Module 1. Load Control and Monitoring for Performance Optimization. Application of Microtechnology

BARÇA INNOVATION HUB Universitas

1. Load Control and Monitoring for Performance Optimization. Application of Microtechnology

In today's elite sports, the focus has shifted from mere entertainment and leisure to a professionalized industry, aiming to generate substantial economic returns. Essentially, it has become a business, which has led to various changes, such as the alteration of sports calendars and the increase in the number of weekly matches. As a result, sports calendars now include a significantly higher number of competitions during the season.

This situation puts elite athletes, both young and adult, under greater pressure to enhance their performance and achieve sporting success. Consequently, this directly affects the physical demands placed on athletes, both in training and during competitions. Elite athletes, both young and adult, have thus experienced an increase in both the volume and intensity of training loads throughout a season and their sports careers.

As a result, technical teams in clubs and national teams aim to optimize performance using various methods, content, and strategies at their disposal.

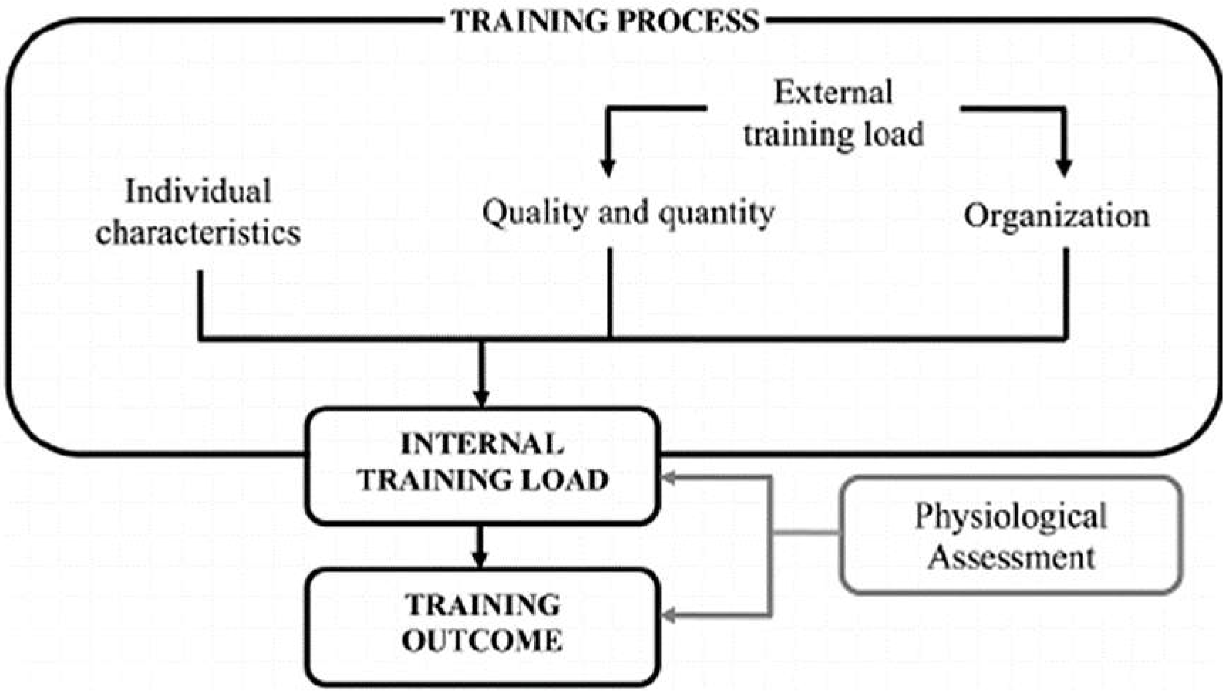
Across all sports, and especially in team sports, the use of technological advancements has become widespread, integrating into different aspects of athletic preparation. The objective of these innovations is to optimize both individual and team performance, reduce injury risk, support rehabilitation, and improve sports equipment, all of which are related to training and competition load.

The key question we can ask is: what exactly is load? Some experts define load as the effect on an athlete's functional state resulting from the effort they exert (Zintl, 1991). In other words, it refers to how an athlete's behavior is influenced by training stimuli.

Meanwhile, González Badillo and Ribas Serna (2002) define internal or real load as the biological and psychological responses triggered by the external or proposed load during training or competition. From this definition, we can understand external load as a synonym for physical demands.

The following figure illustrates the structure of the training process.

Figure 1: Process of training and load



Source: Impellizzeri et al., 2005, https://goo.su/NzkdG9T

The figure above highlights different components of the training process. External load (physical demands) will depend on the quantity, quality, and organization of the exercises during training sessions or across a series of sessions throughout the training process. Naturally, this load also depends on the individual characteristics of each player and the collective dynamics of the team, including the game model.

How does each athlete respond to a given physical demand? Each athlete will have an individual response (internal load), which can vary depending on the external load they experience and their personal characteristics. This individual response will yield results that can be measured physiologically.

Therefore, evaluating the physiological responses to the training process allows us to better understand and interpret physical tests used to assess the effectiveness of training programs, helping us better analyze conditional tests. Moreover, we can assess how training loads are organized, enabling us to design better periodization strategies. This process also helps identify athletes who don't respond as expected to the training stimuli (it's advisable to monitor the alignment between an athlete's actual response to training and the expected response by the coach). In essence, this comparison reveals whether the anticipated outcomes on paper align with the actual responses of each athlete (and the team collectively), which helps us adjust the training process before evaluating final results and provides insight into how training will affect performance.

Recent research has updated the previous understanding of the load-performance relationship, proposing that performance is influenced by several key factors. Training objectives must be defined to target these factors effectively. These objectives are achieved by designing preferential simulation situations (tasks or exercises), which are influenced by quantitative and qualitative elements and their organization over time, both within a session and across multiple sessions (Impellizzeri et al., 2019).

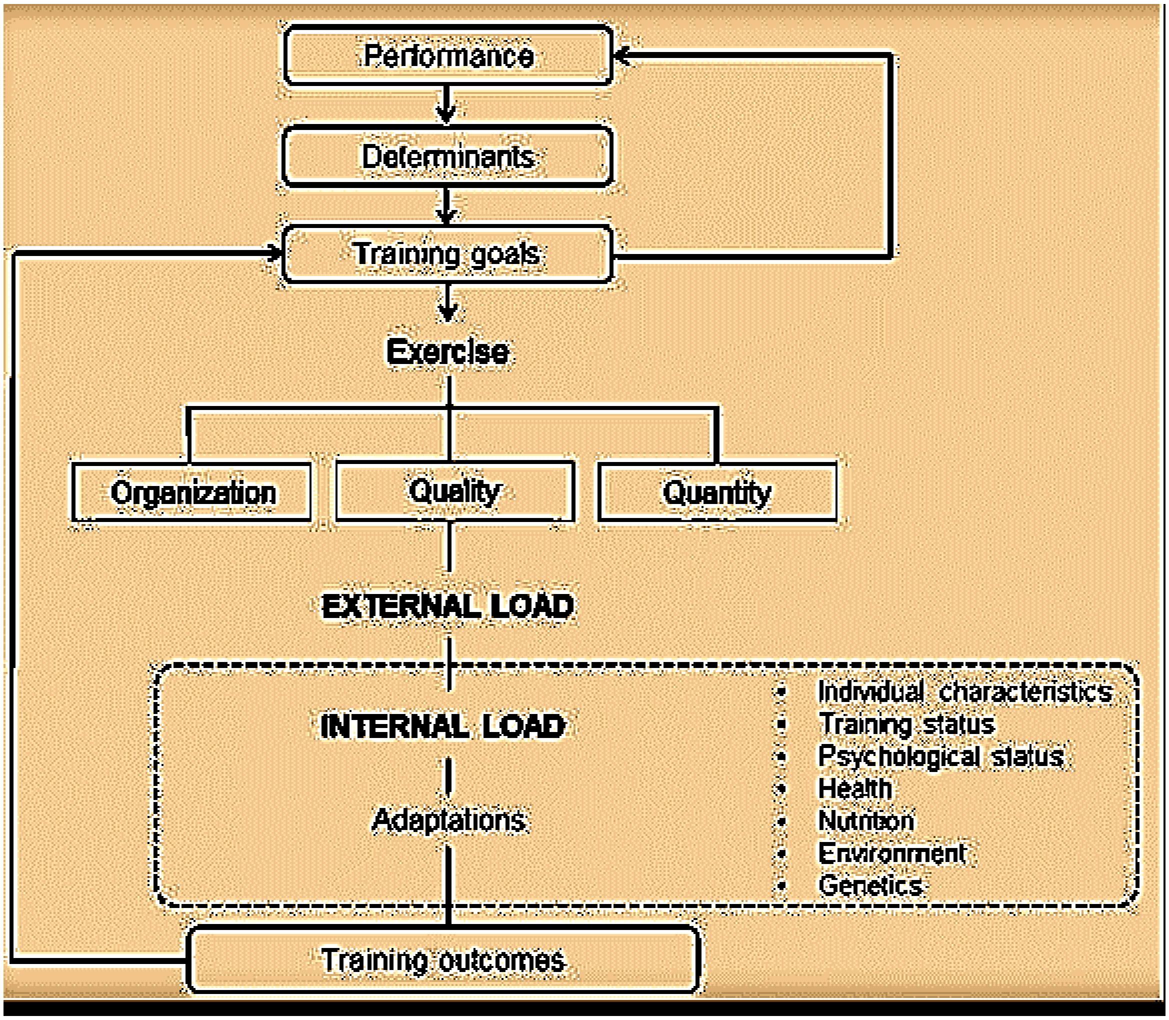
There is a direct connection between the tasks set and the physical demands (external load) experienced, which lead to an individual response (internal load) and ultimately trigger a series of adaptations. These adaptations directly affect training objectives and, by extension, sports performance.

According to González Badillo and Ribas Serna (2002), internal load refers to:

- ○ Maximizing high-speed actions
- ○ The biological and psychological responses triggered by the external or proposed load in training or competition.

SUBMIT

Figure 2: Relationship between external and internal load and performance



Source: Impellizzeri et al., 2019, https://goo.su/SUEl

The following figure offers further information on training and competition stimuli, which comprise a process involving psychological, physiological, and social factors. In the first two elements, two inseparable factors will always be present: stress, accompanied by fatigue, and recovery, which promotes system homeostasis. Both stress and recovery are crucial for optimizing training loads.

Figure 3: Balancing stress and recovery in sports

Source: Adapted from Brink et al., 2010

		Stimulus			
Process					
Psychological – stress/recovery		Physiological – stress/recovery			Social

		IMAGEN SILUETA			
Outcome					
		Athletic balance			
Performance improvement		Adaptation	Misadaptation		Injuries Illness Overtraining

The integration of these processes leads to various changes, producing outcomes for each athlete based on factors such as the relationship between stress (stimulus) and recovery. Consequently, there are two possible outcomes: one that improves performance and another that increases the risk of injury or illness.

