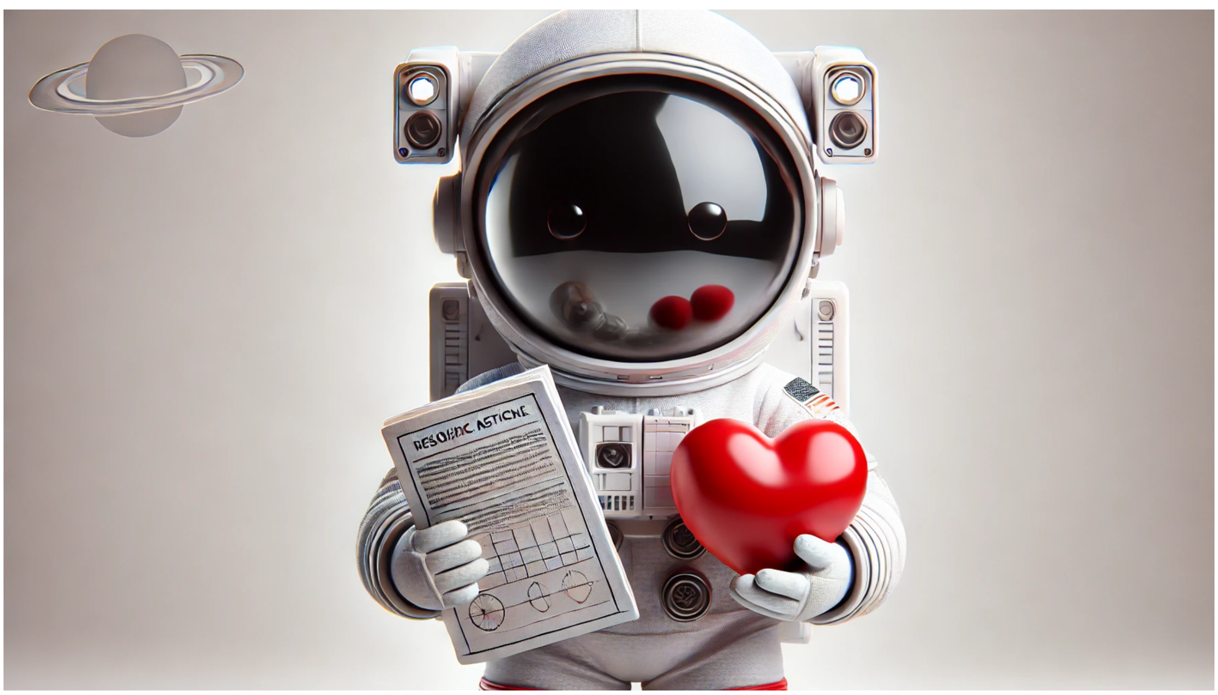
Sports Science 3.0 Series



Data everywhere, insight nowhere: a practical quadrant-based model for monitoring training load vs. response in elite football

Martin Buchheit, [1 2 3 4 5 6] **Karim Hader** [7]

[1]Type 3.2 Performance, Montvalezan, France
[2]Aspetar, Doha, Qatar
[3]Optimo Performance Center, Estepona, Spain
[4]HIIT Science, Revelstoke, Canada
[5]Athletica, Revelstoke, Canada
[6]INSEP, Paris, France
[7]IaM Performance, Lusigny/Barse, France

Training load | Response | Adaptation | Metabolic system | Neuromuscular system | Athlete monitoring | Internal load | External load | Elite football | Sport science framework

Headline

There has never been more research and publications on training load and the associated responses and adaptations, yet this increase has not led to greater clarity. Despite the expanding number of tools and datasets (Cardinale 2017, Seshadri 2021), confusion around terminology, purpose, and application continues to grow, which is a direct consequence of the unchecked growth of sport science 2.0 (Buchheit & Laursen 2024). The evaluation of monitoring tools is often done globally (McGuigan 2021, Woolmer 2025), with all tools treated as if they serve the same purpose, leading to frequent misuse; tools designed to measure load are often used to assess response, and vice versa. For example, over the past years through repeated courses and workshops around the globe, I (MB) have lost count of the number of times I've heard people referring to heart rate (HR) variability (HRV) as a measure of training load, which is clearly incorrect (i.e., HRV is a marker of response and adaptation, Buchheit 2014). Also, while players may prefer GPS to force plate jumps (Woolmer 2025), the two are not interchangeable. GPS helps monitor external load during on-pitch activity, whereas force plate jumps provide insight into neuromuscular performance and fatigue (response to load). Preference doesn't change the fact that each tool serves a distinct purpose. This lack of practical linkage is exactly what drove the writing of this paper. We are collecting more data points, but still failing to connect them meaningfully (Buchheit & Laursen 2024).

While several frameworks have contributed to clarifying why training load and its response should be monitored (Impellizzeri 2023, Gabbett 2017, Gronwald 2020, Vanrenterghem 2017), most have fallen short in addressing the practical task of linking appropriate tools and metrics to each side of the training equation. As a result, they have done little to shift practice, where the focus remains almost exclusively on load, with response often overlooked. Without a clear practical structure, we cannot fully understand the load imposed (the training dose) nor properly evaluate the athlete's response. And if we can't assess the response, we have no basis for adjusting or individualizing training. This is the foundation of any effective monitoring system, yet many approaches fall short by prioritizing technology, data volume, and complexity over clarity, relevance, and the core principles of sport science 1.0 (Buchheit & Laursen 2024).

Aim

This paper presents a framework to distinguish between monitoring of load and monitoring of responses, both acute and medium-to-long-term adaptations. The model is structured along two physiological axes corresponding to the main biological systems: metabolic and neuromuscular (Buchheit & Laursen 2013a & 2013b). It defines four quadrants: 1) metabolic load, 2) neuromuscular load, 3) metabolic adaptation, and 4) neuromuscular adaptation, into which specific technologies, protocols, and test metrics can be mapped. By aligning each tool with its correct function, the quadrant aims to reduce misapplication and improve the precision of player monitoring. We intentionally avoid discussing each technology or metric in depth; that will be the focus of follow-up papers. The purpose here is to clarify the conceptual structure and establish a practical framework for categorizing current and future monitoring approaches.

Sport science 2.0 and the forgotten response

An overview of the literature over the past five decades reveals a clear and growing imbalance in how training is studied: research has increasingly focused on training load, with far less attention given to the athlete's response and adaptation (Figure 1). This trend has accelerated in recent years, driven by the explosion of GPS-based monitoring, a hallmark of sport science 2.0 where technological convenience often overrides physiological relevance (Buchheit & Laursen 2024).

Load is simply easier to track, particularly external metrics like distance covered or velocity, which has led to an overdose of studies centered on what is readily measurable rather than what actually drives adaptation. As we will detail throughout this manuscript, and particularly in our discussion of the neuromuscular load quadrant (Table 3), this shift has come at the expense of quality and insight. Instead of focusing on tools and methods that help us understand the actual training stimulus, sport science 2.0 has prioritized collecting large volumes of data over capturing biological relevance (Buchheit & Laursen 2024).

Focusing on load while ignoring the response is like a musician playing a score without listening to themselves, leaving no opportunity to adjust or improve. Without linking load and response, the critical concept of dose-response is lost (Buchheit 2025c). Irrespective of the biological system, this connection is essential for relevant programming, as it helps identify the minimal effective dose and avoid diminishing returns when the applied load is no longer appropriate.

