlete case report across a pre-Olympic season	T4. Individualised and data-driven monitoring	Daily subjective evaluations of sleep quality, stress, muscle soreness, fatigue and session RPE	13
Di Credico et al.	2024	Italy	Observational case series across a four-day competition period	T1. Autonomic load and competitive stress	Acute Recovery and Stress Scale	12
Toloraya et al.	2026	Russian Federation	Two-group controlled intervention trial	T3. Self-regulation interventions	Sensorimotor function assessment; expert-rated kata performance	14
Yang et al.	2026	China	Single-group repeated-measures preliminary intervention study (6 weeks)	T3. Self-regulation interventions	Visual analogue scales of mental fatigue, mental exertion, motivation and physical fatigue	12
Alfonso et al.	2025	Spain and Canada	Three-arm controlled trial over 40 days with daily monitoring	T4. Individualised and data-driven monitoring	Daily subjective well-being scores including stress, sleep and fatigue items	15
Kubiyeva et al.	2025	Kazakhstan	Controlled intervention trial in the preparatory training period	T3. Self-regulation interventions	Attention, working memory and physiological stress assessment	14

Note. FICO = Focus, Information, Context, Outcome. Minimum retention threshold = 12 of 16.

Figure 2 makes the recency bias plain. The curve tilts hard toward the last few years, with one study published in 2021, four in 2022, seven in 2025, and four more inside the partial 2026 window we searched. That is not the signature of a mature, stable field. It reads more like a literature in rapid expansion, one where most of the evidence has piled up within roughly two years and has not yet faced independent replication.

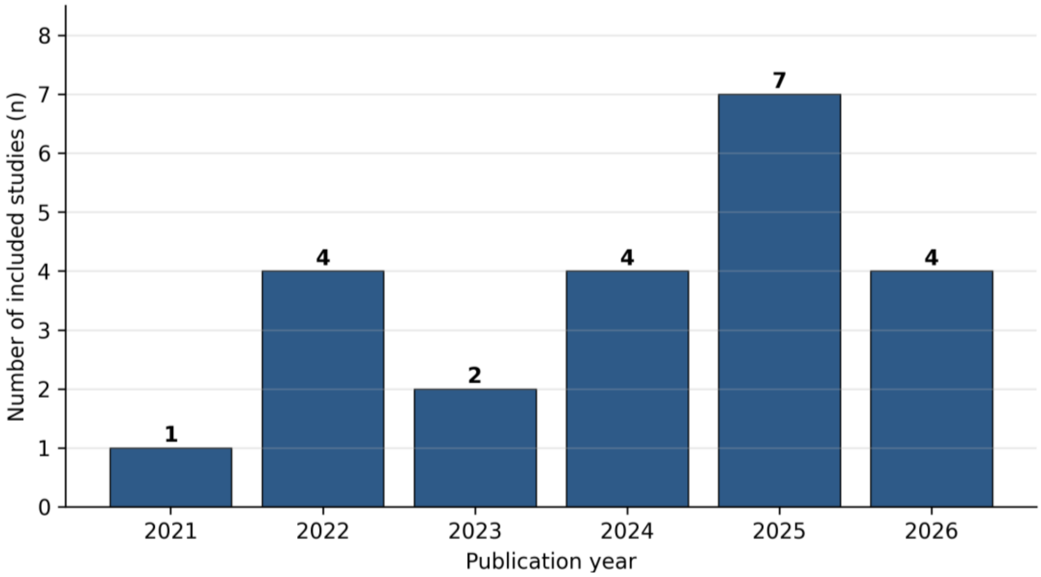

Figure 2. Annual distribution of the 22 included studies (2021–2026).

Geographically, the set is spread across sixteen countries or country pairings. France and China weigh in most heavily, three studies each. Then come single contributions from Brazil, Ukraine, Thailand, Türkiye, the United States, Armenia, Germany, Malaysia, Italy, the Russian Federation, Kazakhstan, and Tunisia. Three cross-national collaborations are also in the mix: Italian, Portuguese, Spanish, Italian, and Spanish, Canadian. No single national research tradition dominates. That is a strength in terms of setting diversity, but a weakness for protocol standardisation. Instruments and thresholds simply differ from tradition to tradition.