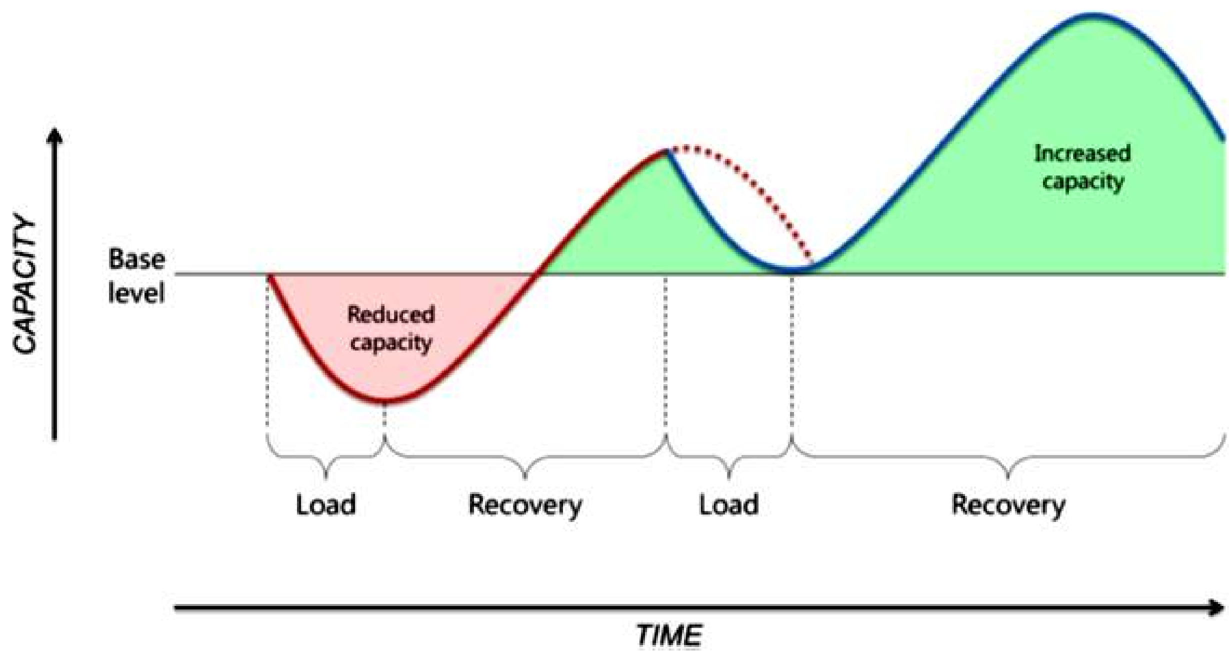
Referring to Selye's law of biological adaptation (1963), a foundational principle in training theory, we know that the nature of prescribed loads determines the adaptations that help improve sports performance, particularly in the athlete's bioenergetic and conditional structures. This principle must be considered to enhance sports performance while understanding the specific structures that are influenced by training loads.

According to Impellizzeri (2019), what factors should be taken into account in relation to external and internal load and sports performance?

- ◯ Psychological - physiological - social factors
- ◯ Metabolic - structural - neuromuscular factors

SUBMIT

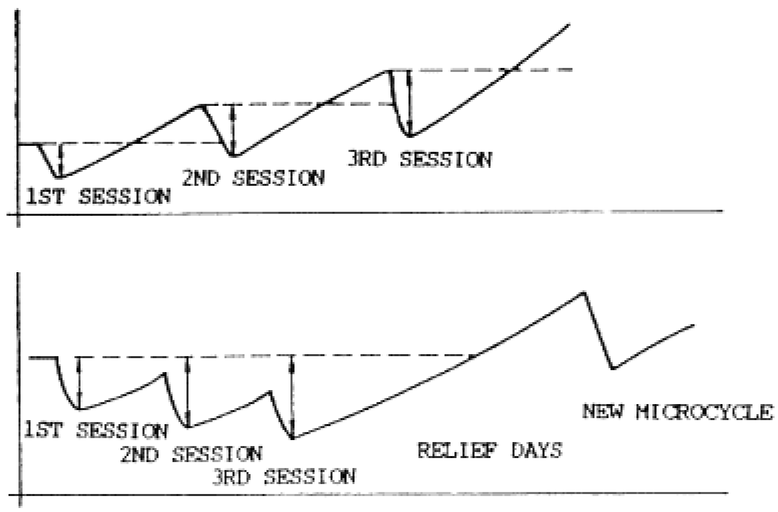
Figure 4: The principle of adaptation to training



Source: Soligard et al., 2016, https://goo.su/bEc5X

Depending on how we manage loads, two main responses occur. One response leads to positive adaptations and performance improvements, while the other occurs when expected adaptations do not take place, resulting in a worse performance. Figure 5 depicts these two types of adaptation responses, classified as either adequate or inadequate adaptation (Viru and Viru, 2000). Despite these dynamics, coaching team may sometimes deliberately seek inadequate responses during preseason, for example.

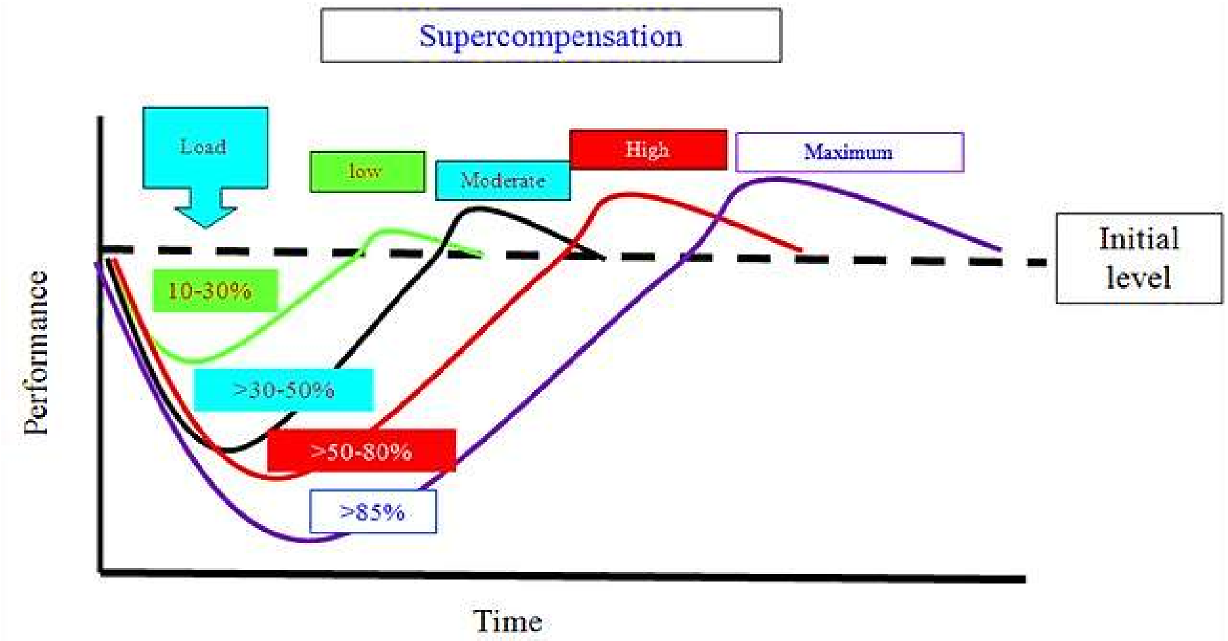
Figure 5: Training and adequate adaptation vs. training and inadequate adaptation



Source: Viru y Viru, 2000, https://goo.su/cADTrq6

Additionally, the next figure shows that the adaptations achieved also depend on the magnitude of the prescribed load (Nacleiro et al., 2013). In other words, stimuli can vary in intensity: low, moderate, high, or maximum load. The choice and combination of these stimuli determine the extent of adaptations, which can vary based on the magnitude of the prescribed load. It is important not to exceed what we define as excessive load—stimuli that surpass desired limits, as we will explore further.

Figure 6: Theoretical adaptations based on load magnitude



Source: Nacleiro et al., 2013, https://goo.su/S7PhB

Typically, coaching team collectively manage training loads, considering the general condition of the team as a whole. However, the true effect of these stimuli on each individual athlete is not considered, meaning the specific responses of each player are often overlooked. Each athlete responds differently to the same training or competition stimulus, so it is crucial to monitor individual responses whenever possible. The outcome of the external load will depend on the unique characteristics of each player, as demonstrated in Figure 2.

External load can be measured using time/movement analysis, optical tracking systems (video analysis), inertial microtechnology, and positioning systems (global or local), which will be explained in detail later.

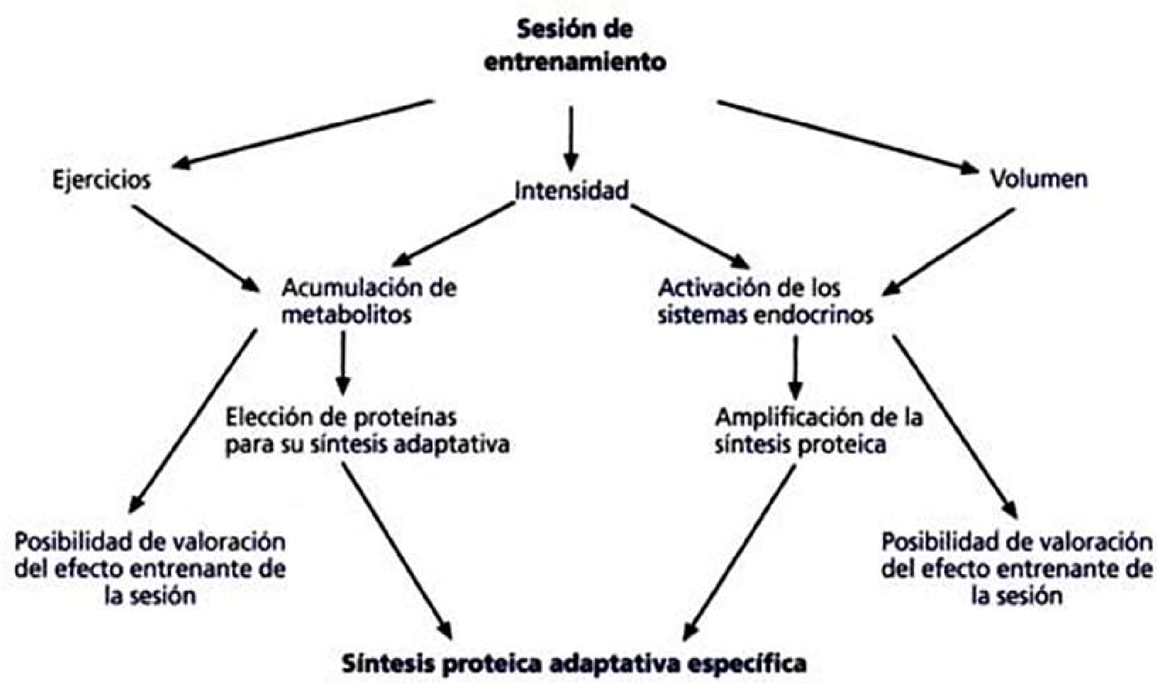
As for internal load, it can be quantified and evaluated using indicators such as heart rate, heart rate variability, lactate levels, oxygen consumption, and the depletion of substrates like potassium and sodium, as well as muscle damage, which can be detected through enzyme markers like creatine kinase.

Returning to the relationship between load and fatigue, it is just as important to properly manage the proposed training stimulus as it is to manage recovery time and methods to prevent a decline in performance, either from excessive or insufficient stimuli. In other words, we need to be mindful not only of overtraining but also of whether the prescribed training load is too low. But how do we measure the stimulus? The stimulus should be assessed by its magnitude.

As mentioned, for a stimulus to be deemed adequate, it depends not only on its magnitude but also on the athlete's current condition and their response to it. In other words, the stimulus magnitude triggers physiological changes in the neuromuscular, hormonal, cardiovascular, respiratory, and metabolic systems, and may also cause biomechanical changes in other variables such as strength, speed, or a combination of both (power).

Looking at the following figure, which illustrates Viru's (1995) model, we see that three key elements stand out in a training session: exercises, intensity, and volume. These elements will generate responses like the accumulation of metabolites or the activation of endocrine systems, leading to a selection of protein synthesis that is specific to the stimulus, depending on the type of training stimulus applied to the athletes.