Conceptual framework: the four-quadrant model

The conceptual framework is structured around two key dimensions (Figure 1).

1. The first distinguishes training load, the "work done", the imposed physical or physiological stress on the body, or input (Buchheit & Laursen 2019a, Impellizzeri 2019, Impellizzeri 2023, McLaren 2022), from the output, the players' response and adaptation, which together capture the body's immediate and longer-term reactions to that load (i.e., dose-response relationship, Buchheit & Laursen 2019b, Impellizzeri 2023, Gabbett 2017, McLaren 2022).
2. The second axis separates the metabolic system, related to energy production and cardiorespiratory function, from the neuromuscular system, which encompasses muscle and tendon activity or strain, and overall structural load (Buchheit & Laursen 2013b).

Together, these dimensions define the four quadrants: 1) metabolic load, 2) neuromuscular load, 3) metabolic response and adaptation, and 4) neuromuscular acute response and adaptation. Figure 1 and Tables 2-5 summarize tools and metrics commonly used to monitor training load (Tables 2 and 3), and acute response and adaptation (Tables 4 and 5) in elite football, organized by physiological quadrant. Each row specifies the type of measure (internal or external load/response metric, tool, and technology associated), its practical applicability in the field, estimated cost, evidence level supporting its use, detailed notes regarding strengths and limitations, and selected and often biased ;) reference sources.

Table 1. Ratio of publications investigating training load vs. training responses. The counts of publications have been obtained from the PubMed website with "training load" and "training response" entered as keywords for searching purposes. A higher ratio indicates more publications investigating training load over training response. Overall, over the 60-year period examined, we identified 3314 publications on load and 547 on response.

	Ratio Training Load/Training Response
All years	**6.1**
2020-2025	12.6
2015-2020	8.0
2010-2015	3.2
2005-2010	2.8
2000-2005	1.2
1995-2000	1.4
1990-1995	1.0
1985-1990	1.1
1980-1985	0.4
1975-1980	0.2
1970-1975	0.0

Differentiating internal and external metrics to assess load and adaptation

Across all quadrants, a further distinction applies between external and internal data sources. External load is the athlete's performance outputs (e.g., movement and activity counts during a session, such as meters run, weight lifted, or thrown). Internal load is the relative, within-exercise biochemical (physiological and psychological) and biomechanical consequence of this external load (e.g., oxygen consumption - VO_2, HR, lactate production) (McLaren 2022). While a comprehensive discussion is beyond the scope of this manuscript, readers are referred to more detailed resources on the topic (Buchheit & Laursen 2019a, Impellizzeri 2019, Impellizzeri 2023, McLaren 2022). Importantly, what drives adaptation is internal load, as it reflects the actual biological stresses experienced by the player. External load measures are useful but only serve as indirect proxies. Ideally, monitoring should focus on accurate, system-specific internal markers of both metabolic and neuromuscular load. When that's not feasible, external metrics can be used, but their limitations must be clearly recognized.

Similarly, response and adaptation can be assessed using internal perceptual (e.g., perceived muscle soreness) and physiological markers (e.g., heart rate variability, blood markers) or inferred from external performance indicators (e.g., reactive strength index while performing a counter movement jump, movement velocity) that reflect the underlying biological state.

Temporal considerations in training LOAD, response and adaptation

Measures of load are typically collected during the exercise itself (e.g., locomotor activity via GPS, Buchheit & Simpson 2017 or HR, Achten 2003) or immediately afterward (e.g., session rate of perceived exertion, sRPE, Impellizzeri 2004, McClaren 2022). In contrast, responses can be divided into two subcategories: short-term responses, such as next-day pain, soreness, or change in muscle temperature, and medium-to-long-term adaptations, including increased hemoglobin mass, muscle hypertrophy, HRV, or measurable physiological and performance improvements (Thorpe 20017). While the general principles and tools for monitoring response apply to both timeframes, some metrics are more specific to one than the other. For example, perceived soreness is more commonly used to assess acute responses, whereas measures of physical capacities are typically used to track longer-term adaptation.

The quadrant model: where sport science 3.0 meets common sense

The quadrant-based model shown in Figure 1 provides, for the first time, a structured framework to differentiate between training load and the associated responses and adaptations across metabolic and neuromuscular domains. It follows the principles of sport science 3.0, emphasizing structured, physiology-driven thinking over technology-led monitoring (Buchheit & Laursen 2024). It addresses the conceptual confusion that has proliferated during the rise of sport science 2.0, where an abundance of tools and metrics, often used outside their intended purpose, has blurred the line between input and outcome, and between physiological systems. By clearly defining terms and mapping tools according to their primary function and target system (Buchheit & Laursen, 2019a, 2019b), this model offers a foundation for more consistent and context-appropriate monitoring practices in elite sport.

