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Wearable and Ecological Monitoring of Psychological Readiness, Sleep, and Autonomic Recovery in Athletes: An Emerging Sports Psychology Perspective

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ABSTRACT

Background

Traditionally, monitoring of athletes has focused on external workload and physiological responses to exercise. Contemporary sport psychology increasingly highlights the importance of psychological preparedness, perceived recovery, sleep, stress, mood, and autonomic responses to daily challenges. Wearable technologies offer repeated or continuous monitoring of heart rate and heart-rate variability (HRV), sleep duration and regularity, activity levels, and other features; mobile applications and ecological momentary assessment (EMA) can capture day-to-day psychological features. Consideration of such combined approaches may offer a greater understanding of athlete readiness than isolated assessment of either psychological or physiological domains.

Objective

This review explores the emerging integration of psychological readiness, sleep, autonomic indicators, wearable technologies, and EMA into athlete monitoring. Particular attention is given to the possible complementarity of subjective and objective measures, individualized monitoring, longitudinal assessment, and practical and ethical considerations.

Methods

A focused narrative literature review was conducted using PubMed and a range of selected peer-reviewed literature published predominantly between 2015 and 2026. Additional literature was identified by screening of reference lists and targeted searches for relevant topics. The following themes were addressed: athlete monitoring, psychological readiness, sleep, HRV, wearable technologies, EMA, mental health, and recovery. Papers that include discussion or analysis of athletes, and mention at least one relevant psychological, sleep, autonomic, or wearable technologies-related topic, were considered for inclusion. This paper is a focused narrative review, so no PRISMA-based study selection or formal risk-of-bias assessment or quantitative meta-analysis was undertaken.

Main Findings

The literature suggests that subjective psychological measures are critically important, as they capture the experience of the athlete that is not captured in physiological measures. Sleep features can contribute valuable insights into the athlete's readiness, as they reflect key aspects of body restoration and are also strongly interconnected with mood, stress, cognition, and performance. While HRV offers non-invasive insights into cardiac autonomic regulation, it must be treated cautiously in its clinical interpretation and application. Recent studies in professional golfers demonstrate associations with sleep, resting heart rate, HRV, and sporting performance, while recent reviews show the increasing use of HRV for training adaptation and monitoring of recovery. EMA and mobile-health approaches offer the ability to repeatedly assess psychological features in the natural environment. Emerging research is also looking at multimodal and machine-learning approaches.

Conclusion

The integration of repeated psychological assessment and wearable technologies sleep and autonomic measures is an emerging area of sports psychology. Future research should consider longitudinal designs, athlete-specific baselines, multimodal models, criterion validation, careful interpretation, privacy, and ethical use of digital data.

Keywords: Sports Psychology; Psychological Readiness; Wearable Technology; Heart-Rate Variability; Sleep; Ecological Momentary Assessment; Athlete Monitoring; Recovery; Psychophysiology; Digital Health

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INTRODUCTION

Background

Athletic performance is dictated by the interaction of physical, physiological, psychological, environmental and behavioral factors. Training load and physical performance are key factors in athlete monitoring, but the modern approach increasingly recognizes that the athlete's well-being and readiness cannot be captured solely by their physical workload. Mood, perceived stress, motivation, perception of recovery, sleep, anxiety, confidence and psychological readiness can vary throughout the training cycle, competitions, travel, injury recovery, and periods of environmental stress. This multifactorial nature has implications for monitoring practices. A laboratory-based psychological assessment may provide useful insight into the athlete's psychology but may miss changes that happen throughout the week or just before or after training. Likewise, a single physiological measure may not capture the interaction between sleep, training load, illness, psychological stress, hydration, environmental conditions, and recovery. Research on athlete monitoring has shown that subjective measures can be highly sensitive to changes in training and well-being. A systematic review comparing subjective and objective monitoring approaches reported that subjective measures often showed greater sensitivity and consistency to changes in acute and chronic training load than commonly used objective measures.

The findings support the use of subjective information either independently or alongside objective monitoring. This does not mean that objective measures are not needed. Rather, it shows that different monitoring systems provide complementary information. Wearable devices have expanded the ability to collect physiological and behavioral information outside a lab. Modern systems can estimate heart rate, HRV, activity, sleep time, sleep timing, sleep consistency and other variables. At the same time, smartphone-based ecological momentary assessment can repeatedly collect psychological information while the athlete is living and training in their natural environment. The convergence of these technologies is of particular interest to the field of sports psychology. Psychological readiness has traditionally been assessed through questionnaires administered at specific time points, particularly in the context of injury rehabilitation and return-to-sport.

A 2025 systematic review identified 62 studies examining psychological readiness scales and reported that psychological readiness measures have been studied in relation to physical recovery, return to sport, quality of life, reinjury, and post-return performance. Sleep represents another important component of this framework. Athlete sleep is influenced by training schedule, competition, travel, environmental conditions, psychological stress, and individual characteristics. Expert consensus recommends an individualized approach rather than assuming that a single target of sleep duration is appropriate for all athletes. Accordingly, the emerging question is not simply whether an athlete slept adequately or whether HRV changed from the previous day. A more interesting question is whether changes in psychological experience, sleep, and autonomic regulation happen together, and whether their combined patterns provide any useful information about individual recovery and readiness.

