Slaves to (GPS) norms

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Global positioning system | Training load | Benchmarks | Normative data | Standardization | Injury risk | Training adaptation | Dashboards | Sport Science 2.0 | Sports technology | Performance analysis | Periodisation | Return to play

Headline

On the surface, performance support appears in a better place than ever. Advancements in performance staff, technology, and analytical capabilities have progressed in tandem with performance capabilities. However, current tech trends, external pressures and misconceptions in various key metrics are resulting in practices that are misguided and detract from our core performance objectives (i.e., Sport Science 2.0 approach, Buchheit & Laursen 2024). Among the areas that require major revision, GPS norms and targets are central. While avoiding abrupt changes in load is sensible, this does not mean that the most common training load is the most effective. It mainly biases us to believe that what we are currently doing is already optimal and towards training methods that easily produce normative metrics rather than those which optimise the training response.

Aim

This paper questions whether current GPS norms and targets are conceptually sound and empirically grounded. It examines how their widespread use may misdirect training decisions and blur what is truly optimal. We argue that there is currently no empirical basis for defining an "optimal" GPS norm, because most benchmarks simply reflect what teams usually do rather than what would produce the best performance or lowest injury risk. Finally, we argue that many commonly used GPS metrics are a poor proxy for neuromechanical and metabolic load, so norms built from them often reflect only a small part of the true work performed.

The GPS Revolution

Assessing the physical demand placed on athletes from training and competition has been a cornerstone of performance support to optimise training adaptations and reduce injury risk. In many sports, GPS has become the central tool for assessing this load. The adoption of GPS was both rapid and widespread, driven by sophisticated tracking and accelerometer technology providing more detailed and wide-ranging data capable of assessing physical loading across diverse movement patterns and intensities - from steady straight-line running to intermittent multidirectional sports.

The novelty and scale of GPS data necessitated the widespread adoption of normative data methodologies to simplify interpretation (Ravé 2020). By converting raw data into standardized scales, normative statistics make it simpler to interpret whether a given value is higher or lower than normal (Figure 1). This approach aligns with the foundational training principles of progression and regression, which describe how excessive changes in training load can be detrimental. Progress load too aggressively and we risk being overcome by fatigue and injury. Reduce training loads too extensively, we risk detraining and being unable to cope with the demands of competition (Impellizzeri et al. 2023). The standardised scaling is especially beneficial when analysing numerous metrics and athletes, and cumulative load across multiple drills and sessions. Normative thresholds, coupled with associated color-coded visualisations (Figure 1) provide intuitive and efficient loading information, and facilitate rapid identification of loads that may be inappropriate for individuals and groups.

Potential Pitfalls of GPS-Based Normative Targets

It is perplexing how something so widespread and conceptually beneficial could potentially have negative implications. There is concern, however, that the pressures and trends of modern sport, particularly the drive to reduce injuries, have fostered an environment overly fixated on GPS-based normative boundaries, leading to practices that may detract from our primary goal of maximizing athletic potential and, paradoxically, increase injury risk in the long-term. Additionally, there is growing recognition that the interpretation of commonly used GPS metrics is flawed, misrepresenting the true physical demands placed on athletes (Buchheit, Balana et al., 2025, Buchheit & Lopes-Segarra 2026).