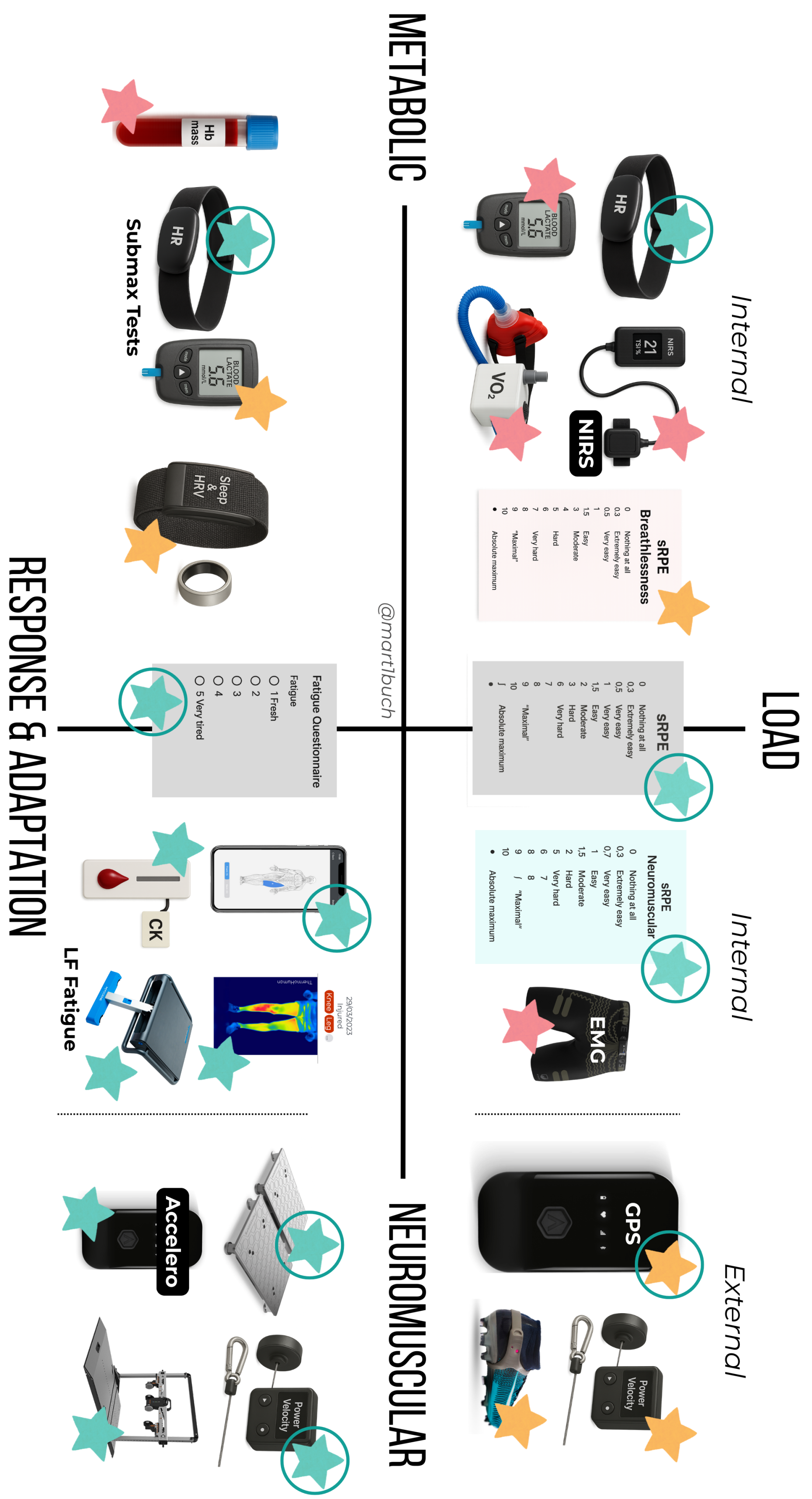

METABOLIC
LOAD
NEUROMUSCULAR
RESPONSE & ADAPTATION
Internal
Internal
External
Submax Tests
LF Fatigue
@martIbuch
Hb mass
HR
VO2
NIRS
Sleep & HRV
sRPE Breathlessness
sRPE
sRPE Neuromuscular
Fatigue Questionnaire
CK
EMG
GPS
Accelero
Power Velocity

Fig. 1. **Quadrant-based representation of available monitoring tools and metrics categorized by physiological domain (metabolic vs. neuromuscular) and purpose (load vs. acute response & adaptation). The color of the stars reflects a combination of validity, practicality, and cost, based on the evaluations in Tables 2–5, ranging from green (ideal) to red (impractical and/or limited). Stars with a circle indicate the recommended practical minimum setup. Non-biological system-specific subjective ratings such as sRPE (load) and sleep, fatigue, mood, or recovery (response) are positioned between quadrants, as they likely reflect, influence or are associated with both metabolic and neuromuscular domains. While sleep is neither a direct metabolic nor neuromuscular response, it serves as both an indicator of overall wellness and a modulator of training response. Poor sleep is typically associated with increased fatigue and reduced training quality, which can ultimately affect the magnitude and direction of adaptation. ADI: athletic data innovation (https://www.adi-data.co/), CK: creatine phosphokinase, EMG: electromyography, GPS: global positioning system, Hbmass: hemoglobin mass, HR: heart rate, HRV: heart rate variability, LF Fatigue: low-frequency fatigue (combination of electrical stimulation and force sensing to measure muscle contractility and low-frequency fatigue), NIRS: near-infrared spectroscopy, sRPE: session rating of perceived exertion, SMFT: submaximal fitness testing, SSG: small-sided games, VO_2: oxygen uptake.**

Table 2. Monitoring tools for metabolic load. This table presents key tools used to assess metabolic load in elite football, categorized by type, practicality, cost, evidence level, and relevant notes. Abbreviations: VO_2max = oxygen uptake, HR = heart rate, sRPE = session rating of perceived exertion, NIRS = near-infrared spectroscopy, GPS = global positioning system.

Quadrant	Type	Tool/ Metric	Practicality	Cost	Evidence Level	Notes	References
Metabolic Load	Internal	VO_2	Very low	High	High	Gold standard for aerobic demands, but totally impractical in elite football environments.	Buchheit & Laursen 2013a
	Internal	Heart rate	Moderate	Low	High	Practical exclusively with known max HR; limitations include dissociation with VO_2, drift, lag at onset/offset, and noise. May over/underestimate VO_2. Better used as a proxy of cardiovascular work than reflecting overall aerobic cost.	Buchheit & Laursen 2013a, Buchheit 2025c
	Internal	Lactate	Low	Moder-ate	High	High evidence for anaerobic system participation when looking at rate of accumulation (rather than end-session values), but not scalable or practical for routine monitoring across a team.	Buchheit & Laursen 2013b
	Internal	NIRS	Low	High	Moderate	Moderate evidence, limited to peripheral relative adjustments (not an absolute measure of muscle VO_2 when exercising freely without occlusion), promising but not viable daily due to cost and setup requirements. Limited validity at high intensities since the signal may reflect more ischemia due to the muscle pump (compression) than real O_2 demands.	Klusiewicz 2021

	Internal	sRPE-Breathlessness	Moderate	Low	High	Low-cost and effective if players are educated and bought in; captures selectively the cardiopulmonary load. Not perfectly calibrated to physiology, though.	Los Arcos 2014, McLaren 2016, McLaren 2022
	Exter-nal	GPS (metabolic power)	High	High	Low	Theoretically appealing but practically irrelevant; fails to accurately assess metabolic demands.	Hader 2016, Buchheit & Simpson 2017

Table 3. Monitoring tools for neuromuscular and overall load. This table lists key tools used to assess neuromuscular load, along with tools capturing overall load in elite football, categorized by type, practicality, cost, evidence level, and relevant notes. Abbreviations: sRPE = session rating of perceived exertion, EMG = electromyography, GPS = global positioning system, MDP = most demanding periods.

Quadrant	Type	Tool/Metric	Practicality	Cost	Evidence Level	Notes	References
Neuro-muscular Load	Internal	sRPE-Neuromuscular	High	Low	Moderate	Low-cost and effective if players are educated and bought in; captures selectively the neuromuscular. Not directly representative of muscle activation or strain though	Los Arcos 2014, McLaren 2016, McLaren 2022
	Internal	EMG (connected shorts)	Very low	High	Moderate	Promising in theory, but lacks sensitivity to eccentric work and is impractical for regular use, and even more at the team level.	Hader 2014, Kalema 2025
	External	GPS	High	Moderate	Low	Overused and misinterpreted; cannot infer muscle/tendon strain. We should at least use MDP exposures and relative thresholds (i.e., % maximal sprinting speed or acceleration)	Buchheit 2024, Buchheit 2025a, Kalkhoven 2021, Mandorino 2924
	External	Accelerome-ters	High	Moderate	Low	Share similar limitations with GPS: metrics such as player load or dynamic stress index reflect only external load. Unlike GPS-derived data, they are not linked to specific movement patterns, making it impossible to associate them with particular muscle groups or infer potential strain	Buchheit 2025a, Buchheit & Simpson 2017, Kalkhoven 2021
	External	Encoder	Moderate	Moderate	Moderate	Can infer work orientation in the gym based on movement speed (e.g., strength vs. power), but limited insight into real biological strain	García-Ramos 2025
Overall Load	Internal	sRPE	High	Low	High	Low-cost and effective if players are educated and bought in; captures both neuromuscular and metabolic load (and likely many other factors, including congitive load)	Impellizzeri 2004, McLaren 2022

Table 4. Monitoring tools for metabolic adaptation. This table presents tools used to assess metabolic adaptations over time in elite football, categorized by type, practicality, cost, evidence level, and relevant notes. Tools include performance-based, internal physiological, and submaximal testing approaches. Abbreviations: VO_2max = maximal oxygen uptake, HR = heart rate, HRV = heart rate variability, SMFT = submaximal fitness testing, SSG = small-sided games.