Figure 3 shows how the studies sort by sport category. Endurance sports form the biggest cluster, with six studies. Combat sports follow with four. Team sports and mixed or multi-sport samples each account for three. Racquet sports, precision sports, and the combined motorsport and board-sport category each contribute two. So sports that call for continuous aerobic load and closed-skill precision get comparatively solid coverage. High-intensity intermittent invasion games, by contrast, appear in only three studies, which is a thin showing for a category that features so prominently in professional sport.

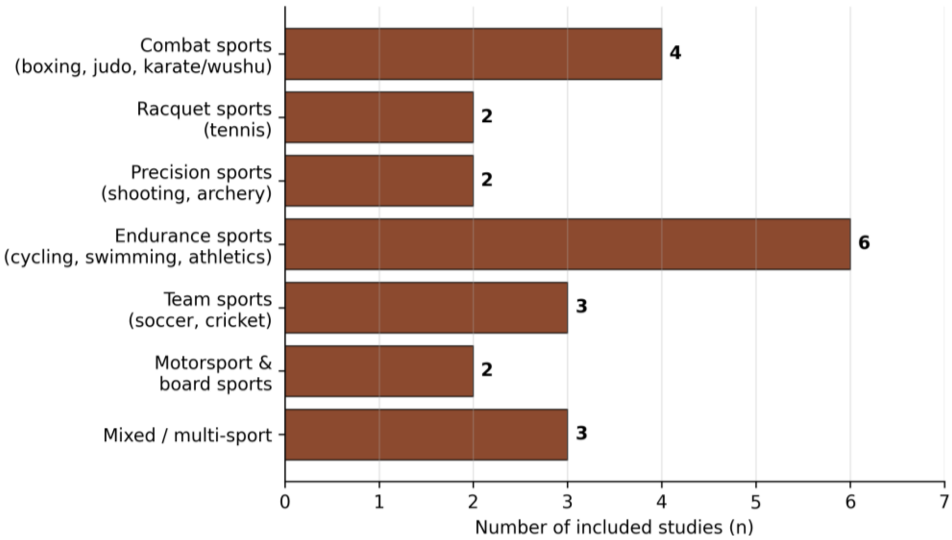

Figure 3. Distribution of the included studies by sport category.

Figure 4 makes the point pretty clearly: one modality dominates. Nineteen of the 22 studies relied on heart rate variability, usually captured with chest straps or dedicated R, R interval recorders. After that the numbers drop quickly. Wearable sleep tracking, or actigraphy, showed up in six studies, and smartwatch or wristband biosensors in four. Electroencephalography appeared in three. Pulse oximetry, plus electrodermal or peripheral temperature sensing, each turned up in just two. Salivary hormone assay played a supporting part in three others. So the evidence base leans heavily, in a way, on cardiac autonomic regulation, with everything else filling secondary roles.

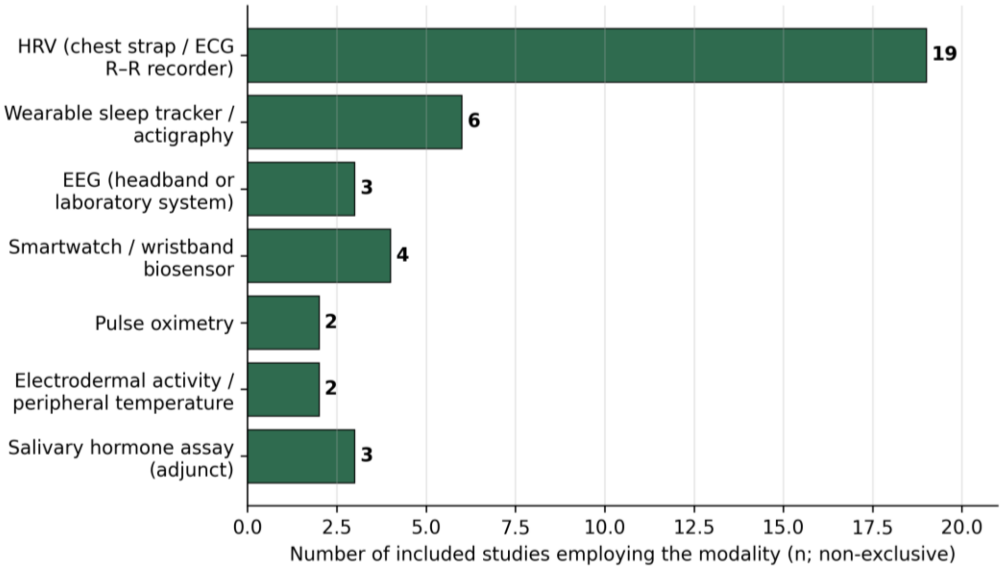

Figure 4. Monitoring modalities employed across the 22 included studies (non-exclusive counts).