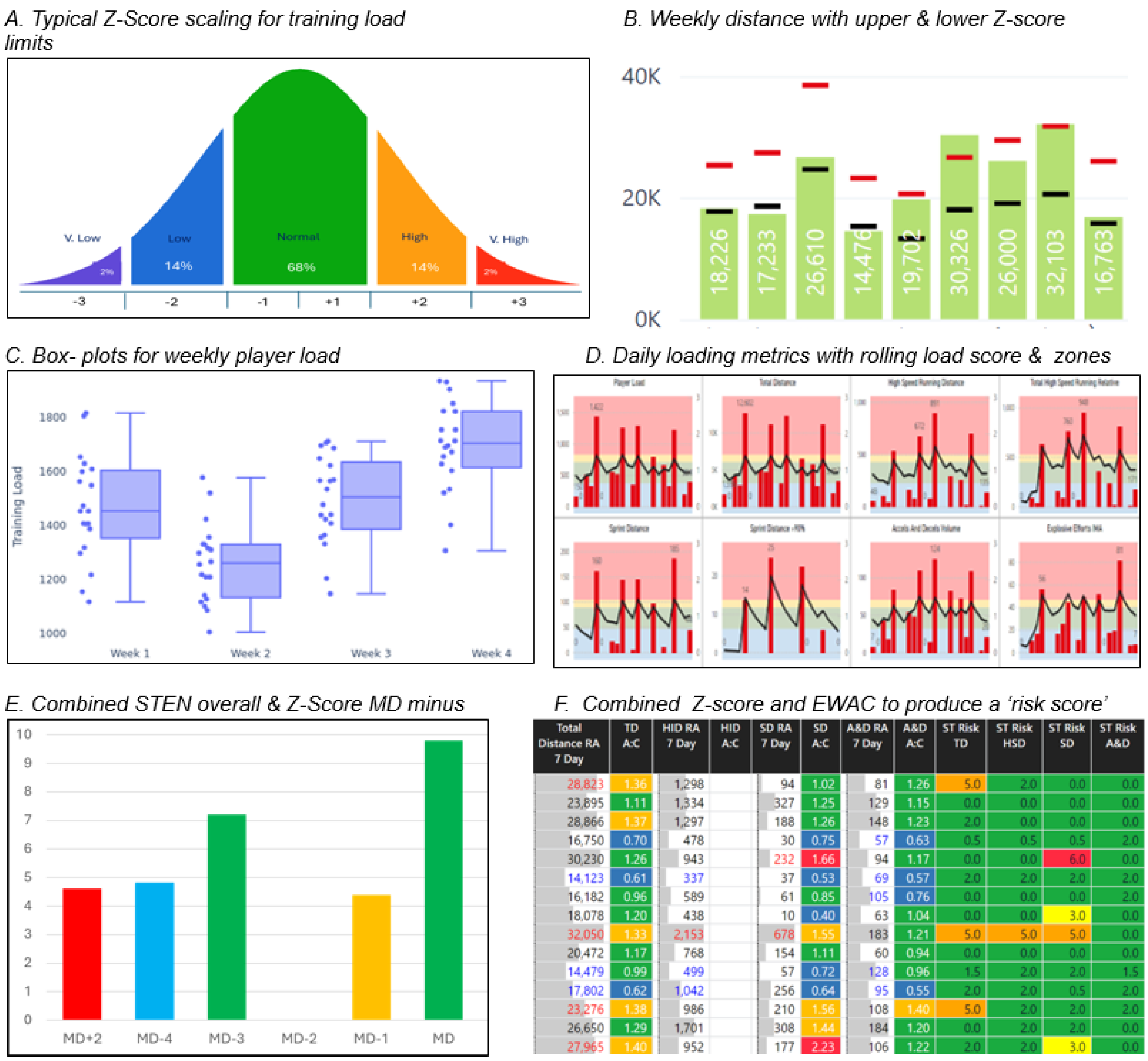
The Increasing Influence of GPS Normative Targets

Recent history witnessed the mesmeric rise of the acute-to-chronic workload ratio concept, following numerous studies and consensus statements proposing its association with injury risk, a relationship that has since been largely refuted due to conceptual and statistical flaws, particularly the disproportionate weighting of low chronic, and increases in acute load (Impellizeri, 2020).

An era of 'load management' emerged as professional sports organizations invested substantial resources in personnel and technology to collect, analyse, and disseminate loading information. Comprehensive Athlete Management Systems have become integral frameworks for evaluating performance strategies, while load management now occupies a central role in multidisciplinary team discussions and executive decision-making processes.

For many organisations, injury prevention has become the key goal of load management, superseding athletic potential. Despite advances in medical and performance support, increased performance demands and competition schedules have meant injury rates have risen, and associated costs soared across many sports (Ekstrand et al. 2022). Changes in performance departments more often follow an injury crisis, as the aftermath of an injury on performance and lost investment are more evident than marginal changes in physical capacity (Ekstrand et al. 2023).

The pervasive use of normative analysis and its association to injury makes aiming for the theoretical 'low-risk zone' of normative targets feels intuitive, minimizing criticism and safeguarding job security. Yet, there are compelling arguments why adherence to normative GPS targets can sometimes be misguided.