Quadrant	Type	Tool/Metric	Practicality	Cost	Evidence Level	Notes	References
Metabolic Adaptation	True performance	VO_2max, 30-15IFT, YoYo tets, Bronco	Low	Depends	High	Gold standards for performance, but very low practicality in congested schedules. Poor player buy-in may also reflect a mix of both metabolic and neuromuscular adaptations (e.g., running economy)	Buchheit 2025d
	Internal	Submaximal exercise HR/lactate response	High	Moderate	High	Valid and reliable, feasible option since embedded (Standardized runs) or even invisible (predicted responses to standardized SSG,) for tracking metabolic adaptation over time.	Buchheit 2014 Buchheit 2025d, Mandorino 2025
	Internal	Resting HR / HRV	Moderate	Low	Moderate	Moderate evidence; players not always willing to monitor themselves, influenced by many confounders, including sleep quality and fatigue so not a specific measure of metabolic adaptation.	Buchheit 2014, Plews 2013
	Internal	Hemoglobin mass	Low	High	High	Invasive, costly, and varies with player preference.	Brocherie 2015, Washsmuth 2012

The declining use of HR monitors in favor of GPS

Tables 2 to 5 underscore the trade-offs in current athlete monitoring practices. While VO_2 is the gold standard for assessing cardiopulmonary load (Table 2), HR remains a more practical proxy despite limitations (Buchheit 2015c). It reflects cardiovascular stress but not full cardiopulmonary function. Once the primary metric in the early 2000s (Achten 2003), HR has since been pushed aside, not because it lost value, but because it belonged to the sport science 1.0 era, when physiological tools were applied with clarity and purpose. The shift toward sport science 2.0 brought a wave of technology-led data collection, often at the expense of simpler, more meaningful measures (Buchheit & Laursen 2024). Today, the widespread reliance on GPS technology, while valuable for tracking external load (Table 3), has inadvertently marginalized HR, even though GPS measures a different domain and belongs to a separate monitoring quadrant (Table 2)!! This shift away from HR has several explanations: wearing a chest strap is generally perceived as more uncomfortable than a GPS vest; GPS technology continues to advance in accuracy and usability; and, in contrast, HR measurement has seen little technological improvement in the training field context over the past two decades. The signal remains noisy, and despite the introduction of connected shirts, these are expensive and often degrade quickly after a few washes. As a result, we still struggle to measure HR consistently and reliably in applied settings.

The limitations of GPS in assessing neuromuscular load

Critically, the neuromuscular load quadrant is the weakest (Table 3). While a detailed discussion is beyond the scope of the present paper, locomotor demands measured by GPS remain among the most widely used yet misunderstood metrics in team sports (Buchheit 2025a). The frequent reference to "GPS targets" is particularly problematic. First, because it contradicts the fundamental nature of team sports, where movement is a consequence of tactical and technical actions, not a goal in itself (Verheijen 2025). Running occurs in response to the game/training context; it should not be a target. Drills designed to elicit specific running demands may be useful for match preparation, but these should be programmed collaboratively by coaches and sport scientists, not driven by arbitrary GPS numbers (Buchheit & Verheijen 2024). Second, the term "GPS targets" is misleading: at best, we could refer to "running targets," but referencing the technology itself (GPS) as a target has no physiological or performance basis (Buchheit 2024). A more fundamental issue is that GPS metrics are often used as proxies for neuromuscular load, yet they remain far removed from the biological reality at the muscular or tendon level (Kalkhoven 2021). A limited set of metrics is commonly accepted and used (e.g., total distance, high-speed running >25 km/h, accelerations >3 m/s^2, decelerations >3 m/s^2). Some effort has been made to associate these metrics with specific muscle groups; for example, accelerations with glutes, quads, and hamstrings, and high-speed running with hamstrings... but these associations remain highly simplistic (Buchheit 2024).

Using individual thresholds (e.g., % of maximal sprinting speed or acceleration) and most demanding periods (MDP) during training and matches is currently the least flawed option for inferring neuromuscular demands (Buchheit 2025a). However, even with relative thresholds and MDP, we still lack any direct measure of internal neuromuscular load. These external metrics cannot capture an absolute level of strain. At best, by comparing standardized differences across sessions, such as increased MDP exposure (Mandorino 2024) or more distance covered in a given relative zone, we can suggest that internal load was likely higher. But unlike HR, which offers a quantifiable indicator of cardiovascular strain, GPS-derived data provide only indirect estimates of changes in neuromuscular load and lack a true physiological anchor. Overall, accurately measuring internal neuromuscular load remains one of the biggest challenges in our field, and the continued commercial push toward GPS-only solutions is unlikely to bring us any closer to solving it.

The overlooked value of differential sRPE

While global sRPE is well accepted and widely used (Impellizzeri 2024), its differential forms such as sRPE Neuromuscular (neuromuscular strain) and sRPE Breathlessness (cardiovascular strain) remain largely overlooked in practice (Los Arcos 2014, McLaren 2016, McLaren 2022). These can provide valuable, targeted information and can be applied across both load quadrants to better characterize internal demands. While I (MB) recognize the benefit of isolating these components, we should avoid using too many separate scales in routine monitoring. The global sRPE should be retained as a consistent anchor. Adding sRPE-Neuromuscular selectively, particularly around gym-based or pitch strength-focused sessions, can offer meaningful information without overcomplicating data collection. Given the current lack of accessible tools to assess neuromuscular load (as discussed below and in Table 3), this low-cost addition is a practical step forward.

A stronger foundation on the response side

In contrast, the response side of the framework is robust (Tables 4 and 5), with numerous tools available for capturing both metabolic and neuromuscular responses and adaptations (Thorpe 20017). For metabolic adaptations, submaximal running tests or HR responses to standardized drills or small-sided games (SGG) offer a practical and repeatable way to assess changes in cardiovascular efficiency (Buchheit 2025d) and provide many advantages over either maximal efforts (e.g., 30-15 IFT, YoYo tests) or invasive physiological assessments (e.g., Hemoglobin mass, Brocherie 2015, Washsmuth 2012). The use of HRV to assess training adaptation is certainly relevant, especially given the ease of monitoring with newer wearables (Figure 1). However, its interpretation is more complex than it appears (Buchheit 2014, Plews 2013). HRV reflects a combination of metabolic conditioning and fatigue, and more importantly, expected changes in HRV are training phase-dependent (i.e., higher values are not always better), making it a useful but highly contextual tool. As such, its effective use requires experience and a nuanced understanding of both the athlete and the training process (Buchheit 2014, Plews 2013).

Subjective response monitoring (also called athlete report outcome measures, AROMs, McLaren 2022) is also well-developed, with a wide range of validated questionnaires available to track selective and specific markers of interest, such as perceived recovery, fatigue, mood, readiness and muscle soreness (McLaren 2022, Saw 2016). While these tools are appealing for their simplicity and low cost, their use in practice presents challenges. Athlete compliance remains a major barrier, with acceptance of monitoring programs identified as a key issue (McGuigan 2021). In addition, only half of practitioners surveyed recently trusted the sensitivity of their self-report measures (Neupert 2024). Fewer than half even said changes in scores led to meaningful action, and half stated that removing their athlete monitoring system would not compromise performance! Overall, the practical impact of subjective monitoring systems is not yet fully realized, and there is still work to be done in educating both practitioners and players on how to make better use of these valuable tools (McLaren 2022, Thorpe 2017).