Thematic Synthesis

Thematic synthesis produced four themes. Theme 1, autonomic load and competitive stress, comprises eight studies; Theme 2, sleep, recovery and subjective well-being, comprises six; Theme 3, self-regulation interventions, comprises five; and Theme 4, individualised and data-driven monitoring, comprises three. Their relative weight is shown in Figure 5.

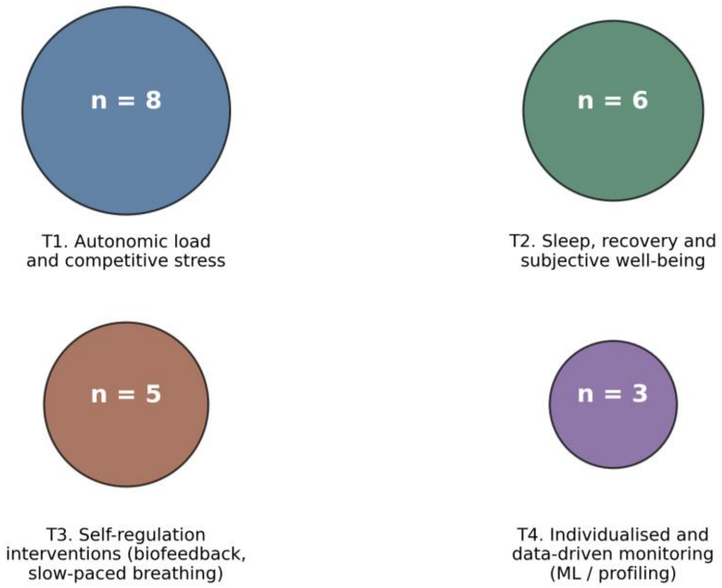

Figure 5. Thematic clusters derived from the 22 included studies.

Findings for RQ1: Technologies and instruments combined

The first research question asked how technologies and instruments tend to be paired. Looking across the included studies, the dominant setup is straightforward: a cardiac autonomic index combined with a validated self-report questionnaire, both administered at the same time point. Botelho et al. (2022) coupled HRV and salivary hormones with a mood profile across a seven-week preseason. Oggionni et al. (2025) paired a composite HRV-derived autonomic index with perceived stress and somatic symptom questionnaires in 117 soccer players. Di Credico et al. (2024) matched time-domain and non-linear HRV indices against the Acute Recovery and Stress Scale during a rally competition. Chiron et al. (2024) used supine and orthostatic HRV alongside daily ratings of sleep, stress, soreness and fatigue across an Olympic season. The consistency across these studies is striking. It reflects two things: cardiac monitoring is low cost, and the associated psychometrics have matured.

A second, less frequent configuration brings sleep-related sensing together with subjective reports of sleep and recovery. Pirlot et al. (2025) used a chest-strap HRV monitor alongside an electroencephalography sleep headband, adding questionnaires on stress and sleep disturbance during altitude acclimatisation. Messaoudene et al. (2025) tracked objective sleep quality, core temperature and HRV, then compared these with subjective sleep and fatigue ratings across two menstrual cycles. Marshall et al. (2026) measured objective sleep metrics, circadian timing and nocturnal autonomic physiology alongside perceived sleep quality. Ataman et al. (2025) went further with short-term HRV and blood pressure, coupling them to a battery that included a fatigue scale, a well-being index, an insomnia scale, a sleepiness scale, and an anxiety and depression scale. Instrumentally, this configuration is richer than the cardiac-only pairing. It just appears in fewer studies.

A third configuration, restricted to four studies, relies on multimodal or non-cardiac sensing tied to cognitive and affective outcomes. Yang et al. (2026) recorded electroencephalography and HRV after a standardised Stroop task, pairing the signals with visual analogue ratings of mental fatigue, exertion and motivation. Canton et al. (2022) took peripheral temperature, skin conductance and heart rate biofeedback and linked them to the State-Trait Anxiety Inventory. Salleh et al. (2023) used a heart rate monitor and a finger pulse oximeter alongside the revised Competitive State Anxiety Inventory. Wang (2025) equipped 100 tennis players with smartwatches, biosensor wristbands, GPS trackers and electromyographic sensors, then administered the Perceived Stress Scale. Only Çamiçi et al. (2025) approached the question qualitatively, focusing on how athletes experience wearable feedback rather than on what the devices record.