ABBREVIATIONS

Abbreviation	Definition
ANS	Autonomic nervous system
EMA	Ecological momentary assessment
HR	Heart rate
HRV	Heart-rate variability
mHealth	Mobile health
RMSSD	Root mean square of successive differences
RHR	Resting heart rate
RTS	Return to sport
PSG	Polysomnography
AI	Artificial intelligence
ML	Machine learning
SD	Standard deviation
CNS	Central nervous system

Psychological readiness as a dynamic construct

Psychological readiness is a multidimensional concept including perceptions of confidence, fear, motivation, self-efficacy, emotional state, and perceived ability to participate in sport. It has received particular attention in injury rehabilitation and return-to-sport research. The recent systematic review by Liu and Noh synthesized 62 studies examining psychological readiness scales in relation to return-to-sport outcomes. The authors categorized the evidence into domains including physical recovery, return to sport practice, quality of life and reinjury, and post-return sport or physical-activity outcomes. Although these findings establish the

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relevance of psychological readiness, an important methodological question remains: when should psychological readiness be measured? A single assessment could be useful for clinical or research decision-making, but athlete psychology is necessarily dynamic. Confidence can change following training, injury-related pain, poor sleep, competitive pressure, interpersonal events, travel, or perceived performance success. Repeated assessment may therefore provide additional temporal information. This does not mean that every athlete should complete lengthy questionnaires several times each day. Rather, short validated measures could be incorporated into monitoring systems at strategically selected time points.

Athlete mental health and the need for responsible monitoring

The increasing interest in athlete psychological monitoring also reflects a broader recognition of mental health in sport. Cosh et al. conducted a systematic review and meta-analysis of athlete mental-health help-seeking and found a pooled formal help-seeking proportion of 22.4% across 11 studies reporting help-seeking rates. The review identified sporting culture, concerns regarding selection, stigma, and confidentiality as barriers. These findings are important for digital monitoring because collecting psychological information does not necessarily equate to psychological care. Wearables and digital questionnaires can identify patterns requiring attention, but they should not be treated as autonomous diagnostic systems. A monitoring system identifying elevated stress, disturbed sleep, or altered HRV should therefore support communication between athletes and appropriately trained professionals rather than replacing clinical assessment.

METHODOLOGY

Review Design

This study adopted a focused narrative review design to examine the integration of wearable technologies, psychological readiness, sleep monitoring, autonomic recovery, and ecological momentary assessment (EMA) in sports psychology. The purpose was to critically synthesize relevant literature, compare the strengths and limitations of existing monitoring approaches, and identify gaps for future research. A narrative approach was considered appropriate because the reviewed literature includes different study designs, populations, measurement instruments, wearable devices, and psychological and physiological outcomes. The review was not designed to estimate pooled effect sizes or establish causal relationships. Therefore, no quantitative meta-analysis was conducted.

Literature Search Strategy

PubMed served as the principal biomedical database. Additional relevant literature was identified through targeted searches of peer-reviewed publications and publisher databases, together with screening of reference lists from relevant articles and reviews. The literature published predominantly between 2015 and 2026 was prioritized, while selected earlier publications were retained when they provided foundational evidence on heart-rate variability (HRV), athlete monitoring, sleep assessment, or measurement methodology.

The search strategy was organized around the following concepts: athlete monitoring, psychological readiness, sports psychology, sleep, autonomic recovery, wearable technology, and ecological momentary assessment. Search terms included combinations of the following keywords:

("athlete*" OR "sport*" OR "athletic performance") AND ("psychological readiness" OR "psychological state" OR "stress" OR "anxiety" OR "mood" OR "motivation" OR "well-being") AND ("sleep" OR "sleep quality" OR "sleep consistency") AND ("heart rate variability" OR "HRV" OR "resting heart rate" OR "autonomic recovery") AND ("wearable technolog*" OR "wearable sensor*" OR "ecological momentary assessment" OR "EMA" OR "mobile health" OR "mHealth").

These concepts were used flexibly across the literature searches to identify studies addressing one or more relevant dimensions of athlete monitoring. Reference-list screening was used to identify additional relevant publications that might not have been retrieved through the initial searches.

Study Selection Criteria

Studies were considered eligible when they met the following criteria:

Included athletes, sport-related populations, or populations providing relevant methodological evidence for athlete monitoring.

Examined at least one relevant domain, including psychological readiness, stress, anxiety, mood, motivation, resilience, sleep, HRV, resting heart rate, wearable-derived measurements, EMA, or recovery.

Reported empirical findings, measurement or validation evidence, systematic reviews, scoping reviews, narrative syntheses, or relevant consensus recommendations.

Provided information relevant to psychological or physiological monitoring, sleep assessment, recovery, or athletic performance.

Were published in peer-reviewed sources, with priority given to literature published between 2015 and 2026.

Studies were excluded from the main synthesis when they focused exclusively on biomechanical or physical-performance variables without a meaningful connection to psychological state, sleep, autonomic regulation, wearable monitoring, or recovery. Publications that did not provide sufficient relevance to the review objectives were also not emphasized.

Screening and Rationale for Study Inclusion

The literature was selected purposively according to its relevance to the objectives of the review. Titles and abstracts were considered first, followed by examination of the full text of potentially relevant publications. Reference-list screening was also used to identify additional studies addressing the relationship between psychological, sleep-related, autonomic, and wearable-derived measures.

The selected literature was organized into thematic categories: (1) subjective psychological monitoring; (2) sleep and athletic

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performance; (3) HRV and autonomic recovery; (4) wearable-device measurement and validity; (5) EMA and mobile-health monitoring; (6) multimodal monitoring and individualized baselines; and (7) ethical considerations and future technological applications.

Studies were prioritized when they provided direct evidence from athlete or sport-related populations, evaluated the validity or limitations of monitoring methods, or offered systematic evidence relevant to the review questions. Research conducted in general populations was included selectively when it offered methodological insights into wearable-based digital phenotyping or machine-learning approaches. Such findings were interpreted cautiously and were not assumed to demonstrate equivalent effectiveness in athletes.

Evidence Synthesis and Methodological Limitations

A qualitative thematic synthesis was undertaken to compare the principal findings, methodological strengths, limitations, and practical implications of the selected literature. Particular attention was given to differences between subjective self-reports and objective physiological measurements, the validity of wearable-derived sleep estimates, the interpretation of HRV, and the extent to which monitoring approaches had been evaluated against meaningful psychological or performance outcomes.

