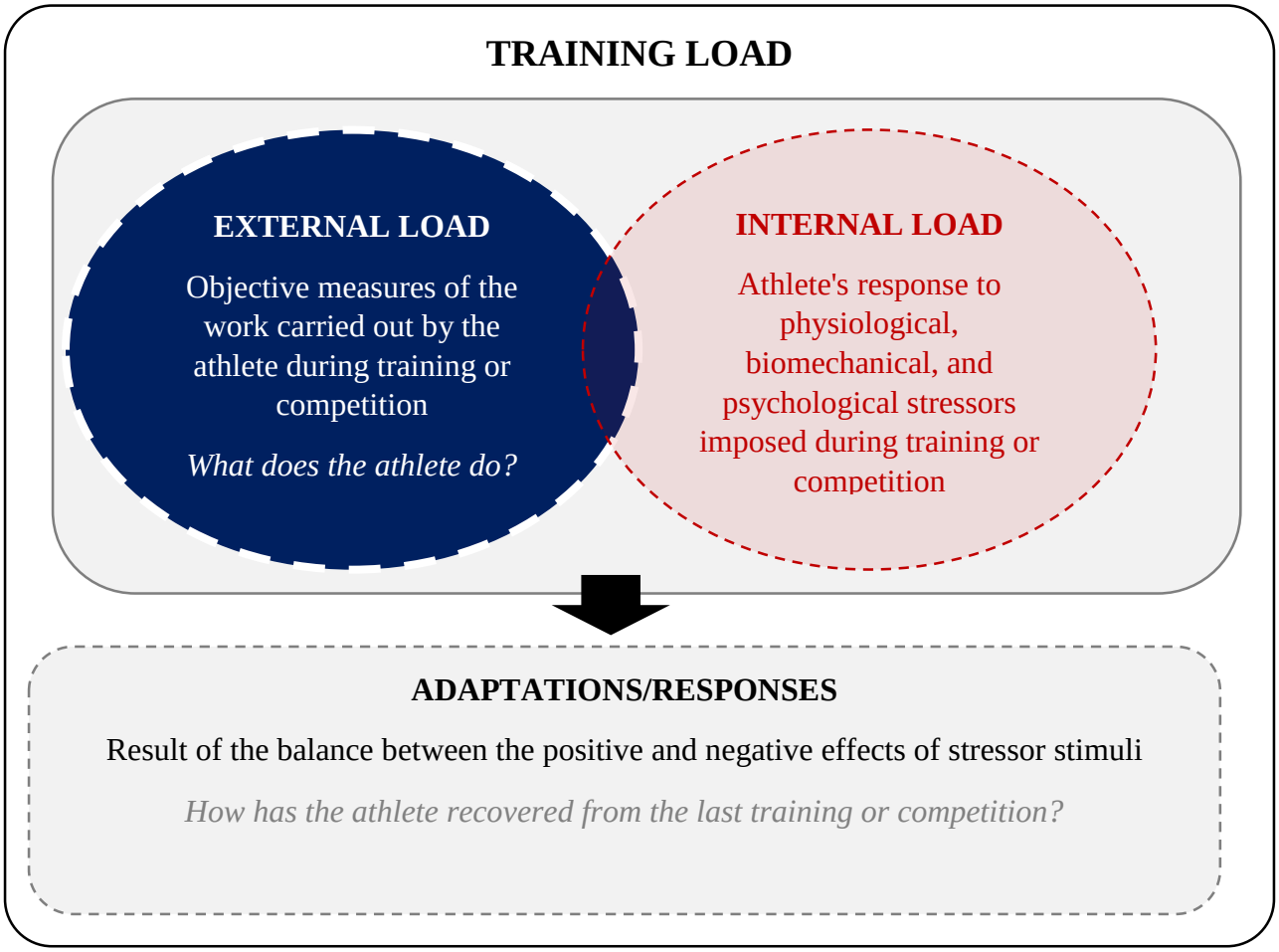
Module 3. External Load

Conceptualisation

The external load refers to the objective measures of the work carried out by the athlete during training or competition" (González, 2020, p. 3). The measurement of the athlete's movement will trigger all internal events and their consequent responses and adaptations. Although not exactly the case, it is the first step in the monitoring process, as mentioned in the scientific contextualisation module.