Put all this together and the answer to RQ1 is clear. Heart rate variability has become the default physiological channel, while established stress, anxiety, mood and recovery inventories serve as the default psychological channel. Sleep sensing forms a secondary cluster, and multimodal configurations remain exceptional. That convergence makes studies more comparable, but it also leaves a gap. Constructs that cardiac autonomic activity does not index well, such as attentional control or motivational state, end up under-measured.

Findings for RQ2: convergence and divergence between the channels

The second research question asked whether the two channels actually converge. In several studies, they clearly do. Zhao et al. (2024) studied adolescent shooters and found that those of higher competitive grade reported lower cognitive and somatic state anxiety. At the same time, they displayed higher RMSSD, total power and normalised high-frequency power, alongside lower normalised low-frequency power. The psychological and autonomic indices pointed in the same direction, and both tracked performance. Botelho et al. (2022) found cortisol correlating with tension and confusion and inversely with the LF/HF ratio. Chiron et al. (2024) reported that supine heart rate correlated positively with perceived exertion, stress, soreness and fatigue across an entire competitive season.

Yet dissociation shows up just as often. Stepanyan et al. (2023) saw adolescent judokas report high well-being, activity and positive mood, all while their index of activity of regulatory systems, low-frequency power and total power sat above normative ranges. That points to regulatory tension the self-report did not disclose. Messaoudene et al. (2025) found that the mid-luteal phase degraded objective sleep quality and elevated core temperature and sympathetic activity, while subjective sleep quality stayed unchanged. Pirlot et al. (2025) saw the inverse later in altitude acclimatisation, with subjective sleep recovering while HRV remained disturbed. Di Credico et al. (2024) observed near-identical autonomic trajectories in a rally driver and co-driver, yet only one showed significant questionnaire-based differences.

Some conditions seem to separate these outcomes. Convergence is more likely when the psychological construct is anxiety or acute stress measured close in time to the physiological recording, and when the comparison pits individuals who differ substantially in expertise, as in Zhao et al. (2024) and Salleh et al. (2023). Dissociation, by contrast, tends to appear when the physiological perturbation comes from a source the athlete does not experience as stressful, such as hormonal phase (Messaoudene et al., 2025), hypoxic exposure (Pirlot et al., 2025) or nutritional timing (Lakhdar et al., 2026). It also shows up when the psychological measure aggregates over a period during which autonomic state fluctuated. This interpretation aligns with wider evidence that self-reported variables and resting vagal activity relate only moderately across athlete populations (Alfonso et al., 2025b; Mosley & Laborde, 2024).

There is a third pattern worth emphasising because it bears directly on practice. Alfonso et al. (2025a) ran an autocorrelation analysis of daily subjective measures and found that perceived stress displayed the highest day-to-day consistency. The subjective channel, in other words, is not simply noisier than the physiological one; it carries a stable signal of its own. Rattanasateankij et al. (2025) came to a comparable conclusion from the opposite direction. Readiness classification in elite female boxers required training load, wearable sleep metrics, recovery regulation and psychological variables all together, because movement analysis alone proved insufficient. The answer to RQ2, then, is that convergence is directionally consistent but partial: the two channels agree often enough to be jointly informative, and they disagree often enough that neither can substitute for the other.

Findings for RQ3: interventions, analytics and methodological constraints

The third research question asked about interventions and analytical strategies. The strongest evidence sits with respiratory and biofeedback-based self-regulation. Canton et al. (2022) showed that six short biofeedback sessions over two weeks significantly reduced psychophysiological activation in amateur marathon runners relative to controls, with significant interaction effects for peripheral temperature and skin conductance. Toloraya et al. (2026) gave 40 martial arts athletes one week of hybrid HRV biofeedback, combining supervised resonance-frequency sessions with smartphone-guided home practice, and found improved sensorimotor indices relative to passive relaxation. Kubiyeva et al. (2025) reported very large improvements in attention and working memory, plus a moderate reduction in physiological stress, in young boxers following HRV biofeedback combined with breathing and emotional regulation exercises.