Figure 7: Key elements of a training session



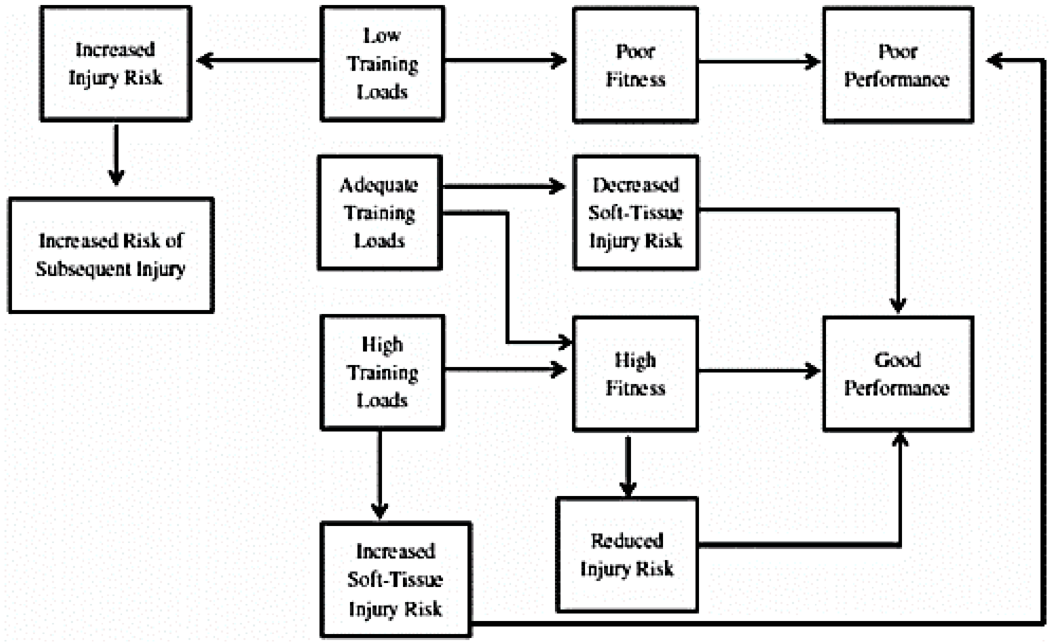
Source: Viru, 1995, https://goo.su/LWi9

Depending on the load magnitude, we have different ways of classifying training loads. If the load is low or very low, it can be considered an insufficient training stimulus, meaning it won't lead to any adaptation. However, a low load can be applied with the aim of aiding recovery, helping the athlete’s body return to homeostasis after one or more previous stimuli (this load won’t enhance performance). A maintenance load will simply maintain the athlete's current performance level, while a "training" load can lead to performance improvements. This type of load is what promotes physical improvement in athletes. Above this load magnitude is what we call an excessive load, which doesn’t yield positive effects but rather negative ones, as it exceeds the athlete’s capacity for adaptation.

Once again, it’s important to emphasize that these adaptations mainly involve the athlete's conditional and bioenergetic structures.

Recent scientific literature offers a practical classification of load based on its magnitude, divided into three categories (figure 8).

Figure 8: Relationship between physical attributes, training load, and injury risk in team sports

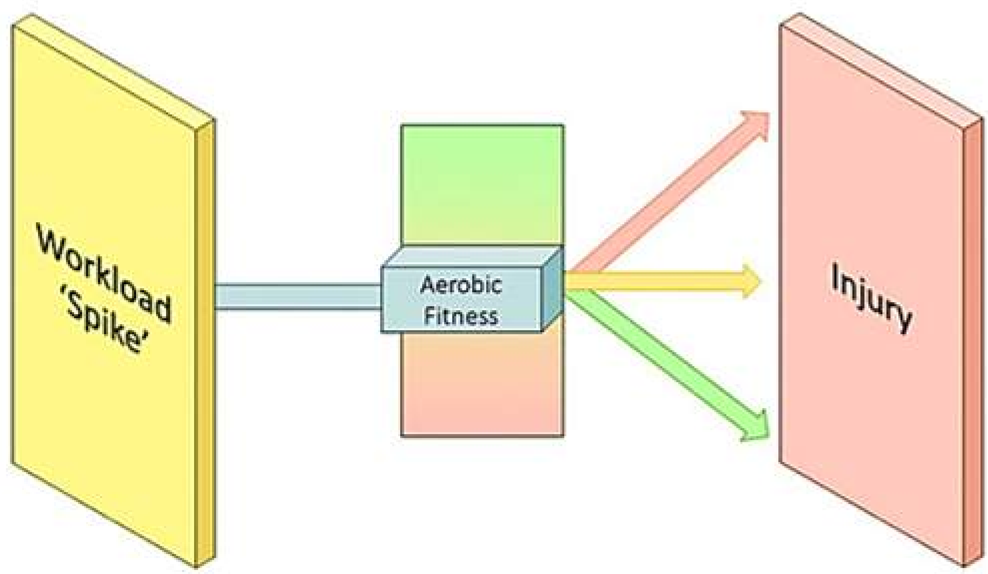


Source: Gabbett, 2016, https://goo.su/waIG

We can differentiate a low load, which results in poor physical conditioning adaptation and low performance, often accompanied by an increased injury risk due to its insufficiency. The next level consists of appropriate/optimal training loads, which minimize injury risk while improving physical conditioning, potentially enhancing sports performance. Finally, high loads may result in a temporary boost in fitness and possibly improve performance temporarily. However, repeated application of high loads will increase the risk of injury. Therefore, as strength and conditioning coaches, our main goal is to find the optimal load dosage to achieve the desired training outcomes and optimize performance.

Additionally, when focusing on the athlete's conditional structure, physical conditioning (speed, repeated sprint ability, and strength) acts as a moderator in the relationship between load and injuries (Gabbett, 2018). For example, a peak in workload may pose varying injury risks depending on the athlete’s level of physical condition (figure 9). This highlights the importance of properly training the athlete's conditional and bioenergetic structure.

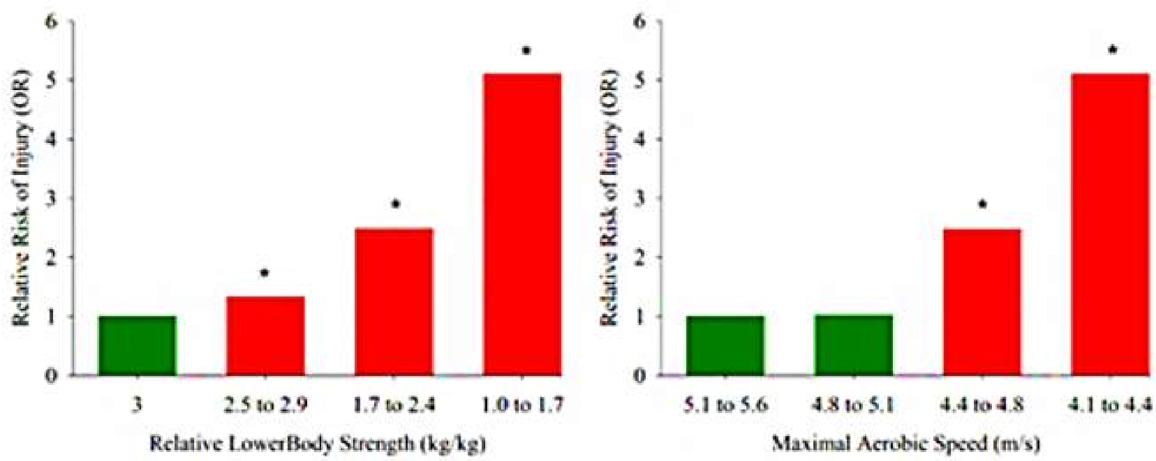
Figure 9: Example of how moderating factors explain the link between a peak workload and potential subsequent injury



Source: Gabbett, 2018, https://goo.su/lH5ZEL

In this regard, Figure 10 presents aerobic capacity and lower body strength levels as moderators of the relationship between workload and injury (Gabbett, 2018).

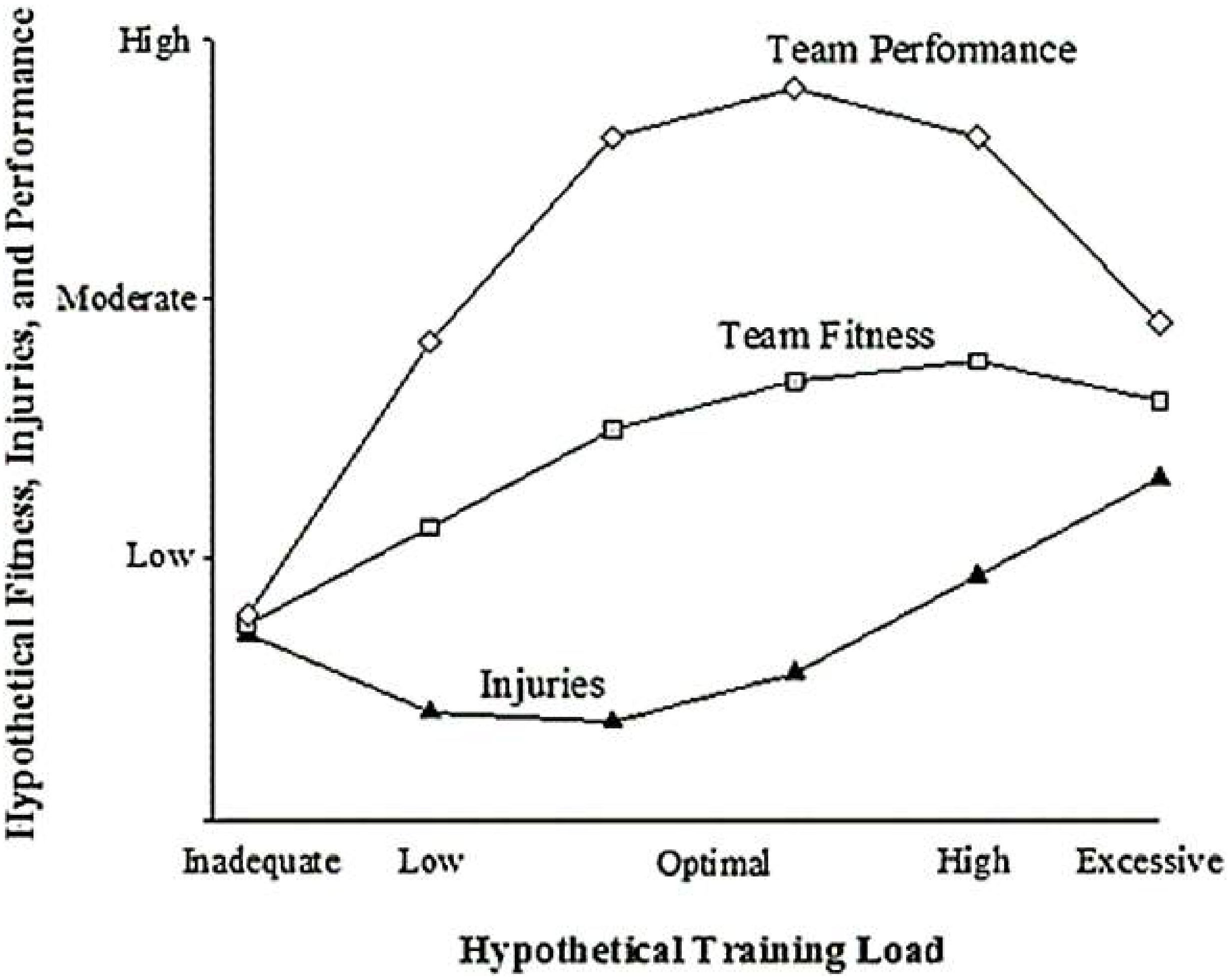
Figure 10: Aerobic capacity and lower body strength as moderators of the workload-injury relationship



Source: Gabbett, 2018, https://goo.su/lH5ZEL

On the other hand, the next figure introduces the hypothetical relationship between three crucial concepts, complementing the information in the previous figure (the link between physical attributes, training load, and injury risk in team sports): team sports performance, injury risk, and fitness/conditioning (Gabbett, 2016).