Image 1



Source: prepared by the authors.

Carga externa	External Load
Medidas objetivas del trabajo realizado por el deportista durante el entrenamiento o la competición	Objective measures of the work carried out by the athlete during training or competition
¿qué hace el deportista?	What does the athlete do?
Carga interna	Internal Load
Respuesta del deportista a los estresores fisiológicos, biomecánicos y psicológicos impuestos durante el entrenamiento o la competición	Athlete's response to physiological, biomechanical, and psychological stressors imposed during training or competition
¿qué siente el deportista?	What does the athlete feel?
Adaptaciones/respuestas	Adaptations/responses
Resultado del balance entre los efectos positivos y negativos de los estímulos estresores	Result of the balance between the positive and negative effects of stressor stimuli
¿cómo se ha recuperado el deportista del último entreno o competición?	How has the athlete recovered from the last training or competition?

Today, thanks to technology, objective measurement of training load is more accessible, valid, and reliable. However, it still has a high economic cost for most sports clubs, which limits their access and even leads them to seek alternative ways that can be complemented for greater analysis richness. Objective measurement will give us the **quantity**, and subjective measurement will give us the **quality** of monitoring. Do not confuse quality with better; as we will see later, it will be an approximation to the reality of the competition.

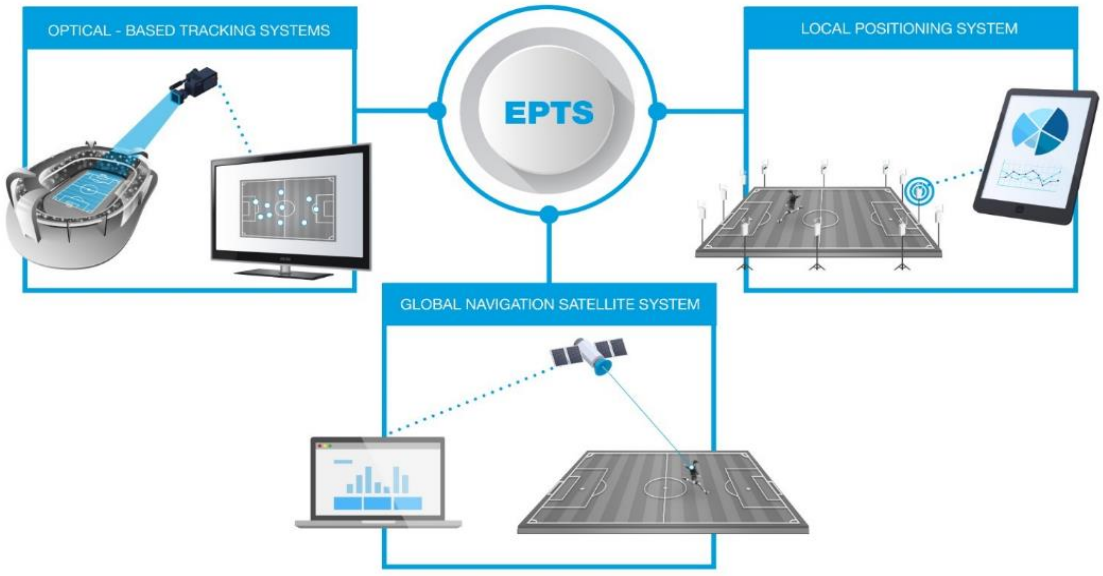
We will propose different ways to monitor the external load to address this quantity and quality of training load.

Objective Monitoring of External Load

Objective monitoring can be done through two systems:

- Electromechanical Performance Tracking System (EPTS), commonly known as GPS. These are subdivided into those that use geolocation to obtain positioning and those that use local positioning through the Ultra-Wide Band (UWB) system.
- Optical tracking, which obtains player positioning through special cameras that allow tracking of the player.

Image 2



Source: prepared by the authors.

Find below the advantages and disadvantages of each system.

Image 3: Optical Tracking

Source: prepared by the authors.