Merlin et al. (2024) offer an instructive qualification. Their seven-week slow-paced breathing protocol in adolescent swimmers significantly predicted biopsychosocial recovery states, perception of control and subjective training performance, but effects on HRV indices were not uniformly significant. A psychological benefit therefore appeared without a corresponding autonomic signature, which cautions against using HRV change as the validation criterion for interventions whose intended outcome is perceptual. Environmental interventions raise a similar point. Marshall et al. (2026) improved perceived sleep quality without disturbing circadian timing or nocturnal autonomic regulation, and Messaoudene et al. (2025) improved objective sleep and perceived fatigue through cryostimulation while sympathetic activity remained elevated.

The analytical strategies constitute the most substantial methodological development in the set. Joseph et al. (2025) modelled performance in 36 elite fast bowlers by rescaling RMSSD within each participant and weighting deviation from a personally optimal state. Under leave-one-participant-out cross-validation, this person-specific approach outperformed group-level alternatives, and explanatory analysis picked out RMSSD distance and affect features as the primary predictors. Alfonso et al. (2025a) found that cyclists whose training was prescribed from HRV, resting heart rate and well-being together improved more than those guided by HRV alone. Rattanasateankij et al. (2025) and Wang (2025) integrated multiple streams in a similar way, and Chiron et al. (2024) demonstrated the same principle in a single-athlete design across a full season.

The methodological limitations, however, are considerable. Sample sizes tend to be small: nine of the 22 studies enrolled fewer than 20 participants, and three were case reports or single-athlete designs. Observation windows are short, with most interventions lasting one to seven weeks, which is not enough to establish whether effects persist through a competitive season. Psychometric reporting is heterogeneous, with instruments ranging from single visual analogue scales to multi-scale batteries, and few studies report the reliability of these instruments in their own sample. Blinding is rarely feasible in biofeedback and breathing protocols, so expectancy effects cannot be discounted. The answer to RQ3 is thus that self-regulation interventions and individualised analytics both show promise, but the evidence supporting them is preliminary in scale and duration.

Comparative and critical analysis of methods

Comparing methodological approaches across the 22 included studies reveals a field in transition. Fourteen studies employed observational or cross-sectional designs, seven employed controlled or randomised intervention designs, and one was qualitative. The cross-sectional studies were useful for identifying associations, but their designs limit causal inference. By contrast, repeated within-person designs such as Merlin et al. (2024), Alfonso et al. (2025a), Pirlot et al. (2025) and Chiron et al. (2024) allowed the investigators to examine temporal coupling within athletes rather than relying only on between-person contrasts. Intervention studies by Canton et al. (2022), Wang (2025), Messaoudene et al. (2025), Toloraya et al. (2026), Yang et al. (2026) and Kubiyeva et al. (2025) further show that physiological and perceptual changes do not necessarily move in lockstep after an intervention. Taken together with the observational evidence from Botelho et al. (2022), Zhao et al. (2024), Stepanyan et al. (2023), Di Credico et al. (2024), Oggionni et al. (2025) and Lakhdar et al. (2026), the pattern supports a conditional dual-channel model rather than a universal correlation.

Two design innovations stand out. The first is repeated within-person measurement across ecologically valid periods, exemplified by the weekly assessment waves of Merlin et al. (2024), the 40-day daily monitoring of Alfonso et al. (2025a), the 19-day acclimatisation protocol of Pirlot et al. (2025) and the season-long case report of Chiron et al. (2024). The second is the use of supervised machine learning on multimodal streams, seen in Joseph et al. (2025) and Rattanasateankij et al. (2025). Both respond to the same underlying recognition: group means are poor descriptors of individual regulatory state.

The underused designs are equally informative. No included study employed a stepped-wedge or cluster-randomised design, even though such designs would suit team environments where individual randomisation is impractical. Only one study was qualitative, despite clear evidence that athletes' interpretation of feedback shapes its effect (Çamiçi et al., 2025). Mixed-methods designs are absent entirely, meaning no study examined both whether a monitoring system changes physiological state and whether athletes trust and act on it. Sex balance is also uneven: five studies sampled women exclusively, three sampled men exclusively, and the remainder used mixed or unspecified samples, with only Oggionni et al. (2025) explicitly analysing sex as a moderator.

Interpretation of findings

A dual-channel view of athlete state makes the most sense of these findings. Physiological monitoring and psychological self-report are not measuring the same underlying quantity with different degrees of precision. They index regulatory processes that overlap only partially. Autonomic indices capture the current operating point of the cardiac branch of the autonomic nervous system. That branch responds to metabolic, thermal, hormonal and circadian inputs, and to psychological appraisal as well. Self-report, by contrast, captures conscious appraisal. Interoception informs it, but so do memory, expectation and social context. Divergence between the two channels is therefore not measurement error to be eliminated. It is information, telling us which inputs currently dominate.