While sleep is neither a direct metabolic nor neuromuscular response, it serves as both an indicator of overall wellness and a modulator of training response. Poor sleep is typically associated with excessive fatigue and can reduce training quality, which can ultimately affect the magnitude and direction of adaptation.

When it comes to more objective neuromuscular responses, the options are even broader, ranging from internal physiological markers such as low-frequency fatigue (e.g., Myocene, Ridard 2022, Tito 2024), creatine kinase (CK, Khaitin 2021, Silva 2018) to thermography (Alburquerque, 2022, Côrte 2019, Gómez-Carmona 2020, Majano 2023). On the performance (external markers) side, field-based neuromuscular indicators like jump tests (Buchheit 2025b), isometric tests (Duarte 2018), velocity-based assessments (García-Ramos 2025, Crowley 2023, Reyes-Laredo 2024), or stride kinetics using (GPS-embedded) accelerometers (supplemented with ADI analysis, Buchheit & Simpson 2017, Buchheit 2018, Garrett 2019, Leduc 2020a and 2020b) responses provide further insight. This is encouraging, as it enables meaningful training adjustments to be made based on how players actually respond to the load.

2025: Twenty years on, still missing the point

Twenty years ago, HR was the only widely available technological tool (Achten 2003), and some pioneers began complementing it with sRPE (Impellizzeri 2024), and eventually custom-made wellness questionnaires. Today, despite the growing visibility of sport science, current monitoring practices remain surprisingly limited. There is a tendency to rely on low-effort, indirect measures and an overconfidence that one or two metrics can capture the full picture of performance and health. Most practitioners now rely almost exclusively on GPS, with sRPE still occasionally added. The use of HR to assess metabolic load has largely disappeared, and as a result, load is commonly estimated using two of the weakest available tools: GPS, which offers little insight into neuromuscular strain (Table 3, Kalkhoven 2021), and global sRPE, which lacks the specificity needed to reflect system-level demands (Table 3).

On the other side of the coin, monitoring of responses and adaptations is often absent altogether, as shown in Table 1, or reduced to a basic questionnaire or a soreness rating. While several frameworks (Impellizzeri 2023, Gabbett 2017, Gronwald 2020, Vanrenterghem 2017) have helped clarify the importance of monitoring both training load and response, most have failed to provide practical guidance on how to connect the right tools and metrics to each side of the equation. More importantly, we have collectively failed to educate practitioners (Bosch 2018). This is no longer about technology or budget, but a lack of applied understanding. Many still don't know how to connect tools to practice, which is a gap that prompted this paper. In 2025, the problem isn't missing tools, but missing structure, clarity, and physiological common sense.

Table 5. Monitoring tools for neuromuscular response, adaptation, and general perceived wellness. This table summarizes tools used to assess neuromuscular response and adaptation in elite football, categorized by type, practicality, cost, evidence level, and relevant notes. Abbreviations: CPK = creatine phosphokinase, SMFT = submaximal fitness testing, ADI = athletic data innovation (https://www.adi-data.co/), TQR = total quality recovery.

Quadrant	Type	Tool/Metric	Practicality	Cost	Evidence Level	Notes	References
Neuromuscular Response and Adaptation	Internal	CPK	Moderate	High	High	Biomarker for muscle damage; passive but invasive and cost-intensive. Varies with player preference.	Khaitin 2021, Silva 2018
	Internal	Thermography	High	High	Moderate	Passive, non-invasive, very quick and easy to use, promising tool; cost-intensive.	Alburquerque, 2022, Côrte 2019, Gómez-Carmona 2020, Majano 2023
	Internal	Differential subjective training effects (soreness)	High	Low	High	Simple, effective, low-cost; dependent on player education and buy-in.	McGuigan 2021, McLaren 2021, McLean 2010
	Internal	Muscle contractility and low-frequency fatigue (Myocene)	Moderate	High	High	Potentially the best tool. Valid for both long-term adaptation and short-term fatigue; passive, requires 90s per player, cost-intensive and measures are limited to the quadriceps. Varies with player preference and buy-in.	Ridard 2022, Tito 2024
	External	Jump tests	Moderate	Moderate	High	Valid for both short-term fatigue and long-term adaptation; requires, however, max effort, precise scheduling, and relates to players' buy-in.	Bishop 2023, Buchheit 2025b
	External	Isometric strength tests (dynamometers)	Moderate	Moderate	High	Preferred to maximal dynamic assessment. Require, however, max effort, precise scheduling, and relates to players' buy-in.	Duarte 2018
	External	Movement velocity	Moderate	Moderate	High	Similar to Standardized runs, it assesses velocity response to a given load, practical with budget-friendly hardware. Possibility to predict changes in 1-RM, without reaching maximal load. Requires, however, max effort, precise scheduling, and relates to players' buy-in.	García-Ramos 2025, Crowley 2023, Reyes-Laredo 2024

	External	Stride kinetics (embedded accelerometers)	High	High	High	Enables invisible monitoring with high ROI during standardized warm-up strides; requires computing solutions such as the ADI App.	Buchheit 2018, Garrett 2019, Leduc 2020a and 2020b
General Response & Adaptation	Internal	Subjective training effects (Overall wellness, TQR)	High	Low	High	Many options available from general wellness to recovery, mood, and fatigue; cheap and practical when athletes are educated and bought in.	McGuigan 2021, McLaren 2022, McLean 2010, Saw 2015

Weighing value and burden in context-specific monitoring

Monitoring systems must be applied carefully, with a clear understanding of both their value and their burden (Carling 2018, Clubb 2024). Especially in environments with limited staff or time, it's important to focus on data that can genuinely inform decisions and lead to meaningful action. Collecting information that can't be used promptly adds unnecessary complexity. Every measure, whether objective or subjective, comes with a cost, and no tool is truly free in terms of time, attention, or effort. Subjective data is also influenced by how athletes think it will be used, which can affect its reliability (Neupert 2024). To be effective, monitoring needs more than good science; it requires the buy-in of all stakeholders. Coaches, players, and managers must see its relevance, and each environment and staff group is unique in how that relevance is defined and acted upon.