As this was a focused narrative review rather than a systematic review, no formal PRISMA-based selection process, registered protocol, quantitative meta-analysis, or formal risk-of-bias assessment was undertaken. The review therefore provides a critical overview of relevant evidence rather than an exhaustive or quantitatively weighted assessment of all available studies. The absence of a formal systematic screening procedure and the use of targeted literature searches may have resulted in the omission of relevant publications. These limitations should be considered when interpreting the findings and recommendations.

MAIN REVIEW CONTENT

Subjective monitoring remains essential

The development of wearable technologies must not replace athlete self-report. Subjective measures provide information which cannot necessarily be obtained from heart rate or movement sensors.

Examples include: perceived recovery, fatigue, muscle soreness, stress, mood, motivation, confidence, perceived sleep quality, anxiety, perceived readiness and general well-being.

The systematic review by Saw et al. demonstrated that subjective measures can be sensitive to training-related changes, and may sometimes provide more consistent information than objective measures. The observation is particularly relevant to psychological readiness. An athlete may have apparently normal resting HRV while reporting low confidence or elevated competitive anxiety. Meanwhile, an athlete may report good psychological readiness despite physiological indicators of inadequate recovery. The disagreement between measures should not be interpreted as measurement failure. Instead, discordance may be valuable information.

For example, high subjective readiness + stable HRV + adequate sleep may represent a relatively coherent recovery profile whereas high subjective readiness + reduced sleep + altered HRV may require contextual interpretation.

Multimodal monitoring should not only consider agreement between measures, but also clinically and practically meaningful discordance.

Sleep as a bridge between psychological and physiological recovery

Sleep is one of the most important components of athlete recovery. Sleep impacts cognitive functioning, mood, physiological restoration, immune function, and physical performance. A systematic review of athlete sleep demonstrated considerable variation in sleep characteristics according to age, sex, sport type, athletic expertise, and training season. Sleep monitoring can be performed subjectively and objectively. Common approaches include sleep diaries, sleep questionnaires, actigraphy, wearable devices, polysomnography, smartphone-based monitoring and combined sleep-wake algorithms.

A systematic review of sleep-quality monitoring in individual sports identified actigraphy, Likert-type ratings, and sleep diaries as commonly-used approaches, but also noted substantial variation in how sleep variables are defined. This heterogeneity is key when interpreting wearable-derived sleep data. Consumer devices do not provide equivalent measurements, and estimates should not be automatically interpreted as being equivalent to polysomnography. A validation study of elite athletes found that activity monitors could demonstrate good sleep-wake agreement with polysomnography under some conditions, but could underestimate sleep duration and overestimate wake time depending on the algorithm and threshold used.

Consequently, wearable sleep data may be very helpful for longitudinal monitoring, but the purpose of the measurement should be considered. A device could be more helpful in identifying an athlete's individual trend, than for making precise clinical statements about sleep structure.

Sleep and athletic performance

The relationship between sleep and performance has received increasing research attention. Cunha et al. systematically reviewed sleep interventions and athletic performance, and highlighted the increasing interest in interventions to modify sleep in athletes. Similarly, research on sleep extension suggests that athletes can often increase habitual sleep time, but the magnitude of performance improvement varies depending on the outcome assessed. Recent wearable research provides an example of how large-scale longitudinal monitoring may be applied. Grosicki et al. analyzed wearable-derived sleep and physiological data from 389 male professional golfers across 521 events and 35,140 nights. Longer and more consistent sleep, lower resting heart rate, and higher HRV were associated with better golf performance. Within-athlete analyses also identified

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associations between changes in sleep consistency, HRV, recovery metrics, and golf scores. These findings are important, but should be interpreted as associations rather than proof that changing a single wearable variable will necessarily lead to a change in performance. These findings illustrate the potential value of within-athlete analysis. Instead of asking if athletes with higher HRV perform better than athletes with lower HRV, future monitoring research can ask, does a meaningful deviation from an athlete's own normal sleep or HRV pattern correspond with changes in that athlete's psychological state or performance? This individualized approach may be more relevant to applied sports psychology.

Heart-rate variability and autonomic recovery

HRV represents beat-to-beat variation in cardiac intervals, and is commonly-used as a non-invasive indicator of autonomic regulation. Among commonly-used measures, RMSSD is frequently applied in sports settings due to its ability to be obtained from short recordings that are relatively practical for repeated monitoring. However, HRV is influenced by numerous factors, including: training load, recovery status, sleep, hydration, illness, respiration, posture, measurement time, environmental stress, psychological stress, caffeine and other stimulants and measurement device and processing methodology.

Therefore, a decrease in HRV should not automatically be interpreted as psychological distress or overtraining. Recent methodological work examining HRV monitoring in athletes emphasizes the importance of standardized measurement conditions, repeated observations, and appropriate interpretation of HRV metrics. The recent bibliometric analysis by Wang, Hu, and Yu further demonstrates the rapid expansion of sports HRV research. The analysis included 1,660 publications, and identified athlete monitoring, biofeedback, concussion, anxiety, and endurance exercise as major research areas. The keyword-burst analysis highlighted sleep, machine learning, and anxiety as emerging themes. Thus, the future of HRV research is increasingly connected to psychological and digital monitoring rather than solely to cardiovascular physiology.

HRV and psychological state

One of the most important conceptual distinctions is that HRV is not a direct measurement of psychological readiness. Psychological readiness is a multidimensional psychological construct, whereas HRV reflects cardiac autonomic regulation. There may be associations between stress and autonomic regulation, but the relationship is not one-to-one.

For example,

Psychological stress → autonomic response is biologically plausible, but the observed HRV value is also affected by sleep, physical training, hydration, illness, posture, breathing, and measurement conditions.

Consequently, the preferred model is psychological measures + sleep measures + autonomic measures + training/ environmental context rather than HRV = psychological readiness.

This distinction is critical for responsible sports-psychology applications.