The specific dissociations fall into place under this interpretation. Take Messaoudene et al. (2025), who observed elevated core temperature and sympathetic activity in the mid-luteal phase alongside unchanged subjective sleep quality. The physiological channel was picking up a hormonal input that never reached conscious appraisal. Or take Stepanyan et al. (2023), who found regulatory tension in judokas who reported high well-being. The perceptual channel was appraising a valued activity; the autonomic channel was registering its cost. Neither reading is wrong. They are simply answering different questions.

Theoretical implications

Three implications follow at the theoretical level. First, composite readiness indices built by summing standardised physiological and psychological scores rest on shaky theoretical ground. Summation assumes the components all indicate a single latent construct. The dissociations documented here suggest they do not, so a profile that keeps the two channels separate is more defensible than any single number.

Second, Joseph et al. (2025) showed that person-specific reference ranges outperform group norms. That result supports an idiographic view of psychophysiological optimality. There may be no universal optimum; each athlete seems to operate within a characteristic band, and the meaningful signal lies in deviation from that band. This fits dynamical accounts that index regulatory capacity by variability and responsiveness rather than absolute level (Crameri et al., 2021; Neumann et al., 2024).

Third, these results carry the literature on vagal regulation of self-regulatory capacity into applied competitive contexts. Higher-graded shooters show lower anxiety alongside greater vagally mediated variability (Zhao et al., 2024). Paced breathing, which experimentally raises vagal activity, improves perceived control (Merlin et al., 2024; You et al., 2024). Both findings fit the idea that parasympathetic capacity underpins emotional regulation. And because the evidence comes from adolescent and elite athletes tested in situ, the claim gains generality well beyond laboratory samples.

Practical implications

For practitioners, the clearest takeaway is to collect physiological and subjective monitoring together and interpret them jointly. Divergence between the two should trigger a conversation, not be filed away as a data-quality problem. Consider an athlete whose vagal indices are suppressed while wellness scores stay high. That pattern may mean load is accumulating without reaching awareness. The reverse case, high reported stress with unremarkable autonomic values, suggests difficulties that are psychological or social in origin. No training adjustment is likely to fix those.

Baselines form the second implication. Since person-specific reference ranges beat group norms, a monitoring system needs an individual baseline built from several weeks of representative training before any threshold-based decision rule is applied. Applying published population cut-offs to an athlete without such a baseline invites systematic misclassification. The danger is greatest for female athletes, whose hormonal cycling introduces predictable variation (Messaoudene et al., 2025), and for adolescents, whose autonomic indices differ from adult norms (Stepanyan et al., 2023; Kubiyeva et al., 2025).

Sleep-related countermeasures deserve special attention. Napping alters cardiac autonomic indices in elite athletes, and it can be scheduled around training at no extra cost (Souabni et al., 2024). The third implication concerns intervention selection. Slow-paced breathing and HRV biofeedback are inexpensive and brief, and they have repeatedly produced psychological benefit. The hybrid supervised plus home-based format used by Toloraya et al. (2026) fits realistically into a normal training week. Even so, practitioners should judge these interventions against the outcomes they are meant to change, which are typically perceptual, not against autonomic indices that may never shift (Merlin et al., 2024).

A fourth implication is about how athletes relate to their own data. Çamiçi et al. (2025) found that wearables fostered self-awareness and intrinsic motivation. Yet the same athletes were largely unaware of the risks: dependence, privacy loss, and the over-quantification of self-perception. Monitoring programmes therefore carry an educational obligation alongside a technical one. And survey evidence shows athletes already self-track on their own, outside formal programmes (Jakowski, 2022).