Figure 11: Hypothetical relationship between training load, fitness, injuries, and performance



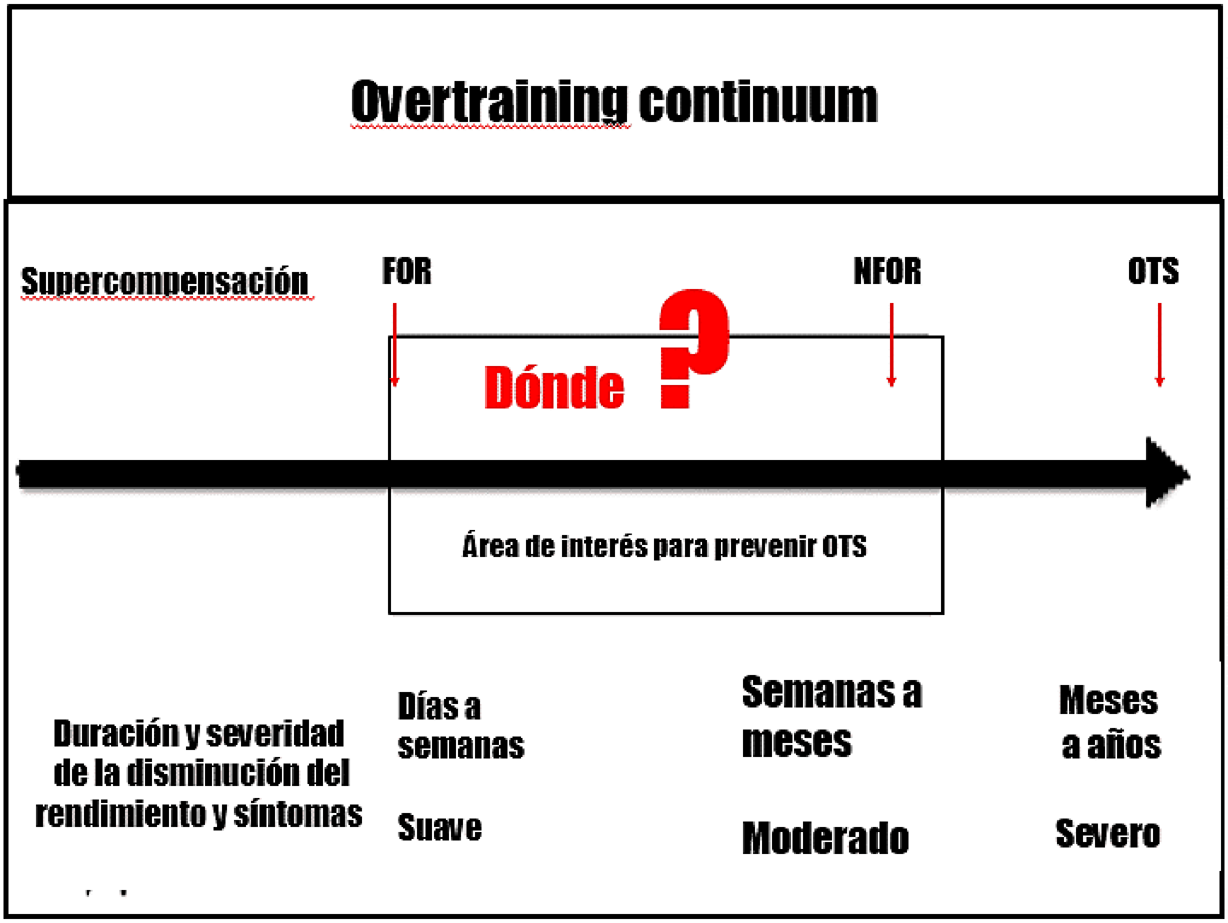
Source: Gabbett, 2016, https://goo.su/walG

These three concepts interact depending on whether the proposed loads are inadequate, low, optimal, high, or excessive. When loads are high or excessive, injuries will increase, and performance and fitness levels will decline. Lowering the load to very low levels may reduce injury risk but will also result in suboptimal performance and fitness. However, if we manage to find the right training load, we can balance the three concepts, achieving peak team performance, low injury risk, and high fitness levels. Therefore, team performance improvements stem, among other factors, from prescribing the optimal training load and allowing appropriate recovery periods to maximize adaptation before competition.

Another challenge when periodizing and applying training loads is that players have different technical-tactical and conditional abilities, which adds complexity to optimizing team performance. This makes it difficult to find the ideal load dose that optimizes most of the team's players during different stages of the microcycle and/or season, especially during key moments in the schedule.

Another topic to clarify in this module is the proper understanding of the overtraining syndrome (OTS) as an ongoing process.

Figure 12: Continuous process of overtraining



Source: Adapted from Brink et al., 2010

Overtraining Continuum				
Supercompensation	FOR	**Where?**	NFOR	OTS
Areas of interest in preventing OTS				

Duration and severity of performance decline and symptoms	Days to weeks	Weeks to months	Months to years
	Mild	Moderate	Severe

This interpretation suggests that there is no specific moment when players become overtrained; rather, the process is gradual and cannot be pinpointed to a single line or moment. However, we can identify different zones throughout this process.

The first is called functional overreaching, where the player's performance is below their usual level. This state is often deliberately induced as part of the periodization process. For instance, during preseason, training loads are designed to achieve medium- or long-term results rather than short-term or immediate gains. To achieve this, we apply different stimuli over time, generating accumulated fatigue, so that, once this fatigue is overcome, and with proper recovery, the athlete produces medium- or long-term adaptations.

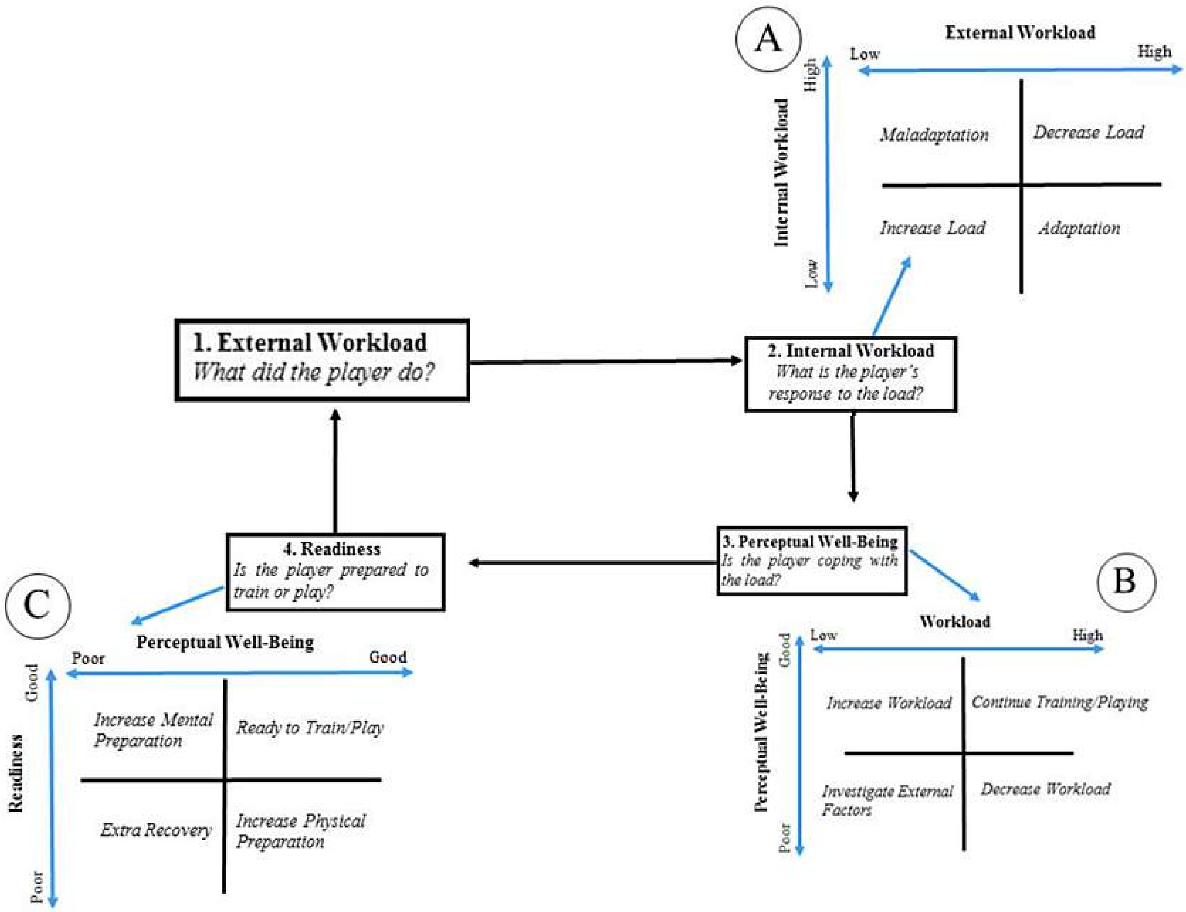
Another zone is non-functional overreaching, which lasts weeks or months. This state is undesirable, arising from poor training periodization and an incorrect choice of training combined with the match schedule.

If the process continues, it may lead to overtraining syndrome. This condition would have serious consequences for both the athlete's performance and health. While it is relatively easy to enter the first zone—and occasionally the second—reaching the overtraining syndrome is rare in indoor team sports, at least based on our experience.

We have emphasized the importance and impact of training load on training outcomes and objectives to optimize performance (and reduce injury risk). Therefore, we must monitor, control, and evaluate both training and competition loads (Gabbett et al., 2017).

To achieve this, we need to establish a cycle of training monitoring, as outlined in the following figure.

Figure 13: Athlete monitoring cycle



Source: Gabbett et al., 2017, https://goo.su/Hug8Us

Before creating the monitoring cycle, it's essential to accept that no single data point can fully represent the total load an athlete experiences as a whole, as emphasized in this certificate. This is because, despite technological advances, most of the player's structures involved in training can't be measured during training or competition. Therefore, we must acknowledge a temporary departure from the complexity-based beliefs presented in the initial course. In this scenario, we have no choice but to isolate certain structures and concentrate mainly on the load carried by conditional and bioenergetic structures.

Based on the monitoring cycle shown earlier, the first phase of this process involves understanding the physical demands (external load). To achieve this, we first quantify how much our players run, jump, and how fast they move; then, we measure the internal response to these demands; next, we assess player well-being after enduring the load; and finally, we determine their readiness for the next session, be it training or competition.

However, this monitoring process doesn't stop here; it’s crucial to establish a relationship between each step mentioned and the previous one. This connection is represented in each quadrant (A, B, and C of the figure), helping us make practical decisions for managing upcoming stimuli. In this way, we can link internal load with the physical demands endured. For example, when facing high external and internal loads, what should we infer and what decisions should we make? The answer is simple. We must reduce the training load for the next session.

On the other hand, if there's a high external load but a low internal response, it indicates a good adaptation of the athlete to the stimuli. In contrast, a low external load with a high internal response may suggest poor adaptation to the training loads. Lastly, if both external and internal loads are low, it’s likely that the training loads should be increased. This approach allows us to progress through each block of the athlete monitoring cycle. The final phase, readiness for the next stimulus, can sometimes be skipped, allowing us to move from the third phase back to the first. In this module, we'll focus on the external load.

Monitoring sports movements has always been a focus of interest, particularly for sports scientists (Carling et al., 2008). Today, we can say that technical staff increasingly rely on scientific evidence to optimize performance and prevent injuries, with an emphasis on monitoring athletes' physical demands. Recent technological advances have contributed significantly to the evolution of sports science. As a result, strength and conditioning coaches have become crucial figures within the multidisciplinary approach of coaching team. One of the key objectives of strength and conditioning coaches, alongside the technical staff, is to keep the team in peak condition for most of the competition.

Four main variables define episodes of duels and dual conflicts in indoor team sports, directly affecting physical demands: game duration, the playing area (Table 2), the number of players, and the rules.

These parameters shape the physical demands in both competition and training, causing specific physiological responses and adaptations in each player.