A practical minimum setup: covering both load and responses

The recommended minimum setup for an elite but cost-effective monitoring system should include GPS with HR capability, allowing for basic estimation of both neuromuscular and metabolic load, acknowledging the known limitations of each. While ideally, players' HR would be monitored continuously across all sessions, we recognize the logistical and compliance challenges this presents. Getting players to consistently wear HR belts can quickly turn into a daily battle for staff. A practical compromise we've used in the past is to choose our battles strategically. For example, on D-2 or D-1 sessions, where cardiovascular demands are typically low and players are unlikely to reach 90% of HRmax (Buchheit 2021, Buchheit 2024), we don't ask for HR monitoring, which reduces burden and gives players a break. Global sRPE should also be included as a simple yet informative internal load marker. To capture training responses, the minimum setup should include a system capable of collecting HR data during standardized runs (to track metabolic adaptations), force plates for jump and isometric tests (to monitor neuromuscular response and adaptation), and simple subjective response tools such as perceived recovery and muscle soreness questionnaires. Similarly, to decrease burden, players only need to wear the belt during the 4 minutes of the standardized runs, and can remove it immediately afterward. This combination strikes a balance between feasibility, relevance, and actionable feedback. For clubs with more resources, adding neuromuscular response measures such as CK, low-frequency fatigue (Myocene) or thermography is clearly beneficial, as these tools provide greater granularity and stronger physiological evidence to support decision-making. This flexibility also allows monitoring to be tailored to player preferences. In some environments, we've worked with players willing to do daily CK blood draws but unwilling to jump on a force plate; in others, blood testing was pointless, but weekly jump assessments were well accepted. The context also matters: monitoring an entire squad differs significantly from tracking an individual during return-to-play, where closer and more tailored monitoring is not only easier but often more important. Return-to-play is also a unique opportunity for 1-on-1 work between the player and the physio or S&C coach. It's a chance to educate the player, who is generally more on tools they may resist in group settings, such as the discomfort of wearing a HR belt or performing jumps on a force plate. The absence of group dynamics makes compliance easier, more time can be dedicated to each session, and it's also the ideal moment to update key reference data (e.g., max sprint speed, jump performance, maximal HR). In this context, there's no excuse; the practical minimum setup should be applied by default.

Practical implementation within the football microcycle

In a future manuscript, we will detail how to practically implement this framework within a typical football microcycle, including the optimal timing and placement of each tool presented in the quadrant (Figure 1).

Key messages

- Load and response/adaptation are distinct but inseparable; misrepresenting or ignoring one undermines the value of the other.
- Several frameworks have helped clarify the importance of monitoring both training load and response, but most have not addressed how to practically link the right tools and metrics to each side.
- Monitoring should also be aligned with the specific physiological system (metabolic or neuromuscular).
- The confusion introduced by sport science 2.0 can be addressed through simple, physiology-based structural models, rather than models driven solely by technology, as emphasized in the shift toward sport science 3.0.
- Load is measured during or immediately after exercise (e.g., distance covered via GPS, HR, lactate, sRPE), while response includes short-term (e.g., next-day soreness) and longer-term adaptations (e.g., cardiovascular fitness gains), with some metrics more specific to one timeframe than the other.
- Today, there is an imbalance in both quantity and relevance of tools, with more options available (and generally better proxies) for response to load than for load.

- There is also a quality imbalance: GPS is widely used but limited, while HR is less practical and underused, raising questions about the actual value of current load monitoring practices.
- To ensure comprehensive coverage, at least one variable should be monitored per quadrant (i.e., one proxy for metabolic load, neuromuscular load, metabolic adaptation, and neuromuscular acute response and adaptation), forming the minimum viable monitoring system.
  - Metabolic Load (Table 2): VO_2 is ideal but impractical; HR is a useful proxy once we accept its limitations.
  - Neuromuscular Load (Table 3): The weakest area; GPS is commonly used but offers little insight into internal neuromuscular strain.
  - Responses and adaptation (Tables 4 & 5): The strongest two quadrants, with many tools available to guide training based on how players respond.
- The recommended minimum setup for an elite yet cost-effective load monitoring system includes GPS with HR capability to infer on both metabolic and neuromuscular demands, respectively (with all limitations known), and sRPE (global marker).
- The recommended minimum setup to capture training responses includes any system with HR sensors for submaximal tests (metabolic adaptations), force plates for jumps and isometric tests (neuromuscular responses and adaptations), and subjective training effects questionnaires (e.g., perceived recovery and muscle soreness).
- Only collect information that can realistically inform timely decisions within your specific staffing and resource constraints.
- The success of any monitoring system depends on stakeholder engagement and contextual fit: what works in one environment may not work in another.

References

1. Achten J, Jeukendrup AE. Heart rate monitoring: applications and limitations. Sports Med. 2003;33(7):517-38. doi: 10.2165/00007256-200333070-00004. PMID: 12762827.

2. Alburquerque Santana PV, Alvarez PD, Felipe da Costa Sena A, Serpa TK, Assis MG, Pimenta EM, Costa HA, Sevilio de Oliveira Junior MN, Torres Cabido CE, Veneroso CE. Relationship between infrared thermography and muscle damage markers in physically active men after plyometric exercise. J Therm Biol. 2022 Feb;104:103187. doi: 10.1016/j.jtherbio.2022.103187. Epub 2022 Jan 11. PMID: 35180966.

3. Bishop C, Jordan M, Torres-Ronda L, Loturco I, Harry J, Virgile A, Mundy P, Turner A, Comfort P. Selecting Metrics That Matter: Comparing the Use of the Countermovement Jump for Performance Profiling, Neuromuscular Fatigue Monitoring, and Injury Rehabilitation Testing. Strength and Conditioning Journal 45(5):p 545-553, October 2023.

4. Bosch G. Train PhD students to be thinkers not just specialists. Nature. 2018 Feb 15;554(7692):277. doi: 10.1038/d41586-018-01853-1. PMID: 29446388.

5. Brocherie F, Millet GP, Hauser A, Steiner T, Wehrlin JP, Rysman J, Girard O. Association of Hematological Variables with Team-Sport Specific Fitness Performance. PLoS One. 2015 Dec 7;10(12):e0144446. doi: 10.1371/journal.pone.0144446. PMID: 26641647; PMCID: PMC4671600.

6. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol. 2014 Feb 27;5:73. doi: 10.3389/fphys.2014.00073. PMID: 24578692; PMCID: PMC3936188.

7. Buchheit M. Running/game metrics and thigh muscle injuries: factors for consideration in rehabilitation and prevention. Presented at: Aspetar International Rehabilitation 2024. Conference – The Complete Guide to Thigh Muscle Injuries; 2024a Nov 16-17.

8. Buchheit M, Balaña O, Ogden A, Saniel G & Harries S. Structuring the daily progression from return-to-run to full team integration. Sport Perf & Science Reports, #251 v1, Feb 2025a.

9. Buchheit, M., Douchet, T., Settembre, M., Mchugh, D., Hader, K., & Verheijen, R. The 11 Evidence-Informed and Inferred Principles of Microcycle Periodization in Elite Football. Sport Perf & Science Reports, #218, v1, Feb 2024

10. Buchheit M, Kotsifaki R, Cohen D. What the jump? A comprehensive guide for force plate jump analysis in sports performance and rehabilitation. Sport Perf & Sci Reports, In preparation 2025b.

11. Buchheit M, Lacome M, Cholley Y, Simpson BM. Neuromuscular Responses to Conditioned Soccer Sessions Assessed via GPS-Embedded Accelerometers: Insights Into Tactical Periodization. Int J Sports Physiol Perform. 2018 May 1;13(5):577-583. doi: 10.1123/ijspp.2017-0045. Epub 2018 May 22. PMID: 28872370.

12. Buchheit M, Laursen PB. High-intensity interval training: solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports Med. 2013a May;43(5):313-38. doi: 10.1007/s40279-013-0029-x. PMID: 23539308.

13. Buchheit M, Laursen PB. High-intensity interval training: solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load, and practical applications. Sports Med. 2013b Oct;43(10):927-54. doi: 10.1007/s40279-013-0066-5. PMID: 23832851.