Ecological momentary assessment

Ecological momentary assessment offers an important methodological development as it allows for repeated measurement of psychological experiences in natural environments. Traditional questionnaires may ask an athlete to recall how they felt during the previous week, whereas EMA asks athletes to report their current or recent state at multiple time points. Potential EMA variables include: current stress, mood, anxiety, motivation, perceived recovery, confidence, emotional valence, perceived workload, sleep quality and readiness to train. The 2026 scoping review by Guillen Cots and colleagues examined the use of mHealth-supported EMA for monitoring the stress-recovery process in athletes. The review identified 71 studies published between 2012 and 2025, and found that approximately half involved elite or international athletes.

This growing literature demonstrates that EMA can bring athlete monitoring closer to the real-world context in which psychological experiences actually occur.

Wearable Technologies

Wearable technology includes wrist-worn devices, rings, chest straps, patches, smart garments, and other sensor platforms.

Commonly available measures include:

Domain	Examples of Measures	Potential Relevance
Cardiovascular	HR, RHR, HRV	Autonomic regulation/recovery
Sleep	Duration, timing, consistency, efficiency	Recovery and behavioral rhythm
Activity	Steps, movement, activity duration	Daily behavior
Training	HR zones, workload estimates	Training response
Temperature	Skin temperature	Environmental/physiological context
Respiration	Respiratory rate	Recovery and physiological state
Psychological	Stress scores, self-report	Subjective state
Context	Training, travel, competition	Interpretation

Wearable technology has enabled the possibility of gathering data outside laboratory environments. A 2025 systematic

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review of wearable physiological monitoring and mental health concluded that wearable physiological monitoring is a promising research avenue but called for standardization of measurement and more reliable biomarkers. An integrative review of wearable technologies in sport similarly described the rising trend of using wearables to monitor heart rate, sleep, movement, and other factors.

However, a measurement being available does not necessarily mean that it is valid for all applications.

Digital phenotyping and machine learning

The increasing amount of wearable data has led to an interest in machine learning. Machine-learning models have the theoretical potential to identify non-linear patterns that would be missed by traditional approaches. For example, a model might be able to combine: sleep duration; sleep consistency; HRV; resting heart rate; training load; previous-day stress; mood; environmental exposure; and performance into a composite score.

Recent digital-phenotyping research in the general population demonstrated the ability of using wearable-derived physical-behavior features and machine learning to detect depression and anxiety symptoms. This work used 54 features from wrist- and waist-worn accelerometry and demonstrated classification accuracy in the ballpark of approximately 66-72%. However, evidence from general populations cannot be directly extrapolated to athletes. Athletes differ from the general populations in terms of training, physiology, schedules, and stressors. Therefore, sport-specific validation must occur before machine-learning systems can be used for psychological interpretation.

A 2026 bibliometric HRV analysis also identified machine learning as an emerging direction in sports HRV research.

Multimodal monitoring and individualized baselines

The key limitation of population-level thresholds is that athletes differ substantially from one another. For example, the same HRV value represents a normal state for one athlete but a significant deviation from the norm for another.

The same goes for: resting heart rate; sleep duration; sleep consistency; perceived stress; training tolerance; and psychological readiness. Instead, individualized baselines may be more informative than population-level thresholds.

A practical monitoring model could involve:

Step 1: Establish baseline: Collect several weeks of data during relatively stable training.

Step 2: Identify normal individual variation: Determine the typical range for each variable.

Step 3: Monitor deviations: Identify meaningful departures from the athlete's usual pattern.

Step 4: Add psychological context: Ask the athlete about stress, mood, confidence, motivation, and perceived recovery.

Step 5: Consider environmental and training factors: Interpret the data alongside training load, competition, travel, altitude, heat, illness, academic/work demands, and other relevant factors.

Step 6: Professional interpretation: Where concerning psychological or health-related patterns emerge, appropriate sport, medical, or psychological professionals should be involved.

Psychological readiness and return to sport

The use of multimodal monitoring may be particularly applicable for injury rehabilitation.

Psychological readiness after injury may be inconsistent with objective physical rehabilitation markers. Alternatively, the athlete may show confidence despite physical deficits. The recent systematic review of psychological readiness scales showed that psychological readiness has been investigated in relation to various return-to-sport outcomes.

A future monitoring system could thus include:

Physical rehabilitation indices, psychological readiness, Sleep, HRV, Daily stress, Training exposure.

It would thus not indicate whether an athlete was medically ready to return. It would, however, provide further longitudinal information to clinicians, coaches, and sport psychologists.

Environmental Stress And Autonomic Monitoring

Environmental conditions can significantly impact psychological and physiological recovery.

Altitude is an established example, as demonstrated by Pirlot et al., who explored psychological, sleep, and HRV responses during early- and middle-term acclimatization to a living-high-training-low-and-high protocol. The study exemplifies the importance of analyzing the interplay between domains: psychological, sleep, and autonomic variables were examined together rather than individually.

This would be particularly applicable to athletes exposed to: altitude; heat; humidity; long-distance travel; jet lag; competition congestion; and unusual training environments.

Environmental exposure can impact sleep, autonomic modulation, and psychological experiences. Thus, it should be incorporated in multimodal monitoring, whenever feasible.

Esports and non-traditional athlete populations

The idea of autonomic monitoring can extend to non-traditional physical sports.A systematic review of HRV in esports identified stress and gaming-related outcomes as major topics of investigation, while underscoring methodological limitations of the published literature.

Esports athletes are likely to have distinctive combinations of: prolonged screen exposure; irregular sleep; competitive stress; cognitive workload; sedentary behavior; high-frequency competition; and psychological pressure. Thus, future multimodal monitoring research can be applicable to both traditional athletes and esports players, though with different measurement considerations.