Table 2: Parameters shaping physical demands in various team sports

	Basketball	Futsal	Handball	Rink hockey	Soccer
Playing area (m)	Indoor 28 × 15	Indoor 40 × 20	Indoor 40 × 20	Indoor 40 × 20 (With fences)	Outdoor 100 × 80
Field players (n)	5	4	6	4	10
Duration (min)	4 × 10	2 × 20	2 × 30	2 × 25	2 × 45
Time-outs (n)	10	4	6	8	No
Clock	Stopped	Stopped	Continuous	Stopped	Continuous
Substitutions	Unlimited when the clock is stopped	Unlimited when the clock is stopped	Unlimited with clock running	Unlimited with clock running	Three per team

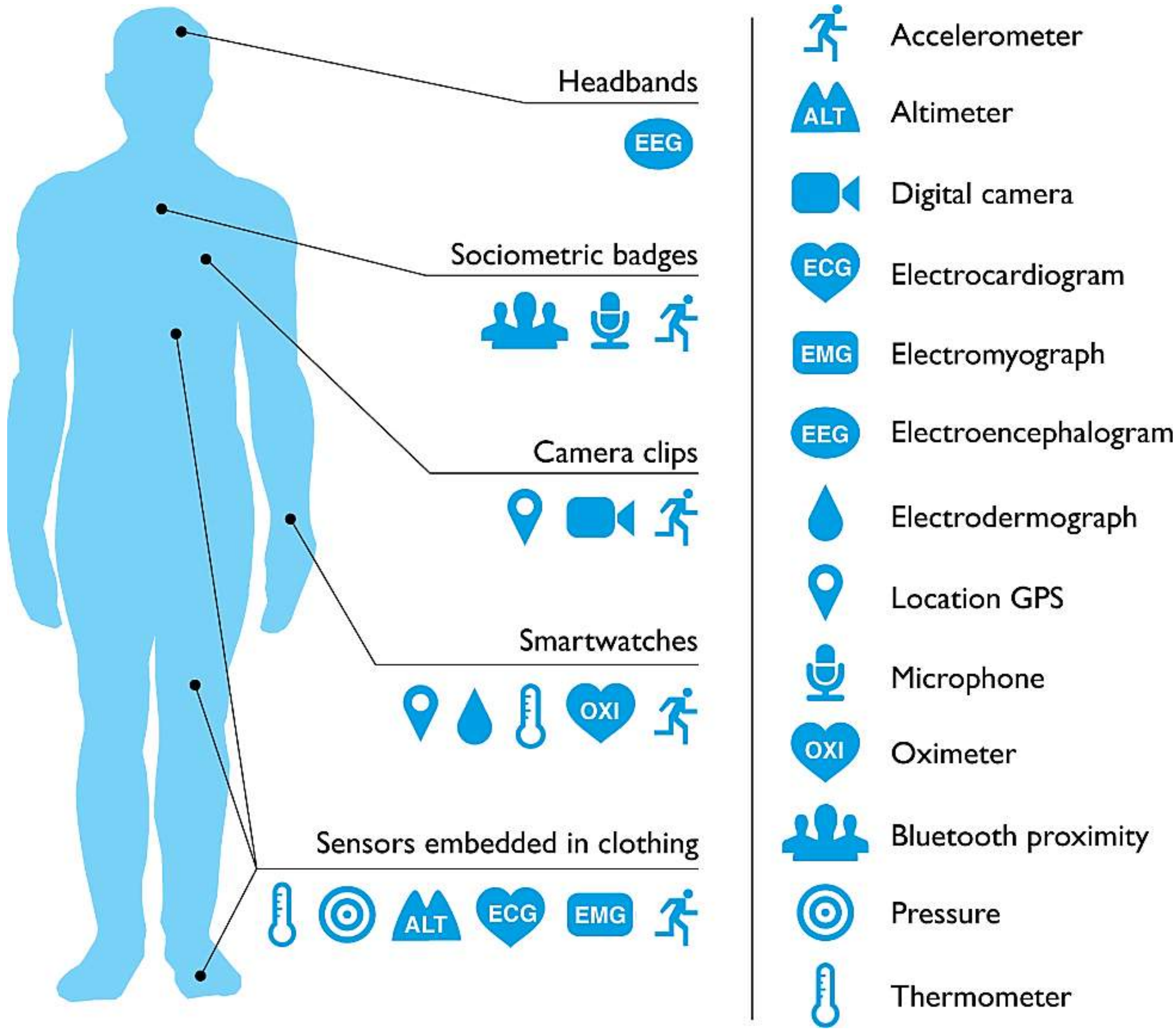
Source: García et al., 2022, https://goo.su/UDbfm

The training plan can steer and promote these adaptations, helping players adjust to the demands of their particular sport, whether it’s futsal, basketball, rink hockey, handball, etc. Adaptation will also depend on contextual factors such as the competition type, player position, and the competitive level or category of the team. As mentioned earlier, certain levels of external load may increase the risk of injury, especially if those levels are high or very high. These factors must be considered, and we will address them in more detail later.

There are three main systems for monitoring external load: video camera systems with optical sensors, inertial systems (IMU, inertial measurement unit), and local or global positioning systems. These systems are collectively referred to as EPTS (Electronic Performance and Tracking Systems). The EPTS concept encompasses the technologies used to monitor individual and team performance in sports.

Today, wearable technology includes headbands, sociometric devices that measure interactions, cameras, smartwatches, and even embedded devices in sportswear (Piwek et al., 2016), as shown in Figure 14. All this is possible thanks to the various applications that help us manage the data. To understand the significance of these technological advancements in sports, it was estimated that in 2018, 119 million people could use these devices and applications (Piwek et al., 2016). However, these developments also bring a critical challenge: ensuring that the data obtained is accurate and analyzed correctly.

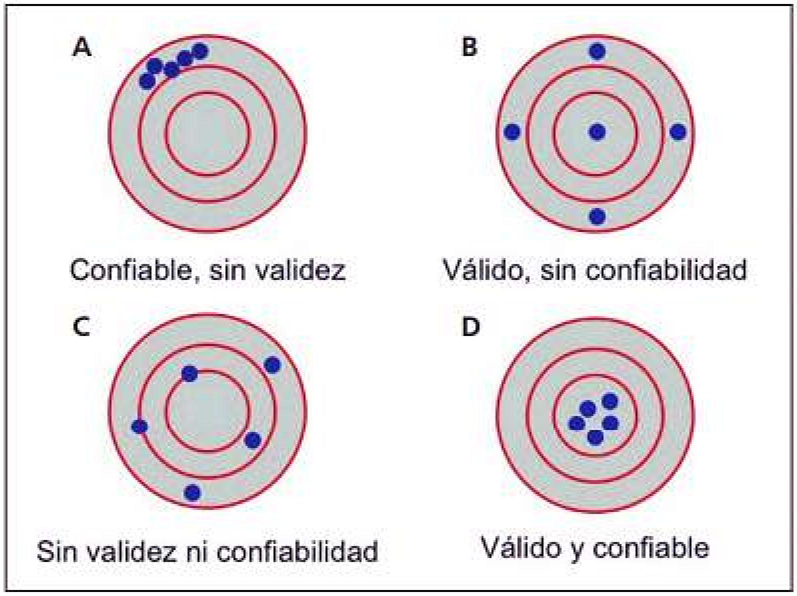
Figure 14: Wearable technology



Source: Piwek et al., 2016, https://goo.su/Y8xiBd

This leads to two important concepts in data collection and analysis: validity and reproducibility. For example, only 5% of current technology is validated, which is why we must ensure the data we collect is rigorously measured, analyzed, and interpreted. As illustrated in the following figure, some systems are neither valid nor reproducible, some are valid but not reproducible, some are reproducible but not valid, and others are both valid and reproducible.

Figure 15: Example of validity and reproducibility



Source: Manterola, 2018, https://goo.su/SSAX

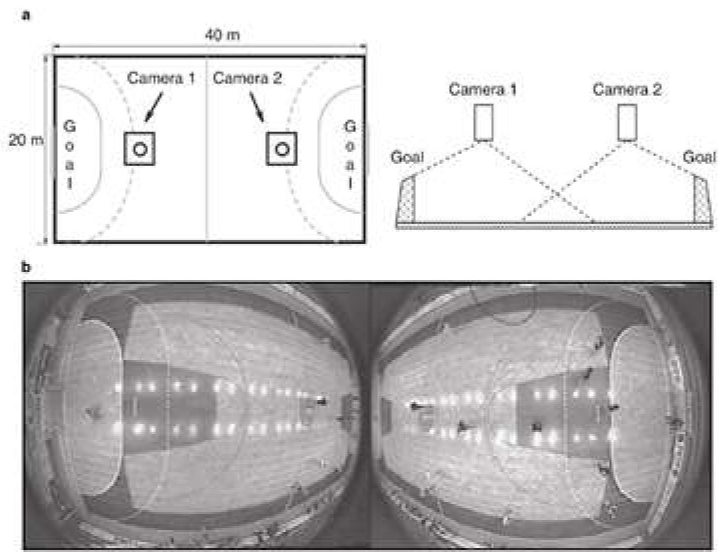
Let’s take an example to clarify this concept. A person steps on a scale and weighs 68 kg, but when they step back on it moments later, it reads 80 kg. This device isn't reproducible. For it to be valid, we’d need to compare it to a gold standard to see if it correctly measures what it claims to.

With that brief clarification, we now return to the three systems for monitoring physical demands mentioned earlier.

Barris and Button (2008) used two cameras mounted on the ceiling to analyze the locomotor actions performed by athletes during the game

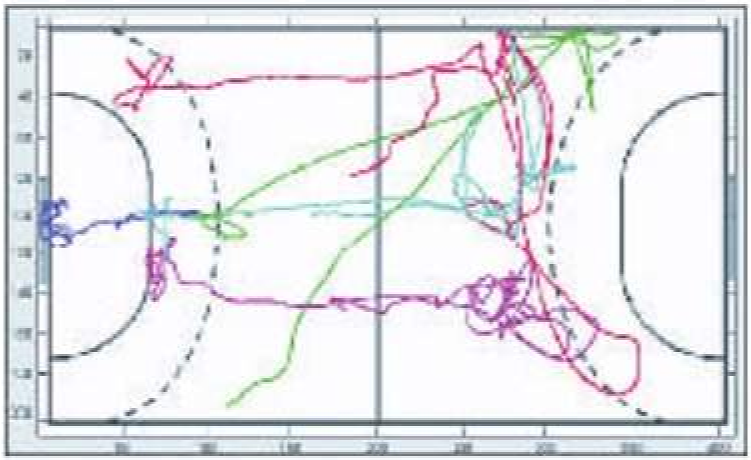
(Figure 16) and track each player's movements (Figure 17).