14. Buchheit M, Laursen PB. Quantifying training load. In: Laursen PB & Buchheit M, editors. Science and Application of High Intensity Interval Training: Solutions to the Programming Puzzle. Champaign, IL: Human Kinetics; 2019. p. 161-178.

15. Buchheit M, Laursen PB, Stanley J, Plews D, Al Haddad H, Lacome M, Simpson B, Saw A. Response to load. In: Buchheit M, Laursen PB, editors. Science and Application of High Intensity Interval Training: Solutions to the Programming Puzzle. Champaign, IL: Human Kinetics; 2019. P. 179-212.

16. Buchheit M & Laursen PB. Sports Science 3.0: Integrating Technology and AI with Foundational Knowledge. 2024 Sport Perform. Sci. Rep, #231, v1.

17. Buchheit M, Malone S, Campos M and Castagna C. Revisiting the dose-response relationship between time in HR zones and training adaptation in elite team sports. Sport Perf

& Sci Reports, In preparation 2025c.

18. Buchheit M, Sandua M, Berndsen J, Shelton A, Smith S, Norman D, McHugh D and Hader K. Loading patterns and programming practices in elite football: insights from 100 elite practitioners. Sports Performance & Science Reports, Nov, 2021, V1.

19. Buchheit M, Simpson BM. Player-Tracking Technology: Half-Full or Half-Empty Glass? Int J Sports Physiol Perform. 2017 Apr;12(Suppl 2):S235-S241. doi: 10.1123/ijspp.2016-0499. Epub 2016 Dec 14. PMID: 27967285.

20. Buchheit M, Shushan T, Barrett S, Altmann S, Rabbani A, Mandorino M, Lacome M, McLaren SJ. Maximizing the submaximal: 20 years of monitoring cardiovascular adaptation through submaximal HR response in team sports. Sport Perf & Science Reports. In press, 2025d.

21. Buchheit M, Verheijen R. Treat the Football Conditioning Problem, Not the Symptom. Training Science Podcast (Episode #99) [Broadcast]. 2024

22. Cardinale M, Varley MC. Wearable Training-Monitoring Technology: Applications, Challenges, and Opportunities. Int J Sports Physiol Perform. 2017 Apr;12(Suppl 2):S255-S262. doi: 10.1123/ijspp.2016-0423. Epub 2016 Nov 11. PMID: 27834559.

23. Carling C, Lacome M, McCall A, Dupont G, Le Gall F, Simpson B, Buchheit M. Monitoring of Post-match Fatigue in Professional Soccer: Welcome to the Real World. Sports Med. 2018 Dec;48(12):2695-2702. doi: 10.1007/s40279-018-0935-z. PMID: 29740792; PMCID: PMC6244616.

24. Côrte AC, Pedrinelli A, Marttos A, Souza IFG, Grava J, José Hernandez A. Infrared thermography study as a complementary method of screening and prevention of muscle injuries: pilot study. BMJ Open Sport Exerc Med. 2019 Jan 3;5(1):e000431. doi: 10.1136/bmjsem-2018-000431. PMID: 30687515; PMCID: PMC6326304.

25. Crowley T. VBT for athlete readiness checks and pregame preparation. Sportsmith. 2023. Available from: `https://www.sportsmith.co/articles/vbt-for-athlete-readiness-checks-and-pregame-preparation/`

26. Duarte JP, Valente-Dos-Santos J, Coelho-E-Silva MJ, Malina RM, Deprez D, Philippaerts R, Lenoir M, Vaeyens R. Developmental Changes in Isometric Strength: Longitudinal Study in Adolescent Soccer Players. Int J Sports Med. 2018 Sep;39(9):688-695. doi: 10.1055/s-0044-100389. Epub 2018 Jun 20. PMID: 29925105.

27. Gabbett TJ, Nassis GP, Oetter E, Pretorius J, Johnston N, Medina D, Rodas G, Myslinski T, Howells D, Beard A, Ryan A. The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. Br J Sports Med. 2017 Oct;51(20):1451-1452. doi: 10.1136/bjsports-2016-097298. Epub 2017 Jun 23. PMID: 28646100.

28. García-Ramos A. Velocity-Based Training: Prescribing and Assessing the Effects of Resistance Training. 1st ed. London: Routledge; 2025.

29. Garrett J, Graham SR, Eston RG, Burgess DJ, Garrett LJ, Jakeman J, Norton K. A Novel Method of Assessment for Monitoring Neuromuscular Fatigue in Australian Rules Football Players. Int J Sports Physiol Perform. 2019 May 1;14(5):598-605. doi: 10.1123/ijspp.2018-0253. Epub 2019 Apr 21. PMID: 30427228.

30. Gómez-Carmona P, Fernández-Cuevas I, Sillero-Quintana M, Arnaiz-Lastras J, Navandar A. Infrared Thermography Protocol on Reducing the Incidence of Soccer Injuries. J Sport Rehabil. 2020 Nov 1;29(8):1222-1227. doi: 10.1123/jsr.2019-0056. Epub 2020 Mar 17. PMID: 32188790.

31. Gronwald T, Törpel A, Herold F, Budde H. Perspective of Dose and Response for Individualized Physical Exercise and Training Prescription. J Funct Morphol Kinesiol. 2020 Jul 14;5(3):48. doi: 10.3390/jfmk5030048. PMID: 33467264; PMCID: PMC7739365.

32. Hader K, Mendez-Villanueva A, Ahmaidi S, Williams BK, Buchheit M. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. BMC Sports Sci Med Rehabil. 2014 Jan 13;6(1):2. doi: 10.1186/2052-1847-6-2. PMID: 24417863; PMCID: PMC3904414.

33. Hader K, Mendez-Villanueva A, Palazzi D, Ahmaidi S, Buchheit M. Metabolic Power Requirement of Change of Direction Speed in Young Soccer Players: Not All Is What It Seems. PLoS One. 2016 Mar 1;11(3):e0149839. doi: 10.1371/journal.pone.0149839. PMID: 26930649; PMCID: PMC4773143.

34. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and External Training Load: 15 Years On. Int J Sports Physiol Perform. 2019 Feb 1;14(2):270-273. doi: 10.1123/ijspp.2018-0935. Epub 2019 Jan 6. PMID: 30614348.

35. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. Med Sci Sports Exerc. 2004 Jun;36(6):1042-7. doi: 10.1249/01.mss.0000128199.23901.2f. PMID: 15179175.

36. Impellizzeri FM, Shrier I, McLaren SJ, Coutts AJ, McCall A, Slattery K, Jeffries AC, Kalkhoven JT. Understanding Training Load as Exposure and Dose. Sports Med. 2023 Sep;53(9):1667-1679. doi: 10.1007/s40279-023-01833-0. Epub 2023 Apr 6. PMID: 37022589; PMCID: PMC10432367.

37. Kalema RN, Duhig SJ, Finni T, Arumugam A, Pesola AJ. Sensitivity to change of quadriceps and hamstrings muscle wearable electromyography outcomes during a professional soccer match. J Sports Sci. 2025 Apr;43(7):658-667. doi: 10.1080/02640414.2025.2469462. Epub 2025 Feb 21. PMID: 39981816.

38. Kalkhoven JT, Watsford ML, Coutts AJ, Edwards WB, Impellizzeri FM. Training Load and Injury: Causal Pathways and Future Directions. Sports Med. 2021 Jun;51(6):1137-1150. doi: 10.1007/s40279-020-01413-6. Epub 2021 Jan 5. PMID: 33400216.