Comparison with prior reviews

Placing these findings next to earlier reviews clarifies what they add. The broader athlete-monitoring literature has repeatedly shown that subjective and objective indicators should be interpreted together rather than assumed to be interchangeable. Saw et al. (2016) reported that subjective well-being often responded more sensitively to training load than commonly used objective measures, while Bellenger et al. (2016) showed that autonomic heart-rate regulation is informative for training status but affected by substantial methodological variability. Thorpe et al. (2017) emphasized the practical challenge of monitoring fatigue in elite team-sport athletes, and Jiménez Morgan and Molina Mora (2017) together with Pagaduan et al. (2020, 2021) found that HRV biofeedback is promising but rests on a relatively small and heterogeneous evidence base. Kim et al. (2018) and Lehrer et al. (2020) further established that HRV can be sensitive to stress and that HRV biofeedback can improve emotional and physical outcomes, respectively, while Vlahoyiannis et al. (2020) highlighted substantial limitations in wearable and objective sleep assessment among athletes. Düking et al. (2021) demonstrated that HRV-guided training can be effective but that device, protocol and decision-rule variation complicate comparison. Preatoni et al. (2022) showed that wearable sensors are increasingly useful in applied sport but require explicit attention to readiness and validation. Welsh et al. (2023) reported theoretical and methodological gaps in HRV use in competitive gaming, and Mosley and Laborde (2024) documented broad heterogeneity in the sport and exercise psychology HRV literature. Alfonso et al. (2025b) found inconsistent associations between self-reported subjective variables and resting vagally mediated HRV, directly reinforcing the present review's dual-channel premise. More recent reviews also emphasize caution: Kaufman et al. (2025) noted that consumer sleep-wearable scores remain difficult to interpret clinically, Lipka et al. (2025) reported variable methodological quality in the HRV-overtraining literature, and recent 2026 reviews recommend longitudinal, contextualized use of mobile HRV and ecological momentary assessment rather than single-threshold decisions (Klier et al., 2026; the 2026 mHealth scoping review). A 2026 systematic review and meta-analysis of HRV and anxiety severity likewise frames HRV as complementary rather than a replacement for psychometric assessment (Óvári et al., 2026). Against this background, the present review contributes a narrower synthesis: every included study had to contain both physiological and psychological channels in the same athlete sample, allowing convergence and dissociation themselves to become the unit of analysis.

Broadly, the conclusions echo those earlier syntheses, but they sharpen them in two ways. Prior reviews noted inconsistent associations; this analysis specifies when convergence and dissociation actually occur. The moderators are temporal proximity of measurement, the nature of the perturbation, and whether the comparison runs within or between persons. Prior reviews also treated individualisation as a recommendation. Here the evidence is direct: person-specific modelling outperforms group-level modelling (Joseph et al., 2025; Alfonso et al., 2025a).

Contradictions in the literature

Three contradictions deserve to be stated plainly. The first is whether psychological and autonomic indices move together at all. Zhao et al. (2024) and Chiron et al. (2024) report substantial correlations. Stepanyan et al. (2023), Pirlot et al. (2025) and Messaoudene et al. (2025) report dissociation. The likeliest reconciliation is moderation by the source of the physiological perturbation. Stressors that are psychologically salient tend to produce convergence; stressors that are physiologically imposed tend to produce dissociation.

The second concerns whether autonomic change is necessary for psychological benefit. In Canton et al. (2022), Toloraya et al. (2026) and Kubiyeva et al. (2025), interventions improved both physiological and psychological indices. Merlin et al. (2024), by contrast, observed psychological improvement without consistent HRV change. Differences in dose and duration could explain the gap. Or it could be that perceived control responds to mechanisms other than vagal augmentation, such as expectancy and the structuring of attention.

The third concerns anxiety and fatigue. Ataman et al. (2025) studied track and field athletes and found persistent fatigue very strongly associated with reduced well-being, moderately with insomnia and sleepiness, but not with anxiety. The competitive-anxiety literature, in contrast, treats anxiety and fatigue as coupled. That discrepancy suggests chronic training fatigue and acute competitive anxiety are distinct states sharing some physiological expression. Instruments built for one may simply be uninformative about the other.

Research gaps

The synthesis points directly to four research gaps. The first is a modality gap. Nineteen of the 22 studies relied on cardiac autonomic measurement, so constructs that channel cannot index well remain untouched. Electrodermal activity, continuous glucose monitoring and ambulatory electroencephalography are barely represented (Holzer et al., 2022; Iammarino et al., 2026; Budnik-Przybylska et al., 2024).

Second is a duration gap. No included study tracked athletes with both channels across a complete competitive season, so the seasonal trajectories of convergence and dissociation are simply unknown. Third is a population gap. High-intensity intermittent invasion sports, para-sport, adventure and lead-climbing disciplines, where psychological, physiological and behavioural responses differ sharply by ability level (Giles et al., 2026), are under-represented. So are athletes in low-resource settings, and sex appears as a moderator in only one study. Fourth is a validation gap. Machine-learning readiness models are reported without external validation in independent samples. Their generalisability beyond the development cohort remains untested (Lu et al., 2026; Smerdov et al., 2021).