Evidence Summary

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Study	Population / Setting	Monitoring or Assessment Approach	Main Variables	Key Evidence / Contribution	Relevance to Present Review
Cosh et al. (2024)	Elite, collegiate and professional athletes	Mental-health assessment and help-seeking measures	Mental health, psychological distress, help-seeking	Synthesised 22 studies and found substantial variation in athletes' mental-health help-seeking, with sport-specific barriers including stigma, selection concerns and confidentiality.	Supports the need for routine and context-sensitive psychological monitoring in athletes.
Reinebo et al. (2024)	Competitive athletes	Psychological intervention studies	Psychological well-being, mental health and performance-related outcomes	Evidence indicates that psychological interventions can influence mental-health and well-being outcomes in competitive athletes.	Provides the psychological basis for monitoring readiness and well-being alongside physical variables.
Walsh et al. (2021)	Athletes and athletic populations	Consensus-based sleep assessment and monitoring	Sleep duration, timing, quality and regularity	Established sleep as an important component of athlete health, recovery and performance and highlighted the importance of adequate sleep monitoring.	Supports sleep as a central component of athlete recovery monitoring.
Cunha et al. (2023)	Athletes	Sleep interventions and performance assessment	Sleep, recovery and athletic performance	Systematic evidence indicates that sleep interventions may influence aspects of athletic performance and recovery, although study methods and outcomes vary.	Supports integrating sleep monitoring with performance and recovery assessment.
Shaffer & Ginsberg (2017)	Clinical and healthy populations	Heart-rate variability measurement	HRV, RMSSD and autonomic activity	Described major HRV measures and methodological considerations relevant to interpreting autonomic activity.	Provides the physiological basis for using HRV as a complementary recovery indicator.
Liu & Noh (2025)	Athletes returning from sports injury	Psychological readiness scales	Psychological readiness, confidence and return-to-sport outcomes	Systematic review examined the predictive utility of self-reported psychological readiness measures following injury.	Demonstrates that psychological readiness can be operationalised and monitored using validated instruments.

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Crosley-Lyons et al. (2023)	Physically active/ general populations	Ecological Momentary Assessment (EMA)	Affect, motivation and psychological state	EMA allows psychological states to be assessed repeatedly in real-world contexts rather than relying only on retrospective questionnaires.	Supports repeated, ecologically valid monitoring of psychological readiness.
Haag et al. (2025)	Adults / active populations	EMA and contextual assessment	Affect, stress and behavioural context	Demonstrates the value of repeated in-the-moment assessment for identifying temporal variation in psychological states.	Supports combining EMA with wearable-derived physiological data.
Pirlot et al. (2025)	Elite endurance athletes	HRV and sleep monitoring	HRV, sleep and adaptation/recovery	Demonstrated the potential value of longitudinal physiological monitoring during environmental and training challenges.	Supports monitoring changes over time rather than relying on single measurements.
Grosicki et al. (2026)	389 professional male golfers across 521 events	Wearable-derived sleep and physiological monitoring	Sleep duration, sleep consistency, HRV, RHR and recovery	Analysed 35,140 nights of wearable data and examined associations between sleep/physiological metrics and professional golf performance.	Provides direct athlete evidence for integrating wearable sleep and autonomic measures with performance monitoring.
Sameh et al. (2026)	General population	Wearable sensors + machine learning	Sleep/physical behaviour and mental-health indicators	Demonstrated the potential of wearable-derived behavioural signals combined with machine learning for identifying mental-health-related patterns.	Provides methodological support for future multimodal prediction models in sports psychology.
Wang et al. (2026)	Sports-science literature	HRV monitoring and machine-learning approaches	HRV, autonomic regulation and predictive analytics	Reviewed the expanding application of HRV and computational approaches within sports science.	Supports the transition from simple monitoring toward multimodal and data-driven interpretation.
Guillen Cots et al. (2026)	Sports populations	mHealth and Ecological Momentary Assessment	Stress, recovery, psychological state and contextual variables	Scoping review identified growing use of technology-supported EMA for assessing stress-recovery processes in sports.	Directly supports the integration of EMA/mHealth with wearable monitoring for longitudinal athlete assessment.
Zhang et al. (2025)	High-level athletes	Psychological intervention and repeated assessment	Mindfulness, anxiety, resilience and well-being	Provides evidence that psychological factors can change	Supports monitoring psychological states

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				in response to structured psychological interventions.	as dynamic rather than fixed characteristics.

Research question	Possible variables
Does reduced sleep correspond with psychological stress?	Sleep duration + EMA stress
Does HRV change alongside perceived recovery?	RMSSD + recovery score
Does sleep consistency relate to performance?	Sleep regularity + performance
Does psychological readiness fluctuate across rehabilitation?	Readiness scale + training status
Do environmental stressors influence recovery?	Altitude/heat + sleep + HRV + stress
Can multimodal variables predict next-day readiness?	HRV + sleep + mood + stress
Can individualized baselines improve monitoring?	Within-athlete deviations + outcomes

Examples Of Multimodal Monitoring Questions

DISCUSSION

The reviewed literature indicates that athlete monitoring is most informative when psychological self-reports, sleep-related measures, autonomic indicators, and training context are considered together. However, the strength of evidence differs across these domains. Some findings are supported by systematic reviews and empirical athlete studies, whereas other applications, particularly automated psychological-readiness prediction using multimodal wearable data, remain prospective research directions.

Comparison of Subjective and Objective Monitoring

Subjective monitoring remains an important component of athlete assessment. Saw et al. (2016) reported that subjective self-reported measures were often more sensitive to changes in training response than commonly used objective measures. This finding supports the inclusion of perceived fatigue, stress, mood, recovery, and readiness in athlete-monitoring programmes. Nevertheless, it does not establish that subjective assessments are universally superior to physiological measurements. Their usefulness depends on the construct assessed, the measurement instrument, the population, and the timing of assessment.

Wearable-derived measurements provide complementary information by documenting physiological and behavioural patterns over time. For example, HRV and resting heart rate may contribute information about autonomic regulation, while wearable-derived sleep measures can describe sleep timing and regularity. However, these measurements do not directly reveal an athlete's confidence, motivation, anxiety, or perceived readiness. Consequently, subjective and objective measures should be treated as complementary sources of information rather than competing alternatives.