Figure 16: Monitoring via optical systems (video cameras)



Source: Barris y Button, 2008, https://goo.su/FtS4FP

Figure 17: Visualization of space-time trajectories covered



Source: Barris y Button, 2008, https://goo.su/FtS4FP

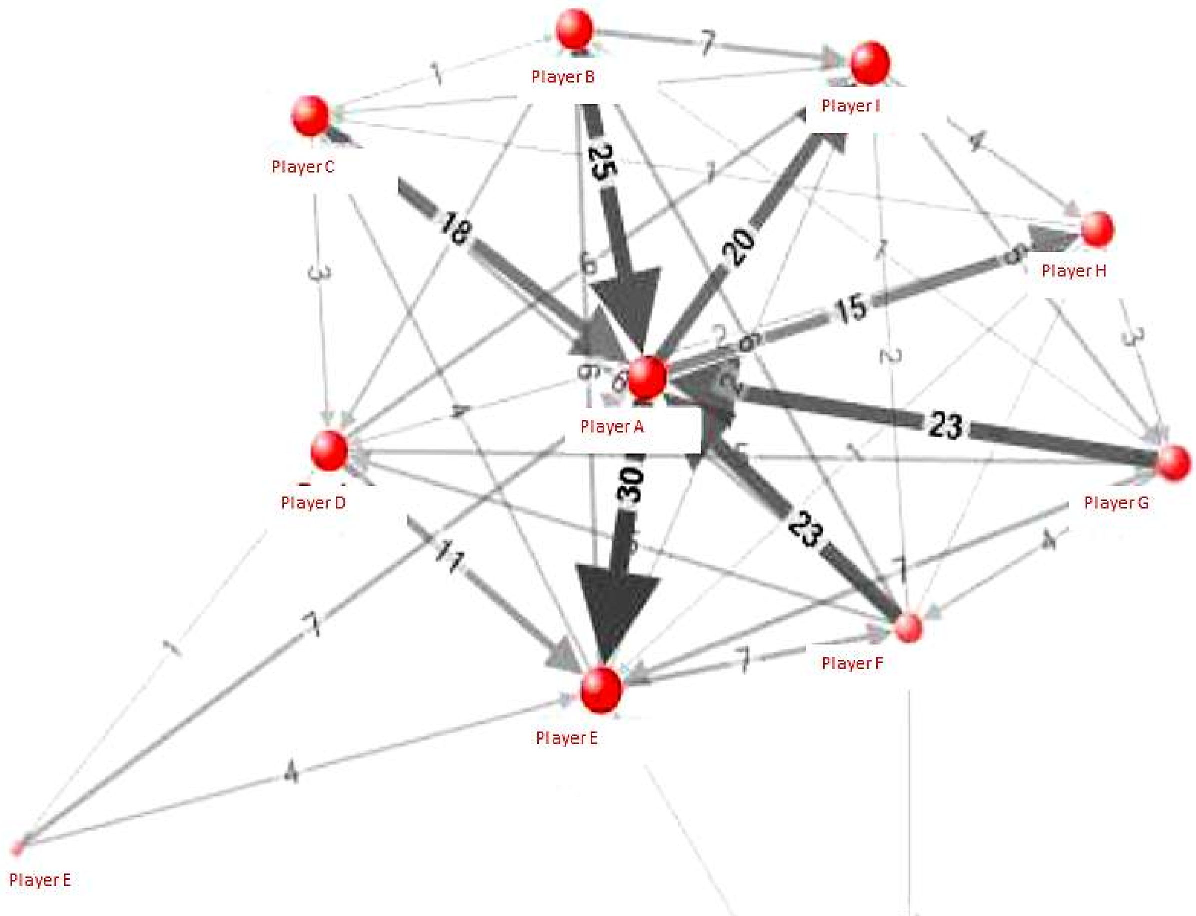
One notable example of these systems is their use in the NBA, the world’s premier basketball league. The SportVU camera-based tracking system can follow player movements in real-time. Originally developed to track ballistic missiles, it's now used by a select few clubs due to its high cost.

This system captures images 25 times per second via special ceiling cameras (calibrated before the game begins). The software then processes the data, generating various statistical analyses. In total, the system can track about 72,000 X/Y coordinates for players in an NBA game. Additionally, it tracks the X/Y/Z coordinates of the ball. One major challenge is avoiding obstacles that affect the artificial vision, such as court lines or reflections from advertising signs. This system provides extensive data, including player speed, distance covered, and more.

Another method for analyzing and interpreting the game was utilized in a study conducted by an engineer from the Polytechnic University of Catalonia, Terrassa, Spain (Cencerrado, 2014). In this study, the author analyzed the 2014 Copa del Rey basketball final between FC Barcelona and Real Madrid. The author assessed the relationships formed between players based on the passes they made or received. This analysis revealed, as shown in Figure 18, that Barcelona's playing style was heavily influenced by the hierarchy between a Brazilian point guard and the team's shooting guard, one of the best Spanish players in the club's history.

The arrows represent the interactions through passes between two players, while the size of the nodes reflects the number of passes received. On the other hand, Real Madrid's model did not demonstrate a similarly significant relationship between their point guard and shooting guard. The pass distribution in Real Madrid was more balanced compared to Barcelona's, resulting in a more evenly distributed style of play.

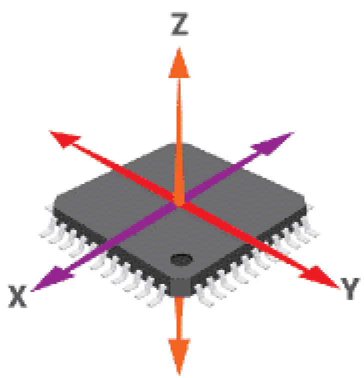
Figure 18: FC Barcelona passing network



Source: Adapted from Cencerrado, 2014

Inertial Measurement Unit (IMU) Systems consist of accelerometers, gyroscopes, and magnetometers. Accelerometers measure linear acceleration; gyroscopes measure angular velocity; magnetometers measure the direction of a magnetic field. Using these three sensors, we can study movement either on a plane or in space, depending on the number of axes the devices have.

Figure 19: Inertial Measurement Unit Systems and Axes of Movement.



Source: Diwo, n.d., https://goo.su/nORDauF

When discussing inertial measurement units, it's important to highlight a variable commonly known as "player load," frequently cited in scientific literature. This variable is calculated as the square root of the sum of the squared differences of instantaneous accelerations across each axis, as illustrated in the following algorithm.

$$\text{Player } \mathcal{Load} = \sqrt{\left(\ _{n}\ \ _{n-1}\right)\left(\ _{n}\ \ _{n-1}\right)\left(\ _{n}\ \ _{N-1}\right)^{2}}$$

Essentially, this parameter provides an overall view of the athlete's movement. It's important to note that the acceleration data obtained via IMU (inertial measurement unit) systems will differ from those gathered through local or global positioning systems, which we will cover next.

To monitor physical demands, in addition to video camera systems (optical systems) and IMUs, global navigation satellite systems (GNSS) are used. Although GNSS systems cannot be used in indoor team sports, it's worth mentioning some of their characteristics since they form the basis of local positioning systems.

GNSS is a satellite-based radionavigation system established by the United States Department of Defense (GPS) in 1973, although it took several more years to be fully implemented. This technology allows the real-time location of any object or person, whether stationary or in motion, at any time of the day.

GNSS relies on magnetic resonance, which in turn relies on atomic clocks. Atomic clocks provide an extremely precise control of time (Nicholson et al., 2015).

Research into the use of GNSS for physical demand monitoring has grown exponentially (Malone et al., 2016), as seen in Figure 20.

Figure 20: The inclusion of GNSS devices in sport science publications.

Source: Malone et al., 2016, https://goo.su/mslY

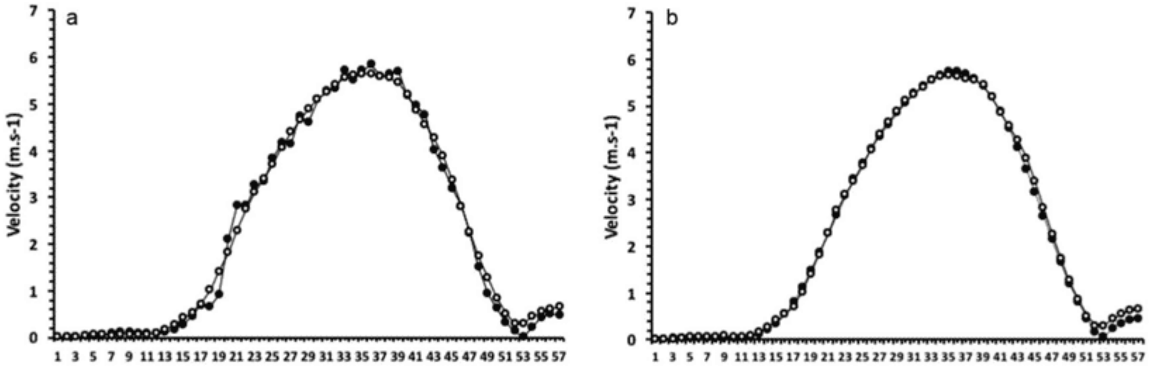
As we've seen, GNSS systems can be used in outdoor sports like football, rugby, and field hockey, but they cannot be used in indoor sports due to the inability to receive satellite signals from space. This issue was initially addressed with the use of IMUs, and today, technology allows for the implementation of local positioning systems (LPS).

Nowadays, it's possible to place antennas inside indoor arenas that replace satellites in space, enabling us to track the position of each player on the field. Typically, six antennas are used, emitting signals received by the sensors each player wears in a vest on their upper back. The system calculates how long it takes to receive the signal and uses this to determine the player's location on the court, as long as the signal is received from at least three antennas (triangulation).

Positioning systems have proven to be valid and reproducible, offering a wealth of information. One disadvantage, however, is the high cost and inconvenience of using portable antennas that need to be placed on each training court, assuming they aren’t installed permanently.

The LPS has been validated as a reliable system, as scientific evidence shows. In this regard, Serpiello et al. (2017) validated the operation of these devices by using the Vicon camera system as the gold standard. In this study, linear movements and 45-degree direction changes were tested. Two different filters were applied to the analysis, both for the Vicon system and the signal obtained via the LPS (Figure 21). The study’s main conclusion demonstrated the validity of this system.

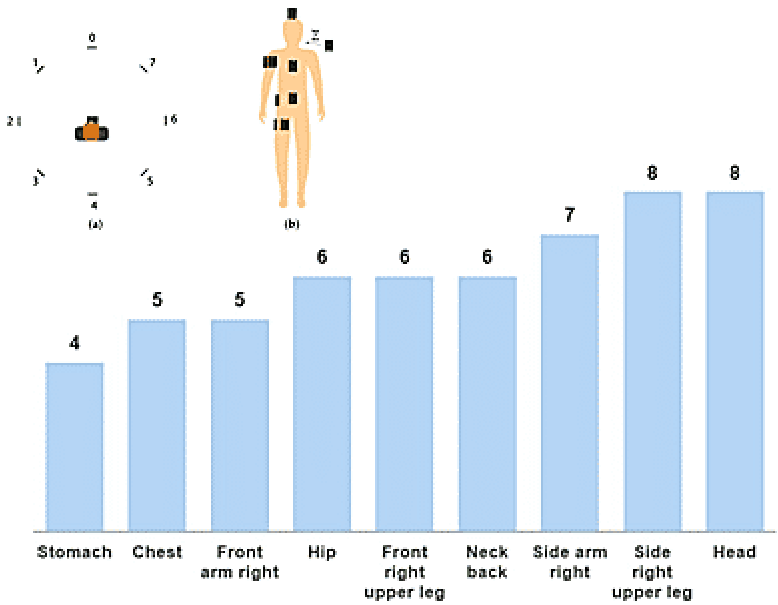
Figure 21: Validation of the local positioning system using the Vicon system.



Source: Serpiello et al., 2017, https://goo.su/5Vld6

Another study in the same vein highlights the validity of the LPS depending on where the devices were placed on the athlete's body. The selected placement areas were the head, lower back, upper back, and leg. On average, the positioning error was 20 centimeters, making these ultra-wideband (UWB) positioning systems suitable for monitoring dynamic athletic activities, i.e., tracking movement in indoor team sports.

Figure 22: Comparison of LPS performance based on device placement on the body.



Source: Ridolfi et al., 2018, https://goo.su/Xhj78

It's also interesting to compare GNSS with LPS. One study compared three types of movements (linear, circular, and zigzag running), measured by both systems. The intraclass correlation coefficient was close to 1, while the bias was very low, approximately 0, 0.01, and 0.02 (Bastida Castillo et al., 2018). The results showed that LPS is valid and reproducible, and even more accurate than GNSS systems. Thus, LPS errors range from 10 to 20 centimeters, while GNSS errors can be larger (Bastida Castillo et al., 2018).