Limitations of this review

Four limitations should be weighed against the conclusions. The first is the single database. Scopus covers the relevant literature well, but studies living in journals indexed only by Web of Science, PubMed, SPORTDiscus or regional databases will have been missed. The exclusion of non-English publications adds a further constraint.

Second, screening and extraction used the abstract and bibliographic fields of the database export, not the full texts. That choice preserves full traceability of every reported detail to the indexed record. The trade-off is that methodological features absent from the abstract, reliability coefficients or attrition for instance, could not be appraised. The FICO scores should therefore be read as appraisals of reported information, not of study conduct.

Third, no protocol was registered prospectively, and screening was not duplicated independently. Selection decisions were rule-governed and auditable, but they were not independently verified. Fourth, the heterogeneity of designs, instruments and outcomes ruled out meta-analysis. All conclusions about convergence are therefore narrative rather than quantitative, and the review cannot put a magnitude on any relationship.

Future research agenda

Four concrete recommendations follow. First, run season-long dual-channel monitoring studies. The same athletes would supply daily physiological and subjective data across a full competitive cycle, with pre-registered analysis of when the channels converge and diverge. Alfonso et al. (2025a) used this design over 40 days, which gives a template worth extending.

Second, intervention trials of paced breathing and HRV biofeedback need adequate power and active, rather than passive, control conditions. Where the mechanism is perceptual, the trial should nominate a perceptual primary outcome, following the logic set out by Merlin et al. (2024). Sham-breathing controls would help separate expectancy from genuine physiological effect.

Third, machine-learning readiness models should publish their feature set and decision thresholds, and they should report external validation in an independent cohort. Practitioners need that to judge transportability. The within-person rescaling approach from Joseph et al. (2025) should also be tested against conventional group-normed models in prospective settings.

Fourth, the psychological channel needs minimum reporting standards comparable to those already in place for HRV acquisition. That means the instrument, its version, the recall window, the administration time relative to training, and sample-specific reliability should all be reported as a matter of course. Without this, the heterogeneity documented here will keep obstructing synthesis.

Summary answers to the research questions

In summary, RQ1 can be answered directly. The great majority of studies paired heart rate variability with validated stress, anxiety, mood and recovery inventories. Sleep sensing formed a secondary cluster, and genuinely multimodal configurations stayed rare.

RQ2 gets a more conditional answer. Convergence between physiological and psychological indices is directionally consistent but only partial. It is more likely when the stressor is psychologically salient and when measurement is temporally proximate, less likely when the perturbation is physiologically imposed. Neither channel can stand in for the other.

And for RQ3: HRV biofeedback, slow-paced breathing and sleep-environment modification have all shown benefit, and person-specific analytical modelling beats group-level modelling. Even so, small samples, short observation windows, heterogeneous psychometric reporting and missing external validation limit the translation into confident practice.

Conclusion

This systematic review synthesised 22 empirical studies published between 2021 and 2026 using a PRISMA 2020-aligned Scopus search, PICOS eligibility framework, FICO reporting-quality appraisal and three-stage thematic synthesis. RQ1 is answered by the clear dominance of HRV paired with validated psychological or subjective instruments, with sleep sensing and multimodal configurations appearing less frequently. RQ2 is answered conditionally: physiological and subjective measures are often directionally concordant but can diverge in magnitude and timing, especially when physiological state is altered by hormonal, hypoxic, nutritional, circadian or other perturbations that are not necessarily perceived as psychological stress. RQ3 indicates preliminary support for HRV biofeedback, slow-paced breathing, sleep-environment modification and individualized analytical models, while the evidence remains limited by small samples, short follow-up and incomplete external validation. The review therefore supports a dual-channel monitoring model in which physiological and subjective signals are interpreted together rather than collapsed into a single proxy score. Meta-analysis was not performed because the studies did not share a sufficiently common estimand; accordingly, no I-squared, Q or tau-squared statistics were calculated. The main review-level limitations are the single Scopus database, English-only restriction, one-reviewer screening and extraction, abstract-level information capture, non-registered protocol, use of a bespoke FICO reporting rubric, and inability to quantify pooled effect sizes. Future research should prioritize season-long dual-channel monitoring, independent screening, standardized psychometric reporting, adequately powered active-control trials, and external validation of individualized readiness models.

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