Differences between subjective and objective findings also require careful interpretation. An athlete may report good readiness despite altered HRV, or report substantial fatigue despite relatively stable physiological indicators. Such disagreement may reflect different aspects of recovery, environmental influences, measurement error, or individual variation. Future empirical research should investigate whether these discrepancies provide useful information about subsequent readiness or performance rather than assuming that agreement between measures is always necessary.

Sleep Monitoring and Athletic Performance

Sleep is an important component of athlete recovery, but the evidence must be interpreted according to the study design and measurement approach. Walsh et al. (2021) emphasized individualized sleep assessment, while Cunha et al. (2023) reviewed the effects of sleep interventions on athletic performance. These publications support the importance of sleep in athlete health and recovery, although the effects of interventions may vary according to the intervention, population, and performance outcome assessed.

Grosicki et al. (2026) examined wearable-derived sleep and physiological measures among 389 professional male golfers across 521 events and 35,140 nights. Their findings demonstrated associations between sleep characteristics, HRV, resting heart rate, recovery-related measures, and golf performance. The large longitudinal dataset provides relevant athlete-specific evidence for examining relationships between wearable-derived measures and performance. However, the observational nature of these associations does not establish that changes in a particular wearable measurement cause improved performance. The findings may also have limited generalizability to female athletes, younger athletes, amateur participants, and athletes from other sports.

The validity of sleep measurements represents an additional limitation. Wearable devices use different sensors and algorithms, and their estimates are not necessarily equivalent to polysomnography. Differences in sleep definitions, device characteristics, and validation procedures make direct comparisons between studies difficult. Therefore, wearable sleep monitoring may be useful for examining individual trends, but precise claims about sleep stages or clinical sleep conditions require appropriate validation.

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HRV and Psychological Readiness

HRV is a useful non-invasive measure of cardiac autonomic regulation, but it should not be interpreted as a direct measure of psychological readiness. HRV is influenced by several factors, including physical training, sleep, respiration, hydration, illness, posture, measurement time, and environmental and psychological stress. Consequently, a reduction in HRV cannot independently establish psychological distress, inadequate recovery, or overtraining.

The literature on athlete monitoring supports the potential value of repeated HRV measurements under standardized conditions. Nevertheless, methodological differences between devices, recording durations, processing algorithms, and measurement protocols can limit comparability. Individualized baselines may help researchers identify deviations from an athlete's usual pattern, but the practical significance of these deviations must be established against relevant psychological, physiological, or performance outcomes.

The central distinction is that HRV provides physiological information, whereas psychological readiness represents a multidimensional psychological construct. Although associations may occur between these domains, the available evidence does not justify replacing validated psychological assessments with HRV measurements. A more defensible approach combines HRV with self-reported stress, confidence, perceived recovery, sleep, and contextual information.

EMA and Real-World Psychological Monitoring

Ecological momentary assessment offers a method for repeatedly assessing psychological experiences in athletes' natural environments. Unlike retrospective questionnaires, EMA can capture changes in stress, mood, motivation, and perceived recovery close to the time they occur. The scoping review by Guillen Cots et al. (2026) identified growing use of technology-supported EMA in athlete stress-recovery monitoring.

However, the feasibility of repeated data collection should be distinguished from evidence of predictive effectiveness. EMA may improve the temporal detail of psychological assessment, but frequent questionnaires can increase participant burden, reduce adherence, and generate missing observations. Moreover, repeated measurements do not automatically produce accurate predictions of readiness or performance.

The most appropriate interpretation is that EMA provides a promising complementary method for understanding fluctuations in psychological state. Whether combining EMA with wearable-derived sleep and autonomic measurements improves prediction beyond established self-report and performance measures requires direct empirical testing.

Wearable Technologies and Machine-Learning Applications

Wearable technologies enable repeated measurement of physiological and behavioural variables outside laboratory settings. Nevertheless, the availability of a measurement does not establish its validity for every intended application. Device-specific algorithms, sensor accuracy, data-processing procedures, and differences between populations may affect the reliability and interpretation of collected data.

Machine-learning approaches may eventually help identify complex relationships among sleep, HRV, resting heart rate, training load, mood, stress, and subsequent performance. However, this possibility should be distinguished from demonstrated effectiveness in sports psychology. Sameh et al. (2026) investigated wearable-derived physical-behaviour features and machine learning for identifying depression and anxiety symptoms in a general population. Such findings provide methodological context, but they cannot be directly generalized to athletes because athletic training, physiological adaptation, competition schedules, and psychological demands differ from those of the general population.

Before machine-learning models are used to estimate psychological readiness, they require sport-specific validation, adequate sample sizes, transparent reporting, and testing in independent populations. Researchers should also compare model performance against simpler approaches, including validated questionnaires and individualized baseline monitoring. Without such comparisons, a complex model may add technical complexity without providing meaningful improvements in decision-making.

Critical Synthesis and Practical Implications

Taken together, the reviewed evidence supports the complementary roles of subjective psychological assessments, sleep monitoring, and autonomic measurements. However, the strength of evidence is not uniform. Systematic reviews provide broader evidence regarding subjective monitoring, sleep, and psychological readiness, while individual observational studies provide more context-specific findings. Wearable validation research identifies important measurement limitations, and emerging digital-phenotyping studies suggest possible future applications rather than established athlete-monitoring solutions.

Three implications follow from this synthesis. First, established assessment methods should remain central to monitoring psychological readiness. Second, wearable-derived variables should be interpreted in relation to individual baselines, measurement quality, training conditions, and psychological self-reports. Third, predictive applications should be introduced only after their accuracy, reliability, and practical value have been evaluated in the intended athletic population.

The concept of minimum sufficient monitoring is therefore relevant: collecting a smaller number of valid, interpretable, and actionable measures may be more useful than collecting numerous variables without a clear purpose. Monitoring systems should also minimize unnecessary data collection and protect athlete privacy, particularly when information could influence selection, playing time, contracts, or access to support.