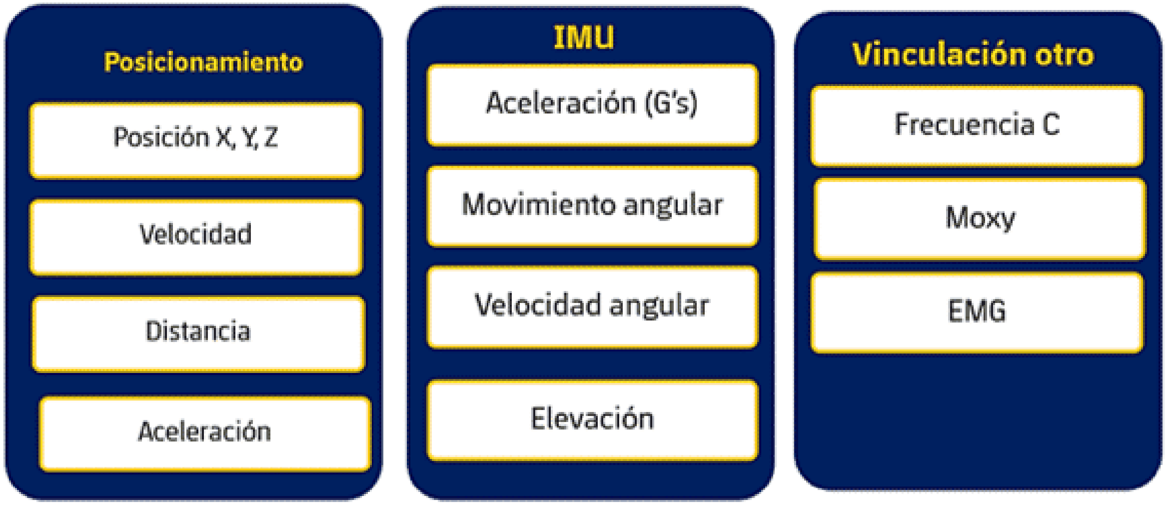
LPS also provides real-time data and post-session processing and analysis, allowing for more detailed information collection and analysis. We can also track variables related to tactics (e.g., distance between players, area covered, and recent trajectories), as well as those linked to kinematics and physiology.

Most of these variables are based primarily on positioning. In other words, they are derived from the player's position in the X, Y, and Z axes. From this, physical demands such as speed, distance, and acceleration are calculated. IMU systems, on the other hand, measure acceleration in G's, angular motion, angular velocity, elevation, and player load.

When combined with LPS, we can also measure heart rate, oxygen saturation (with a device known as Moxy), and muscle electrical signals (EMG). These variables are related to internal load.

The key variables monitored with LPS and IMU systems can be grouped into three components of load: volume, intensity, and density. For volume, we can measure total distance and player load. For intensity, we track high-intensity speed >18 km/h, accelerations and decelerations over 2-3 m/s^2, jumps (separating take-off and landing), and horizontal impacts classified as >3-5 G’s for landings and >5-8 G’s for horizontal impacts.

Figure 23: Key variables monitored using LPS and IMUs.



Positioning	**IMU**	**Other connections**
X, Y, Z position	Acceleration (G's)	Heart rate
Speed	Angular motion	Moxy
Distance	Angular speed	EMG
Acceleration	Elevation	

Source: Original work

Regarding tactical variables, we can track the player's position at any given moment, the area they cover, the distance between players, and the Voronoi diagram.

To interpret data obtained through these systems, we must primarily consider the following types of variables.

- Variables showing absolute values of physical demands during a session or task. For example, if 5 km was covered during the session.

- Variables showing relative values of physical demands during a session or task. For instance, knowing that the distance covered was 65 m/min in a particular session or task. This figure could differ significantly if, in the same task during another session, the distance covered was 45 m/min.

- The magnitude of certain variables like speed or acceleration. For example, 21 km/h or 3.87 m/s^2, respectively.

- Relative values compared to the maximum. For example, calculating what percentage the speed or acceleration achieved in a specific task or session represents in relation to the player's maximum. This approach gives us a more comprehensive view and allows for individualized load management.

The main objectives we aim to achieve through the use of these systems are:

- Understanding the physical demands required by the game model in competition.

- Planning and scheduling daily and/or weekly training loads.
- Individualizing training loads.
- Minimizing injury risk.
- Supporting the design and development of the injury rehabilitation phase.

Additionally, we can monitor and compare differences between playing periods; different positions; age-related categories; performance levels (elite or not); and whether a player is a starter or non-starter of the match.

Another crucial aspect is the management of information. Once analyzed and interpreted, the data must be shared with the medical staff, coaches, and players (Figure 24).

Figure 24: Information shared with players, coaching team, and medical team.

	COACHING TEAM
PLAYERS	INFO
	MEDICAL TEAM

Source: Original work

For instance, the following figure shows a brief report with six variables that can be sent to each player daily so they know their results.

Figure 25: Club report for the player.

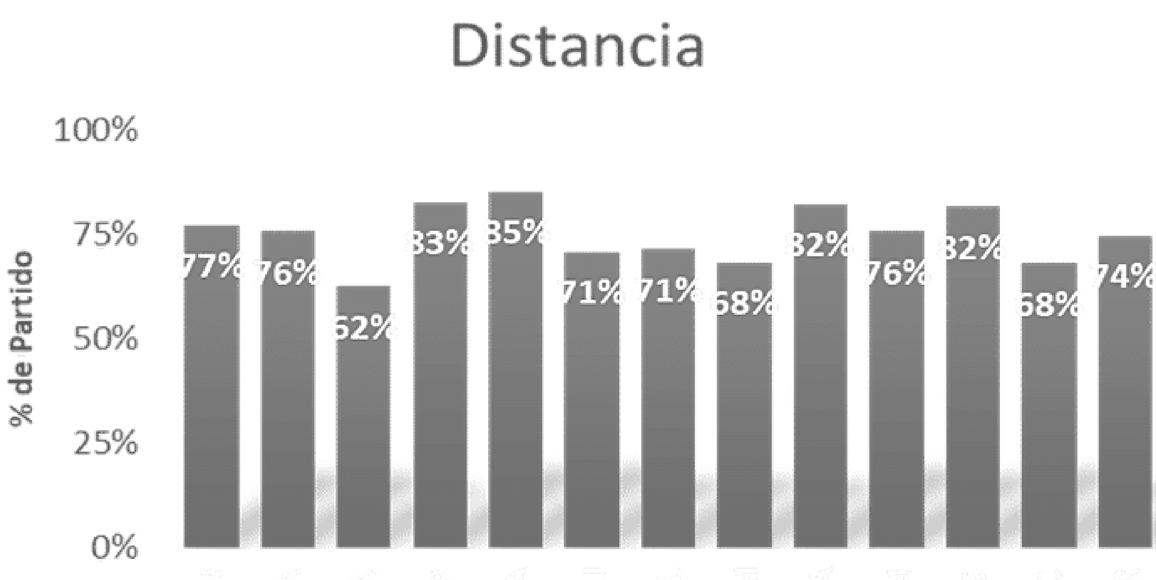
Source: Original work

This particular report includes the following information about the player: total distance, high-intensity distance, maximum speed reached, number of times they surpassed 18 km/h, number of accelerations over 2 m/s^2, and the number of decelerations below -2 m/s^2 in that session.

These data can also be used to understand the following:

1. The percentage difference between the training session load and match load for each player.

Figure 26: Percentage difference between the distance covered in a training session and a match for each player.

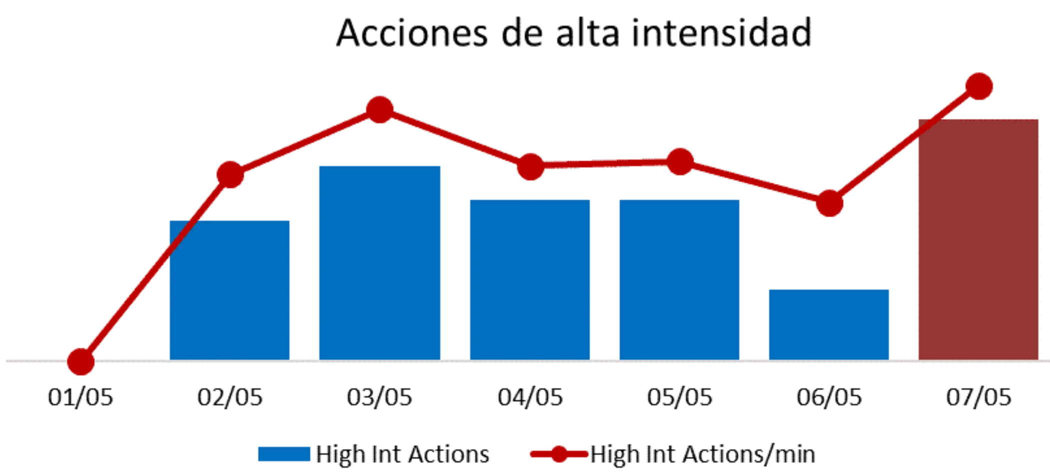


Source: Original work

2

The dynamics of load in the microcycle vary according to the match day, applying to both absolute and relative variables.

Figure 27: Load dynamics in a microcycle based on the day in relation to the match.

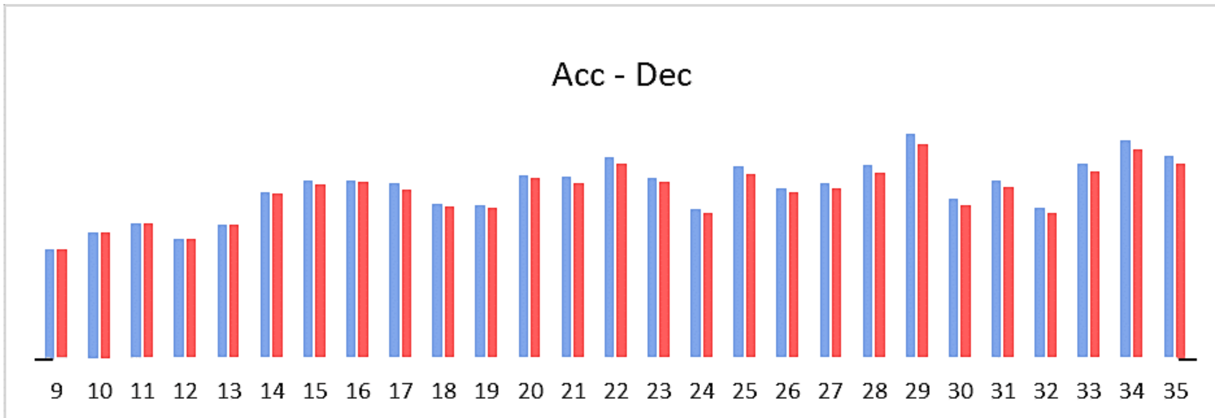


Source: Original work

3

Dynamics of weekly load throughout a competitive season.

Figure 28: Dynamics of weekly load throughout a competitive season.



Source: Original work

An important point to highlight is the correlation between the physical demands experienced and the physical capacities (strength, speed, and endurance) of the players.

Figure 29: Correlation between the physical demands experienced and the physical capacities.

		Maximum acceleration (+ / -)		Jumps and landings		
	+ Acceleration - Acceleration		**STRENGTH**		Impacts	
Number of	Distance >	Maximum speed			Total distance	Heart rate

sprints	18 km/h					
	SPEED				**Endurance**	

Source: Original work

All these variables should also be related to the technical-tactical concepts of the game to provide better contextualization, understanding, and interpretation of the data. For instance, we should assess the distance covered, the number of high-intensity accelerations and decelerations executed, etc., within different game concepts (defensive transitions, counterattacks) and relate these to the players' positions and other contextual factors, such as the match score. This approach would more accurately reflect the inherent complexity of these sports.

In indoor team sports, we can push the limits of the conditional and bioenergetic structures at specific moments during competition. Therefore, it is essential to discuss maximum demand scenarios. These scenarios correspond to specific moments in the match (for example, at the 1-minute, 2-minute, 3-minute, or 5-minute marks) when at least one physical demand peaks compared to the match average. In the literature, these maximum demand scenarios are also referred to as worst-case scenarios or the most demanding passages.

Consequently, we recommend analyzing and interpreting peak physical demands or maximum demand scenarios during training and competition to prepare our players (conditional structure) and optimize performance in indoor team sports.

As we often cannot obtain this type of information, it is advisable to consult literature for approximate values that can enhance the physical preparation of our athletes. The following outlines maximum demand scenarios in various elite indoor team sports.

Figure 30: Maximum demand scenarios in team sports.