Total Distance RA 7 Day	TD A:C	HID RA 7 Day	HID A:C	SD RA 7 Day	SD A:C	A&D RA 7 Day	A&D A:C	ST Risk TD	ST Risk HSD	ST Risk SD	ST Risk A&D
28,823	1.36	1,298		94	1.02	81	1.26	5.0	2.0	0.0	0.0
23,895	1.11	1,334		327	1.25	129	1.15	0.0	0.0	0.0	0.0
28,866	1.37	1,297		188	1.26	148	1.23	2.0	0.0	0.0	0.0
16,750	0.70	478		30	0.75	57	0.63	0.5	0.5	0.5	2.0
30,230	1.26	943		232	1.66	94	1.17	0.0	0.0	6.0	0.0
14,123	0.61	337		37	0.53	69	0.57	2.0	2.0	2.0	2.0
16,182	0.96	589		61	0.85	105	0.76	0.0	0.0	0.0	2.0
18,078	1.20	438		10	0.40	63	1.04	0.0	0.0	3.0	0.0
32,050	1.33	2,153		678	1.55	183	1.21	5.0	5.0	5.0	0.0
20,472	1.17	768		154	1.11	60	0.94	0.0	0.0	0.0	0.0
14,479	0.99	499		57	0.72	128	0.96	1.5	2.0	2.0	1.5
17,802	0.62	1,042		256	0.64	95	0.55	2.0	2.0	0.5	2.0
23,276	1.38	986		210	1.56	108	1.40	5.0	2.0	2.0	2.0
26,650	1.29	1,701		308	1.44	184	1.20	0.0	2.0	2.0	0.0
27,965	1.40	952		177	2.23	106	1.22	2.0	2.0	3.0	0.0

Fig. 1. Examples of normative presentation of loading

The Illusion of Optimal GPS Training Loads

Evidence-based guidelines for optimizing GPS-derived loading to elicit desired adaptations and balance overall load and recovery are limited, with current practices largely grounded in empirical observation and practitioner experience. There is no clear evidence that any specific GPS-derived norm is definitely optimal for performance or injury risk; at best, current values describe typical practice (Ravé 2020). GPS-based training loads showed low correlations to training adaptations and recovery (Ellis et al., 2020, 2023) and only a microcycle match ratio of HSR of 60-90% has been associated with less injury (Buchheit, Settembre et al. 2024). Even recent attempts to relate detailed loading patterns to injury trends, including our own work, remain exploratory and injury-focused, and do not identify performance-enhancing "sweet spots". Physical testing and competitive performance offer organisations a method of assessing training load efficacy, but issues with time and load constraints, and validity mean teams often infer optimal practices from reviewing training data. Practitioners have therefore attempted to gleam insight from theoretical ideals, such as normative boundaries, leading to a blurring of the lines between normative and optimal. Whilst there are certainly benefits to not changing load too abruptly, this does not mean that the most common training load is necessarily the most optimal – it just serves to prejudice that our current practices are optimal. In reality, GPS norms may simply encode long-term undertraining, overtraining, or poor sequencing of load and recovery. Normative boundaries could theoretically be producing long term under or overtraining or imbalanced loading and recovery. Despite this, specific and cumulative training load recommendations are commonly based on normative analysis.

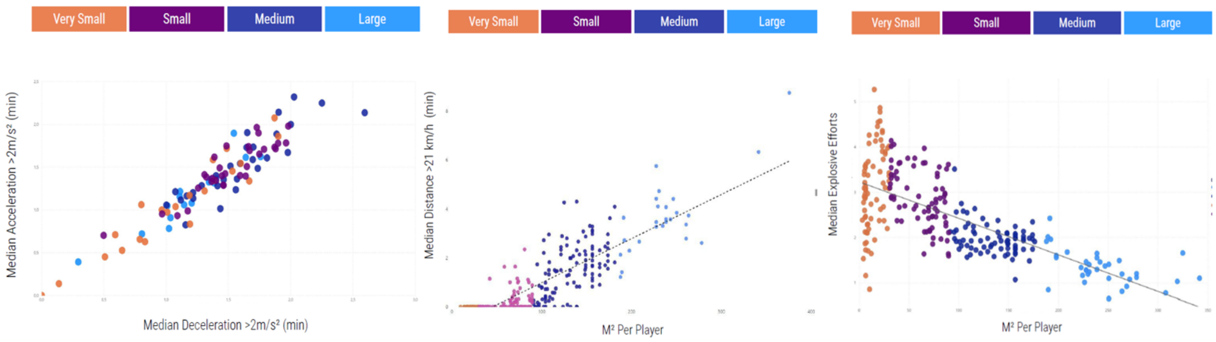


Fig. 2. Figures showing that high-band A:D & HSR decrease with smaller teams/ pitch sizes despite exertion and accelerometery demands increasing (Lisboa, unpublished).