Research Gaps and Future Applications

Several research questions remain unresolved. Longitudinal studies should determine whether within-athlete changes in

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sleep, HRV, and psychological self-reports are associated with meaningful changes in readiness and performance. Researchers should also examine whether multimodal models improve prediction beyond validated psychological questionnaires and conventional monitoring approaches.

Future studies may investigate personalized alerts, machine-learning-based readiness estimates, and real-time integration of wearable data with EMA. At present, these applications should be regarded as proposed research directions rather than established methods for psychological diagnosis or performance decision-making. Their clinical and practical utility requires prospective validation, external testing, explainable outputs, and assessment of potential harms.

Further research should include more diverse athlete populations, particularly female athletes, youth athletes, and participants from different sporting contexts. Studies should also report device validity, missing-data procedures, adherence, measurement burden, and ethical safeguards. These developments would help establish whether integrated wearable and psychological monitoring can improve athlete support beyond what is already achieved through established assessment practices.

Methodological Challenges

Measurement validity

Wearables are not interchangeable. Different algorithms, sensors, sampling rates, proprietary analyses, and definitions can generate different data. Therefore, researchers should report: the manufacturer of the device; the model of the device; the site of measurement; the sampling rate, if available; the algorithm; the length of the recording; when the measures were taken; procedures for cleaning the data set; and how missing data are handled.

Reliability and standardization

HRV is sensitive to measurement conditions.

Researchers should consider: Time of day; body position; respiratory conditions; duration of recording; recent exercise; caffeine; hydration; illness; and sleep. Repeated measures collected under standardized conditions may be more interpretable than sporadic measures collected under uncontrolled conditions.

Psychological measurement burden

Repeated psychological assessment may be burdensome. Should athletes be required to complete long questionnaires several times per day, adherence may be poor. Short validated instruments and carefully selected measurement times may therefore be preferable.

EMA systems should balance: measurement frequency with participant burden and information value.

Missing data

Monitoring of athletes in real-world settings may necessarily entail missing data.

Reasons may include: removal of device; charging; travel; technical problems; sleep without device use; competition restrictions; and participant fatigue.

Future research should transparently report missingness and use appropriate statistical approaches rather than simply deleting or discarding incomplete observations.

Ethical And Privacy Considerations

Digital athlete monitoring generates potentially sensitive information. Psychological data, sleep patterns, physiological values, and behavioral information may reveal information about an athlete's health and daily life.

Therefore, monitoring programs should establish: informed consent; data minimization; secure data storage; clear access permissions; transparent data ownership; clear retention periods; athlete rights regarding data; appropriate interpretation procedures; and safeguards against inappropriate selection or employment decisions. This is especially important in professional sport, wherein monitoring data may influence selection, contracts, playing time, or perceived value of an athlete. Psychological information should not be collected simply because technology makes collection possible. The purpose of monitoring should be clearly established before data are collected.

Future Research Directions

Several areas require further investigation.

Longitudinal within-athlete research

Future studies should move beyond cross-sectional comparisons and examine individual trajectories across weeks, months, training cycles, and competitive seasons.

Multimodal models

Studies should investigate combinations of:

psychological + sleep + HRV + training + environmental + performance data

rather than evaluating each variable independently.

Individualized thresholds

Research should assess whether individual baselines provide more informative information than universal cut-off values.

Female athletes

Future studies should ensure adequate representation of female athletes as sleep, hormonal factors, training demands, and psychological experiences may differ across individuals and contexts. Existing sleep literature demonstrates the importance of examining sex-specific research.

Youth athletes

Wearable monitoring in adolescent athletes requires additional ethical considerations because psychological development, consent, privacy, and safeguarding differ from adult populations.

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Machine learning and explainability

Machine-learning systems should not only demonstrate predictive performance, but should provide interpretable outputs and transparent validation.

Clinical integration

Future research should establish how monitoring information can integrate well with sport psychologists, physicians, physiotherapists, strength and conditioning professionals, and coaches.

Prospective Validation of Integrated Monitoring Systems

Future research should prospectively evaluate whether combining wearable-derived sleep and autonomic measures with EMA-based psychological assessments improves the identification of changes in athlete readiness. Such studies should compare multimodal models against validated psychological questionnaires and conventional monitoring approaches. Independent validation, transparent reporting of prediction errors, appropriate handling of missing data, and evaluation across different sports and athlete populations are necessary before these systems can be recommended for routine decision-making. Researchers should also assess whether monitoring-based alerts lead to meaningful improvements in athlete support without increasing psychological burden, compromising privacy, or encouraging inappropriate selection decisions.

CONCLUSION

Wearable and ecological monitoring represent an emerging intersection at the confluence of sports psychology, psychophysiology, sleep science, digital health, and athlete performance research. Current evidence reveals that psychological readiness, subjective wellbeing, sleep, HRV, and resting heart rate represent different types of information about the athlete. Psychological measures capture subjective experiences; sleep monitoring provides information about behavioral recovery; HRV provides information about regulation of the autonomic nervous system; and wearable systems enable repeated measurement in real-world settings. Recent evidence from professional sport demonstrates the feasibility of collecting large volumes of wearable-derived sleep and physiological data, while emerging EMA and mHealth literature demonstrate the possibility of repeatedly capturing psychological and recovery experiences in natural environments. Nevertheless, wearable measurements should not be interpreted as direct substitutes for psychological assessment or clinical evaluation. HRV should not be equated to psychological readiness, and consumer wearable sleep estimates should not automatically be interpreted as equivalent to laboratory based sleep assessment. The most promising area for future research is therefore not the replacement of psychological assessment by technology but the integration of subjective and objective information. Future longitudinal research should examine individualized baselines, multimodal measurement, within-athlete variation, machine-learning approaches, female and youth athlete populations, environmental stressors, privacy, and professional interpretation. A carefully designed multimodal system may therefore ultimately allow sports psychologists and interdisciplinary athlete-support teams to understand not only how an athlete is performing, but also how psychological state, sleep, autonomic regulation, and contextual stress interact around performance.