39. Khaitin V, Bezuglov E, Lazarev A, Matveev S, Ivanova O, Maffulli N, Achkasov E. Markers of muscle damage and strength performance in professional football (soccer) players during the competitive period. Ann Transl Med. 2021 Jan;9(2):113. doi: 10.21037/atm-20-2923. PMID: 33569415;

PMCID: PMC7867942.

40. Klusiewicz A, Rębiś K, Ozimek M, Czaplicki A. The use of muscle near-infrared spectroscopy (NIRS) to assess the aerobic training loads of world-class rowers. Biol Sport. 2021 Oct;38(4):713-719. doi: 10.5114/biolsport.2021.103571. Epub 2021 May 20. PMID: 34937982; PMCID: PMC8670802.

41. Leduc C., Lacome M, and Buchheit M. The use of standardised runs (and associated data analysis) to monitor neuromuscular status in team sports players: a call to action. Sport Perf Sci & Reports, 2020, #117, v1.

42. Leduc C, Tee J, Lacome M, Weakley J, Cheradame J, Ramirez C, Jones B. Convergent Validity, Reliability, and Sensitivity of a Running Test to Monitor Neuromuscular Fatigue. Int J Sports Physiol Perform. 2020 Jul 8;15(8):1067-1073. doi: 10.1123/ijspp.2019-0319. PMID: 32663385.

43. Los Arcos A, Yanci J, Mendiguchia J, Gorostiaga EM. Rating of muscular and respiratory perceived exertion in professional soccer players. J Strength Cond Res. 2014 Nov;28(11):3280-8. doi: 10.1519/JSC.0000000000000540. PMID: 24845209.

44. Mandorino M, Lacome M. Defining Worst-Case-Scenario Thresholds in Soccer: Intensity Versus Volume. Int J Sports Physiol Perform. 2024 Jun 19;19(8):836-840. doi: 10.1123/ijspp.2024-0038. PMID: 38897574.

45. Mandorino M, Lacome M, Verheijen R, Buchheit M. Time to drop running as a KPI in elite football: football fitness and freshness as match-day preconditions. Sport Performance & Science Reports. 2025 Apr; Report #254.

46. Majano C, Garcia-Unanue J, Fernández-Cuevas I, Escamilla-Galindo V, Alonso-Callejo A, Sanchez-Sanchez J, Gallardo L, Felipe JL. Association between physical demands, skin temperature, and well-being status in elite football players. Sci Rep. 2023 Aug 23;13(1):13780. doi: 10.1038/s41598-023-40396-y. PMID: 37612294; PMCID: PMC10447551.

47. McGuigan HE, Hassmén P, Rosic N, Stevens CJ. Monitoring of training in high-performance athletes: What do practitioners do? J Sport Exerc Sci. 2021;5(2):121-129.

48. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. Int J Sports Physiol Perform. 2010 Sep;5(3):367-83. doi: 10.1123/ijspp.5.3.367. PMID: 20861526.

49. McLaren SJ, Coutts AJ, Impellizzeri FM. Perception of effort and subjective monitoring. In: French DN, Torres-Ronda L, editors. NSCA's Essentials of Sport Science. Champaign, IL: Human Kinetics; 2022. Chapter 17, p 231-254.

50. McLaren SJ, Graham M, Spears IR, Weston M. The Sensitivity of Differential Ratings of Perceived Exertion as Measures of Internal Load. Int J Sports Physiol Perform. 2016 Apr;11(3):404-6. doi: 10.1123/ijspp.2015-0223. Epub 2015 Jul 27. PMID: 26218099.

51. Neupert E, Holder T, Gupta L, Jobson SA. More than metrics: The role of socio-environmental factors in determining the success of athlete monitoring. J Sports Sci. 2024 Feb;42(4):323-332. doi: 10.1080/02640414.2024.2330178. Epub 2024 Mar 17. PMID: 38493350.

52. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. Sports Med. 2013 Sep;43(9):773-81. doi: 10.1007/s40279-013-0071-8. PMID: 23852425.

53. Reyes-Laredo F, Pareja-Blanco F, López-Lluch G, Rodríguez-Bies E. The Evolution of Physical Performance throughout an Entire Season in Female Football Players. Sports (Basel). 2024 Feb 6;12(2):52. doi: 10.3390/sports12020052. PMID: 38393272; PMCID: PMC10891543.

54. Ridard J, Rozand V, Millet GY, Lapole T. On-field low-frequency fatigue measurement after repeated drop jumps. Front Physiol. 2022 Nov 9;13:1039616. doi: 10.3389/fphys.2022.1039616. PMID: 36439261; PMCID: PMC9681803.

55. 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 Mar;50(5):281-91. doi: 10.1136/bjsports-2015-094758. Epub 2015 Sep 9. PMID: 26423706; PMCID: PMC4789708.

56. Seshadri DR, Thom ML, Harlow ER, Gabbett TJ, Geletka BJ, Hsu JJ, Drummond CK, Phelan DM, Voos JE. Wearable Technology and Analytics as a Complementary Toolkit to Optimize Workload and to Reduce Injury Burden. Front Sports Act Living. 2021 Jan 21;2:630576. doi: 10.3389/fspor.2020.630576. PMID: 33554111; PMCID: PMC7859639.

57. Silva JR, Rumpf MC, Hertzog M, Castagna C, Farooq A, Girard O, Hader K. Acute and Residual Soccer Match-Related Fatigue: A Systematic Review and Meta-analysis. Sports Med. 2018 Mar;48(3):539-583. doi: 10.1007/s40279-017-0798-8. PMID: 29098658.

58. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring Fatigue Status in Elite Team-Sport Athletes: Implications for Practice. Int J Sports Physiol Perform. 2017 Apr;12(Suppl 2):S227-S234. doi: 10.1123/ijspp.2016-0434. Epub 2017 Jan 17. PMID: 28095065.

59. Tito S, Maia F, Correia M, Ribeiro J. Recovery Patterns of Low-frequency Fatigue in Elite Youth Soccer Players after Official Matches. Int J Sports Med. 2025 Apr;46(4):263-270. doi: 10.1055/a-2456-2151. Epub 2024 Oct 29. PMID: 39472024.

60. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. Sports Med. 2017 Nov;47(11):2135-2142. doi: 10.1007/s40279-017-0714-2. PMID: 28283992.

61. Verheijen R. Football periodisation. Chapter 9: Designing Football Fitness Training - Designing Training Situations. In print, 2025 June.

62. Wachsmuth N, Kley M, Spielvogel H, Aughey RJ, Gore CJ, Bourdon PC, Hammond K, Sargent C, Roach GD, Sanchez RS, Claros JC, Schmidt WF, Garvican-Lewis LA. Changes in blood gas transport of altitude native soccer players near sea-level and sea-level native soccer players at altitude (ISA3600). Br J Sports Med. 2013 Dec;47 Suppl 1(Suppl 1):i93-9. doi: 10.1136/bjsports-2013-092761. PMID: 24282216; PMCID: PMC3903154.

63. Woolmer E, Morris R, Noon M, Tallis J, Clarke ND, Eyre E. What do athletes really think? Athlete perceptions and attitudes towards athlete monitoring in professional soccer. Int J Sports Sci Coach. 2025 Feb 24. doi:10.1177/17479541251318846. Epub ahead of print.