	Dist (m)	Dist >18km·h^{-1} (m)	Dist >18km·h^{-1} (n)	Acc >2m·s^{-2} (m)	Dec >2m·s^{-2} (m)	Acc >2m·s^{-2} (n)	Dec >2m·s^{-2} (n)
30 s Time epoch							
Basketball	82.8 ± 8.2	19.8 ± 6.7	2.4 ± 0.8	34.6 ± 5.7	31.5 ± 5.7	7.1 ± 1.3	6.7 ± 1.3
Futsal	92.3 ± 8.1	25.4 ± 8.2	2.3 ± 0.7	37.6 ± 6.8	33.8 ± 6.2	6.8 ± 1.2	6.7 ± 1.2
Handball	87.3 ± 14.6	30.3 ± 14.9	2.4 ± 0.9	32.9 ± 8.6	29.8 ± 9.7	4.7 ± 1.0	4.1 ± 1.0
Rink Hockey	128.0 ± 9.6	60.5 ± 14.3	4.1 ± 0.8	50.7 ± 7.1	50.1 ± 8.2	6.9 ± 1.0	6.4 ± 0.8
Soccer	135.2 ± 46.3	63.8 ± 25.5	10.3 ± 3.7	52.5 ± 14.1	33.4 ± 12.9	5.5 ± 1.1	5.4 ± 1.1
60 s Time epoch							
Basketball	138.4 ± 11.8	23.0 ± 7.2	2.9 ± 0.9	48.4 ± 8.0	42.7 ± 8.3	10.3 ± 2.2	9.6 ± 2.3
Futsal	152.5 ± 13.5	29.3 ± 9.8	2.9 ± 0.9	50.7 ± 8.9	46.1 ± 8.2	9.7 ± 2.0	9.4 ± 1.9
Handball	133.2 ± 19.7	37.9 ± 20.0	3.0 ± 1.1	43.4 ± 10.6	37.4 ± 12.5	6.4 ± 1.5	5.5 ± 1.4
Rink Hockey	221.0 ± 12.7	76.4 ± 16.3	5.3 ± 1.1	71.9 ± 9.0	68.9 ± 10.7	10.3 ± 1.4	9.5 ± 1.4
Soccer	212.4 ± 68.7	72.8 ± 27.9	12.1 ± 4.5	66.2 ± 16.0	40.8 ± 13.1	7.4 ± 1.4	7.1 ± 1.4
120 s Time epoch							
Basketball	235.1 ± 34.9	27.2 ± 8.9	3.6 ± 1.2	68.3 ± 12.6	59.5 ± 12.6	15.1 ± 4.1	14.2 ± 3.8
Futsal	262.3 ± 21.6	36.2 ± 13.6	3.6 ± 1.3	74.7 ± 14.6	66.2 ± 11.8	14.5 ± 3.0	14.1 ± 3.0
Handball	217.8 ± 32.1	47.8 ± 26.7	3.9 ± 1.6	60.6 ± 15.4	50.7 ± 18.5	9.2 ± 2.1	7.7 ± 1.9
Rink Hockey	390.4 ± 25.4	101.3 ± 22.4	7.4 ± 1.5	107.7 ± 15.2	100.9 ± 15.1	15.9 ± 2.2	14.7 ± 2.3
Soccer	345.1 ± 95.0	87.3 ± 32.5	15.2 ± 5.4	89.9 ± 19.9	54.1 ± 15.5	10.5 ± 2.0	10.2 ± 2.1
180 s Time epoch							
Basketball	316.2 ± 28.1	31.5 ± 10.7	4.2 ± 1.3	85.1 ± 16.7	73.7 ± 16.1	19.5 ± 5.5	18.1 ± 5.3
Futsal	363.9 ± 29.1	41.1 ± 15.9	4.2 ± 1.5	96.1 ± 19.1	83.0 ± 15.4	18.8 ± 3.8	18.3 ± 3.9
Handball	306.8 ± 57.4	58.5 ± 35.5	5.0 ± 2.3	77.5 ± 21.9	62.5 ± 23.8	11.8 ± 2.8	9.7 ± 2.8
Rink Hockey	552.5 ± 37.0	122.1 ± 26.0	9.1 ± 1.8	139.3 ± 20.2	128.6 ± 20.3	20.9 ± 3.1	19.2 ± 3.3
Soccer	465.0 ± 97.3	104.8 ± 36.3	18.0 ± 6.4	113.8 ± 26.2	68.1 ± 17.9	13.7 ± 3.2	13.3 ± 3.2
300 s Time epoch							
Basketball	456.1 ± 62.9	38.0 ± 14.5	5.1 ± 1.8	113.7 ± 26.5	96.4 ± 23.8	26.6 ± 8.4	24.3 ± 7.8
Futsal	556.6 ± 45.3	49.6 ± 21.2	5.2 ± 1.9	131.8 ± 27.0	113.8 ± 22.3	26.3 ± 5.1	25.2 ± 5.4
Handball	450.4 ± 72.0	74.7 ± 47.5	6.2 ± 2.9	102.8 ± 28.9	80.6 ± 30.7	16.0 ± 3.7	13.0 ± 3.5
Rink Hockey	845.2 ± 63.6	158.8 ± 35.4	12.1 ± 2.5	198.8 ± 33.1	181.7 ± 29.7	30.0 ± 4.7	27.3 ± 4.9
Soccer	647.7 ± 188.8	123.9 ± 45.7	21.9 ± 8.7	143.3 ± 43.0	83.9 ± 26.6	17.2 ± 5.4	16.8 ± 5.4

Source: García et al., 2022, https://goo.su/UDbfm

Regarding tactical variables, what types of data can be extracted?

- The tactical organization of the team in relation to the ball.
- The player's position at each moment, the area they occupy, the distance between players, and the Voronoi map.

SUBMIT

CONTINUE

References

Barris, S.; Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine (Auckland, N.Z.)*, *38*(12), 1025–1043. https://doi.org/10.2165/00007256-200838120-00006

Bastida Castillo, A.; Gomez Carmona, C. D.; De la Cruz Sanchez, E.; Pino Ortega, J. (2018). Accuracy, intra- and inter-unit reliability, and comparison between GPS and UWB-based position-tracking systems used for time-motion analyses in soccer. *European Journal of Sport Science*, 1–8. https://doi.org/10.1080/17461391.2018.1427796

Brink, M. S.; Visscher, C.; Arends, S.; Zwerver, J.; Post, W. J. y Lemmink, K. A. (2010). Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *British Journal of Sports Medicine*, *44*(11), 809–815. https://doi.org/10.1136/bjsm.2009.069476

Buchheit, M.; Simpson, B. M. (2017). Player-Tracking Technology: Half-Full or Half-Empty Glass? *International Journal of Sports Physiology and Performance*, *12*(2), 235–241. https://doi.org/10.1123/ijspp.2016-0499

Carling, C.; Bloomfield, J.; Nelsen, L.; Reilly, T. (2008). The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Medicine (Auckland, N.Z.)*, *38*(10), 839–862. https://doi.org/10.2165/00007256-200838100-00004

Diwo, (n.d.). *Sensores del terminal acelerómetro y sensor de orientación*. http://diwo.bq.com/usando-los-sensores-del-terminal-acelerometro-y-sensor-de-orientacion

Gabbett, T. J. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2015-095788

Gabbett, T. J. (2018). Debunking the myths about training load, injury and performance: empirical evidence, hot topics and recommendations for practitioners. *British Journal of Sports Medicine*, https://doi.org/10.1136/bjsports-2018-099784

Gabbett, T. J.; Nassis, G. P.; Oetter, E.; Pretorius, J.; Johnston, N.; Medina, D.; Rodas, G.; Myslinski, T.; Howells, D.; Beard, A.; Ryan, A. (2017). The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. *British Journal of Sports Medicine*, *51*(20). https://doi.org/10.1136/bjsports-2016-097298

García, F.; Fernández, D.; Illa, J.; Reche, X.; Font, R.; Guitart, M.; Pla, F.; Tarragó, J. R.; Vázquez-Guerrero, J. (2022). Comparing the most demanding scenarios of official matches across five different professional team sports in the same club. *Apunts Sports Medicine*, *57*(215). https://doi.org/10.1016/j.apunsm.2022.100390

González Badillo, J.; Ribas Serna, J. (2002). *Bases de la programación del entrenamiento de fuerza*. INDE

Impellizzeri, F. M.; Marcora, S. M.; Coutts, A. J. (2019). Internal and External Training Load: 15 Years On. *International Journal of Sports Physiology and Performance*, *14*(2), 270–273. https://doi.org/10.1123/ijspp.2018-0935

Impellizzeri, F.; Rampinini, E.; Marcora, S. (2005). Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, *23*, 583–592. https://doi.org/10.1080/02640410400021278

Malone, J.; Lovell, R.; Varley, M. y Coutts, A. (2016). Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *International Journal of Sports Physiology and Performance*, *12*, 1–30. https://doi.org/10.1123/ijspp.2016-0236

Manterola, C. (2018). Confiabilidad, precisión o reproducibilidad de las mediciones. Métodos de valoración, utilidad y aplicaciones en la práctica clínica. *Revista Chilena de Infectología*, *35*(6).

https://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0716-10182018000600680

Nacleiro, F., Moody, J.; Chapman, M. (2013). Applied periodization: a methodological approach. *Journal of Human Sport and Exercise*, *8*(2), 350–366. https://www.redalyc.org/articulo.oa?id=301028374004

Nicholson, T. L.; Campbell, S. L.; Hutson, R. B.; Marti, G. E.; Bloom, B. J.; McNally, R. L.; Zhang, W.; Barrett, M. D.; Safronova, M. S.; Strouse, G. F.; Tew, W. L. y Ye, J. (2015). Systematic evaluation of an atomic clock at 2 × 10–18 total uncertainty. *Nature Communications*, *6*, 6896. https://doi.org/10.1038/ncomms7896

Piwek, L.; Ellis, D. A.; Andrews, S.; Joinson, A. (2016). The Rise of Consumer Health Wearables: Promises and Barriers. *PLOS Medicine*, *13*(2). https://doi.org/10.1371/journal.pmed.1001953

Ridolfi, M.; Vandermeeren, S.; Defraye, J.; Steendam, H.; Gerlo, J.; De Clercq, D.; Hoebeke, J.; De Poorter, E. (2018). Experimental Evaluation of UWB Indoor Positioning for Sport Postures. *Sensors (Basel, Suiza)*, *18*(1). https://doi.org/10.3390/s18010168

Serpiello, F.; Hopkins, W.; Barnes, S.; Tavrou, J.; Duthie, G.; Aughey, R. y Ball, K. (2017). Validity of an ultra-wideband local positioning system to measure locomotion in indoor sports. *Journal of Sports Sciences*, *36*. https://doi.org/10.1080/02640414.2017.1411867

Soligard, T.; Schwellnus, M.; Alonso, J.-M.; Bahr, R.; Clarsen, B.; Dijkstra, H. P.; Gabbett, T.; Gleeson, M.; Hägglund, M.; Hutchinson, M. R.; Janse van Rensburg, C.; Khan, K.; Meeusen, R.; Orchard, J. W.; Pluim, B. M.; Raftery, M.; Budgett, R.; Engebretsen, L. (2016). How much is too much? (Parte 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*, *50*(17), 1030 LP – 1041. https://doi.org/10.1136/bjsports-2016-096581

Viru, A. (1995). Mecanismos de adaptación biológica y entrenamiento. *Journal of Sports Training, 9*(2), 5–11. https://dialnet.unirioja.es/servlet/articulo?codigo=3720023

Viru, A.; Viru, M. (2000). *Nature of training effects*. En Exercise and Sport Science (pp.67 - 95). Lippincott Williams & Wilkins. https://www.researchgate.net/publication/299838539_Nature_of_training_effects

Zintl, F. (1991). *Entrenamiento de la resistencia. Fundamentos, métodos y dirección del entrenamiento.* Ediciones Martínez Roca.

CONTINUE