Sistemas de seguimiento mediante sensor óptico	Tracking systems using optical sensors
Ventajas	Advantages
No invasivos para el jugador	Non-invasive for the player
Utilizados habitualmente en el mercado futbolístico	Commonly used in the football market
Alta frecuencia de muestreo, disponible el seguimiento del balón	High sampling frequency, ball tracking available
Desventajas	Disadvantages
Número limitado de mediciones	Limited number of measurements
Bloqueos del seguimiento requieren correcciones manuales	Tracking disruptions require manual corrections

Tiempo de instalación	Installation time
Cámaras en el Estadio	Cameras in the stadium
Datos	Data
Algoritmos matemáticos de reconocimiento de jugadores y balón	Mathematical algorithms for player and ball recognition
Posicionamiento: coordenadas x, y	Positioning: x, y coordinates
Distancia y Velocidad: coordenadas y tiempo	Distance and Speed: coordinates and time
Aceleración: derivada de la velocidad	Acceleration: derivative of velocity
Sin datos de sensores inerciales: Impactos, Saltos, Player loas, ...	No data from inertial sensors: impacts, jumps, player loads, etc.

This type of tracking only records data related to movement in the XY plane. It is unlikely that a sports club will invest in its installation due to its high cost and limitation to the field where it is installed. It is normally used by major leagues to track official matches. The main differential aspect is that data on the ball is obtained, a decisive aspect to understand the contextualised conditional demands in relation to the reality of the game. Since the player does not wear any device, data from inertial sensors cannot be obtained, which means that the vertical plane (jumps and landings) and the main variables with high biomechanical impact cannot be recorded.

Advantages of optical tracking:

- Adaptability to any situation. Thanks to the images obtained by the cameras, the position of any mark is obtained and stored along with the time at which the sample was taken, making it easy to make reconstructions with that data.
- It is a non-invasive system, as it is not necessary for the athlete to wear any device.

- It allows monitoring of performance in closed spaces, such as indoor facilities or stadiums, with structures that would be limited with GNSS technology.
- It allows ball tracking. (Reche Soto, 2020, p. 29).
- Its sampling frequency is higher than that of other EPTS devices.

However, the disadvantages presented by this technology are:

- The number of cameras necessary to avoid dead spots and prevent some locations from being absent from tracking.
- They only provide positioning variables and spatial movement derivatives, so it is not possible to analyse other load parameters, such as impacts and jumps that are obtained from inertial sensors.
- Data beyond what happens outside the system's installation area cannot be obtained.
- The installation time of the camera system is long and expensive. (Reche Soto, 2020, p. 29).

Image 4: Local Positioning System

Source: prepared by the authors.

Sistema de posicionamiento local	Local Positioning System

Ventajas	Advantages
Disponen de un alto número de mediciones	High number of measurements available
Exactitud de los datos recopilados en tiempo real	Real-time accuracy of the collected data
Tecnología de banda ultra ancha que reduce interferencias en la vía de transmisión	Ultra-wideband technology that reduces interference in the transmission path
Receptor	Receiver
Desventajas	Disadvantages
Instalación fija	Fixed installation
Gastos de instalación	Installation expenses
Tiempo de instalación	Installation time
Unidad LPS	LPS unit
Posicionamiento mediante satélites. Ofrecen distancia recorrida	Positioning via satellites. They offer distance travelled
Posicionamiento: latitud y longitud	Positioning: latitude and longitude
Velocidad: efecto Doppler	Velocity: Doppler effect
Aceleración: derivada de la velocidad	Acceleration: derivative of velocity

Resto de variables: a partir de posicionamiento y sensores inerciales	Other variables: from positioning and inertial sensors

The local positioning system is the most accurate of all in terms of positioning signals. Without going into technical details, the fact that antennas are installed around the field, simulating the satellites orbiting the Earth, eliminates much of the signal transmission noise. It is a system that is increasingly gaining popularity, although it is dependent on the field where it is installed, the installation is simple, and it can be moved from field to field if required. A physical device is worn by the player so with this system the inertial sensors are already available for calculations of variables in the vertical plane and high biomechanical impact variables.

The main advantages offered by LPS systems are as follows:

- They allow performance monitoring in indoor facilities (halls) or stadiums with limited coverage for GNSS technology.