Context is King & Misguided Metrics

When analysing load, we typically focus on the load value rather than how it was achieved. However, the context of how metrics are achieved is central to their effect. Aspects such as movement type, intensity, rest ratios, training area and environmental factors can all have significant effects on load metrics and athlete adaptations. As an example, Buchheit, Balaña et al. (2025) showed the amount HSR distance achieved in 45 min of a typical soccer match, is achieved in just 6 min of a typical linear conditioning drill. It is imperative that the metric(s) we utilise is a valid representation of the physical loading imparted on an athlete. Accordingly, GPS has an array of sophisticated velocity and accelerometery metrics capable of quantifying training load during different movement strategies and training methodologies. However, misinterpretation of what metrics represent, coupled with the array required for comprehensive analysis, often results in commonly utilised metrics substantially misrepresenting both external and internal load.

Many sports involve multiplanar efforts that require acceleration, deceleration and change of direction through cutting, curvilinear motion and pivoting – often termed 'mechanical load'. Such sports often use of sport-specific training (SST), such as small-sided games (SSG) and multidirectional running drills to condition athletes. Speed-based accelerations and decelerations (A:D) are often used to represent mechanical load, especially higher-band A:D (e.g. > 3m/s) due to the demands of faster speed changes. However, high-band A:D counts are often inversely correlated to mechanical demands during SSG's, as shown in Figure 2. Mechanical load typically increases as team size and area decrease, due to greater involvements in play and agility demands, but high-band A:D decrease due to insufficient space and continuous movement to achieve high velocities. Speed-based metrics also do not account for the increased centrifugal demands of curvilinear running and turning (Buchheit & Simpson 2017; Buchheit & Lopes-Segarra 2026). Furthermore, the 10-20 Hz data capture is often insufficient to pick up the constant micro-actions that occur in SST (Buchheit 2013). Collectively, these factors result in a substantial underestimation of physical loading during SST. As a result, many GPS norms used in practice describe only a fraction of the true work performed, especially during multidirectional, high-agility content.

Accelerometer-based inertial metrics provide a more detailed representation of changes in speed and direction, and therefore mechanical load. However, their adoption is less widespread due to familiarity and the need for multiple metrics and bands, plus noise affects from impacts and GPS unit instability. There are significant developments in this area, such as 'mechanical power' from ADI but currently there is not yet widespread adoption of this global measure for mechanical demands (Buchheit & Lopes-Segarra 2026). This is not a fault of the GPS, but the reality that we often use inappropriate metrics, and current analysis of mechanical demands requires multiple metrics, meaning interpretation and informed decision making is difficult. Development of a valid representation of external load during SST will hasten the evidence base for optimal training (Buchheit & Lopes-Segarra 2026).

Influence of Normative GPS Targets on Training Content

We have long held good knowledge about how to set training parameters to target specific qualities and balance load and recovery across the week. Historically, in line with the dose–response concept (Impellizzeri 2023), loading metrics were mainly used to check that planned work matched these aims.

For GPS-derived loads, this link is still weak. We do not yet know whether most GPS metrics show a clear dose–response relationship with adaptation. One of the few consistent findings comes from Ellis and colleagues (2020 & 2022), and even that work covers only a small part of the question. Basic issues remain open: how much is enough, how much is too much, and what a "minimum effective dose" looks like when it is defined from GPS rather than from performance or physiology. In the absence of this, targets often default to simple rules (for example "two times match demands") or arbitrary norms (Ravé 2020).

At the same time, GPS only gives a narrow view of load (Buchheit & Hader 2025). Locomotor data capture parts of neuromechanical stress but give very limited insight into neural demands and almost nothing about metabolic load (Buchheit, Akubat et al. 2025). Under pressure to produce desirable numbers, training plans often end up shaped by normative GPS targets instead of physiological needs, and the drive to avoid immediate injuries favours work that satisfies GPS benchmarks rather than work that best stimulates adaptation.

An example is the emergence of session 'top-ups' where conditioning is performed at the end of the planned session to achieve training load targets (Buchheit 2019a & 2019b). Most commonly, top-ups consist of linear running, as it offers an efficient and precise method to elicit key external metrics, such as distance and high-speed running. This efficiency and prior loading mean top-ups are often an insufficient stimulus to induce meaningful adaptation. Typical examples include performing a small number of pitch-length strides on extensive days to meet high-speed targets, or rehabbing athletes performing a few km low-intensity run to achieve weekly distance targets. Empirical observations indicate an increase in linear-based conditioning, driven partly by emergence of speed profiling methodologies and anaerobic speed reserve research, but further reinforced by an implicit bias toward efficiently satisfying normative GPS-derived key load metrics (Buchheit & Lopes-Segarra 2026). More challenging, sport-specific training loads may stray from normative boundaries and carry slightly higher short-term injury risk, but will better serve foundational objectives of enhanced performance potential and robustness over the long-term.