AUTHOR CONTRIBUTIONS

Yogesh Muthuraj: Conceptualization, literature review, evidence synthesis, manuscript preparation, and writing of the original draft.

Sukumaran Clementswami: Supervision, critical review, intellectual input, and manuscript editing.

CONFLICT OF INTEREST

The author declares no conflict of interest related to this manuscript.

REFERENCES

1. Cosh SM, McNeil DG, Jeffreys A, Clark L, Tully PJ. Athlete mental health help-seeking: a systematic review and meta-analysis of rates, barriers and facilitators. Psychol Sport Exerc. 2024;71:102586.
2. Reinebo G, Alfonsson S, Jansson-Fröjmark M, Rozental A, Lundgren T. Effects of psychological interventions to enhance athletic performance: a systematic review and meta-analysis. Sports Med. 2024;54(2):347-373.
3. Walsh NP, Halson SL, Sargent C, Roach GD, Nedelec M, Gupta L, et al. Sleep and the athlete: narrative review and 2021 expert consensus recommendations. Br J Sports Med. 2021;55(7):356-368.
4. Cunha LA, Costa JA, Marques EA, Brito J, Lastella M, Figueiredo P. The impact of sleep interventions on athletic performance: a systematic review. Sports Med Open. 2023;9(1):58.
5. Vlahoyiannis A, Aphamis G, Bogdanis GC, Sakkas GK, Andreou E, Giannaki CD. Deconstructing athletes' sleep: a systematic review of the influence of age, sex, athletic expertise, sport type, and season on sleep characteristics. J Sport Health Sci. 2021;10(4):387-402.
6. Saw AE, Main LC, Gastin PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. Br J Sports Med. 2016;50(5):281-291.
7. Liu S, Noh YE. The utility of psychological readiness scales in predicting return to sport: a systematic review. BMC Psychol. 2025;13:1213.
8. Shaffer F, Ginsberg JP. An overview of heart rate variability metrics and norms. Front Public Health. 2017;5:258.
9. Wang Z, Hu J, Yu W. Mapping HRV in sports science: from monitoring to machine learning. Front Sports Act Living. 2026;7:1714962.
10. Grosicki GJ, von Hippel W, Fielding F, Kim J, Chapman C, Holmes KE. Wearable-derived sleep and physiological metrics are associated with performance in professional golfers. Int J Sports Physiol Perform. 2026;21:180-191.
11. Guillen Cots J, Capdevila L, Losilla JM, Parrado E. Ecological momentary assessment of the stress-recovery process through technology mHealth in sports: a scoping review. BMC Sports Sci Med Rehabil. 2026;18:199.

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12. Sameh A, Nauha L, Seppänen M, Niemelä M, Oussalah M, Korpelainen R, et al. Digital phenotyping using wearable-determined physical behaviours and machine learning to detect depression and anxiety symptoms in a general population. Psychiatry Res. 2026;364:117242.
13. Welsh MR, Mosley E, Laborde S, Day MC, Sharpe BT, Burkill RA, et al. The use of heart rate variability in esports: a systematic review. Psychol Sport Exerc. 2023;69:102495.
14. Silva AC, Facundo LA, Amaral AS, Borba DA, Rosa JPP, Silva A, et al. Evolution of research on elite adult athlete sleep: a systematic review. Int J Sports Exerc Med. 2021;7:204.
15. Miles KH, Clark B, Fowler PM, Miller J, Pumpa KL. What are the sleep characteristics of elite female athletes? A systematic review with meta-analysis. Biol Sport. 2022;39(3):751-763.
16. Chen F, Zhao L, Pang L, Zhang Y, Lu L, Li J, et al. Wearable physiological monitoring of physical exercise and mental health: a systematic review. Intell Sports Health. 2025;1:11-21.
17. Sekeroglu MO, Pekgor M, Algin A, et al. Transdisciplinary innovations in athlete health: 3D-printable wearable sensors for health monitoring and sports psychology. Sensors. 2025;25(5):1453.
18. The impact of wearable technologies on marginal gains in sports performance: an integrative overview on advances in sports, exercise, and health. Applied Sciences. 2024;14:6649.
19. Monitoring training adaptation and recovery status in athletes using heart rate variability via mobile devices: a narrative review. Int J Mol Sci. 2026.
20. Pirlot T, et al. Psychological, sleep, and heart rate variability responses during early- and middle-term acclimatization of "Living High-Training Low and High". High Alt Med Biol. 2025;26:291-300.
21. Lopez Blanco C, Tyler WJ. The vagus nerve: a cornerstone for mental health and performance optimization in recreation and elite sports. Front Psychol. 2025;16:1639866.
22. Silva AC, Silva A, Edwards BJ, Tod D, Souza Amaral A, de Alcântara Borba D, et al. Sleep extension in athletes: what we know so far—a systematic review. Sleep Med. 2021;77:128-135.
23. Sleep quality monitoring in individual sports athletes: parameters and definitions by systematic review. J Sports Med Phys Fitness. 2021.
24. Sargent C, Lastella M, Halson SL, Roach GD. The validity of activity monitors for measuring sleep in elite athletes. J Sci Med Sport. 2016;19(10):848-853.
25. Wang W, Schweickle MJ, Arnold ER, Vella SA. Psychological interventions to improve elite athlete mental wellbeing: a systematic review and meta-analysis. Sports Med. 2025;55(4):877-897.
26. Crosley-Lyons R, Do B, Hewus M, Dunton GF. An ecological momentary assessment study of affectively-charged motivational states and physical activity. Psychol Sport Exerc. 2023;67:102423.
27. Haag D, Smeddinck JD, Vogelsang A, Blechert J. Contextual and affective precursors of physical activity intention and enactment examined through ecological momentary assessment. Psychol Sport Exerc. 2025;77:102796.

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