Non-Normative may be the Norm

Periodisation is a core principle of training design. Many programs intentionally vary their training content, which means rigid normative boundaries often fail to apply. This variation can occur in sports that use traditional periodisation models or during phases of rapid progression, such as preseason or rehabilitation. Even in sports with stable microcycles, factors like fixture scheduling, opponent demands, and injuries frequently lead to significant fluctuations in both training content and load.

Very high-intensity actions tend to occur infrequently due to less necessity, and exponential effect on fatigue and injury risk. Because they are performed in an all-or-nothing manner, their distribution is often non-normative. Their value is also typically low so a minor change can disproportionately affect normative statistics. While tools like box plots and log transformations can improve interpretation, decisions based solely on normative data for such metrics are often misguided.

Discussion and Conclusion

Normative GPS load analysis is widely adopted because it simplifies interpretation of wide-ranging load metrics and accumulative loads, and provides a theoretical safeguard against potentially excessive changes in physical load (Figure 1). However, industry trends and pressures mean many performance coaches feel bound to it. Its alignment to injury prevention is contributing to an environment where many are swayed towards job safety over fulfilling our core remit of maximising physical performance potential.

The extremely limited evidence-informed guidelines regarding locomotor loads (and so-called "GPS loads") has promoted normative analysis to fill the void, blurring what represents optimal and biasing current practices (Ravé 2020). At present, no GPS-based normative threshold can be defended as an evidence-derived optimal dose; most norms simply mirror historical loading patterns. The complexity and misrepresentation of GPS loading during multidirectional sport specific training (Buchheit & Lopes-Segarra 2026), and pressure to minimise immediate injury risk (Buchheit, Settembre et al. 2024), mean there is a preference for conditioning methods and metrics that are easily applied and efficiently meet normative targets, rather than what is truly impactful. These fallacies in GPS load management, combined with the strong influence of training context and the regular requirement to change training content, renders broad normative boundaries across multiple metrics both unrealistic and unsuitable. More work is needed to link detailed loading patterns to both performance and injury outcomes, rather than relying on descriptive norms as a proxy for dose–response.

When aiming to optimise training content, we should start with founding training principles, i.e., what are the main elements we want to improve, what are the training parameters required to do so (i.e., understanding the dose-response) and when can we best apply them to optimise performance at specific times. Applying the answer to these questions will best serve our performance aims and indirectly produce a framework that normative data aspires to.

Using normative information to adjust the training plan is often advantageous, but equally straying from normative boundaries should be wholly acceptable if there is good rationale, such as mitigating injuries, optimising athletic adaptations, periodisation strategies and training specificity. In practice, we still rely on normative GPS analysis for day-to-day squad monitoring, because it allows us to track many athletes and sessions and to present information in a way that coaches will act on. Our critique is not that norms should never be used, but that they should not be treated as evidence-informed targets or as a substitute for sound training principles. We would gladly reduce our dependence on normative dashboards if fewer, more valid metrics could capture the demands of sport-specific and multidirectional work (Buchheit & Lopes-Segarra 2026). Context is always key when examining data, and relevant planning and application will always be the cornerstone of elite performance (i.e., Sport Science 3.0 approach, Buchheit & Laursen 2024).

Key points

- GPS is central to load monitoring, and normative analysis (z-scores, benchmarks, traffic lights) is widely used to simplify large datasets.
- There is no evidence-based "optimal" GPS norm; current norms mainly mirror usual practice and may encode long-term undertraining, overtraining, or poor load–recovery sequencing.
- Standard GPS metrics, especially speed-based distance and acceleration counts, can misrepresent true mechanical and internal load in sport-specific, multidirectional training such as small-sided games, so many norms are built on a partial view of the work done.
- Training content is often adjusted to "hit the numbers" (e.g., linear running top-ups) rather than to target the most relevant physical qualities or context-specific needs.
- Broad GPS norms clash with periodisation, rapid progressions (preseason, rehab), and rare very high-intensity actions, making rigid adherence unrealistic and potentially harmful.
- The paper questions the validity of current GPS norms as targets and argues that training should be driven by foundational principles (dose–response, specificity, periodisation), using GPS data as contextual support rather than strict constraints.
- More work is needed to link detailed loading patterns with both performance and injury outcomes instead of using descriptive GPS norms as a proxy for dose–response.
- GPS norms remain useful for day-to-day squad monitoring and communication with coaches, but they should act as contextual guides, not fixed targets or substitutes for sound training principles.

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