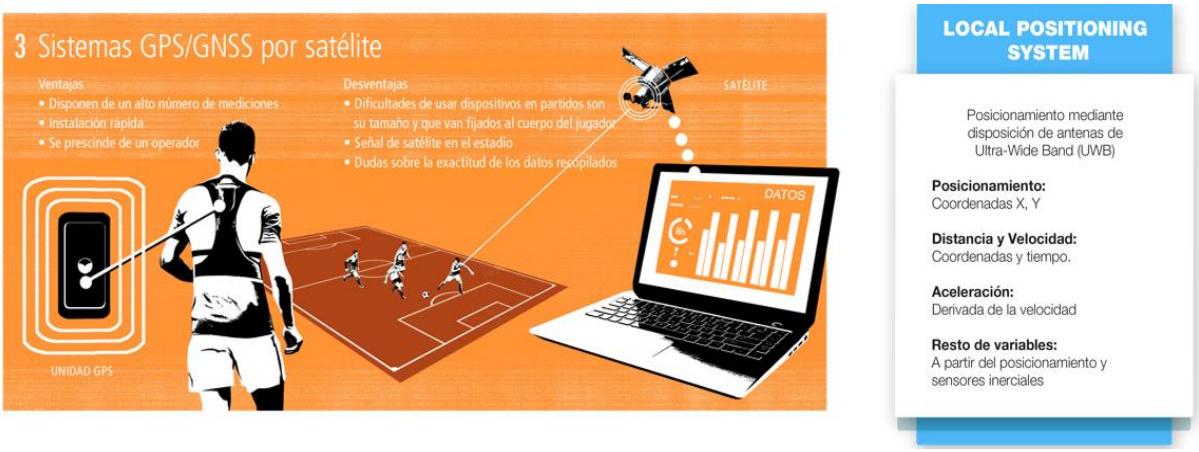
- Similar to GNSS technology, they provide numerous variables for performance analysis, as we can combine positioning variables (distances, speeds, and accelerations), variables obtained from inertial sensors (jumps and impacts, for example), and variables extracted from other sensors with heart rate.

  (Reche Soto, 2020, p. 24).

On the other hand, we find the disadvantages:

- A fixed installation of an antenna system around the field is required to obtain accurate data.
- It is a somewhat invasive technology for the player, as it is necessary to attach a device to them to obtain the data.
- It allows ball tracking. (Reche Soto, 2020, p. 24).
- The economic cost of installing the LPS system is relatively high.

Image 5: Global Positioning System



Source: prepared by the authors.

Sistemas GPS/GNSS por satélite	GPS/GNSS satellite systems.
Ventajas	Advantages
Disponen de un alto número de mediciones	High number of measurements available
Instalación rápida	Quick installation.
Se prescinde de un operador	No operator required
Desventaja	Disadvantage
Dificultades de usar dispositivos en partidos son su tamaño y que van fijados al cuerpo del jugador	Difficulties of using devices in matches include their size and the fact that they are attached to the player's body.
Señar de satélite en el estadio	Satellite signal in the stadium.

Dudas sobre la exactitud de los datos recopilados	Doubts about the accuracy of the collected data.
Unidad GPS	GPS unit.
Satélite	Satellite.
Posicionamiento mediante disposición de antenas de Ultra-Wide Band (UWB)	Positioning through Ultra-Wide Band (UWB) antenna deployment.
Posicionamiento: coordenadas x,y,	Positioning: x, y coordinates
Distancia y velocidad: coordenadas y tiempo	Distance and Speed: coordinates and time
Aceleración: derivada de la velocidad	Acceleration: derivative of velocity
Resto de variables: a partir del posicionamiento y sensores inerciales	Other variables: from positioning and inertial sensors

The most popular system of all is where the player wears a device that, through the GPS sensor, allows determining their position. It is the most widely used system in outdoor sports, such as football. It provides the same information as LPS, with the small drawback that the quality and precision of positioning are lower.

Its main advantages over other systems are:

- It is quick and easy to use, as it only requires placing a device on the athlete and starting data collection.
- No additional installation is required, such as cameras or antennas.
- Due to its simplicity, one person is enough to ensure that all devices are functioning correctly.

- It provides numerous variables for performance analysis by combining positioning variables with other types of sensors, such as inertial or heart rate sensors.

  On the other hand, GNSS technology also has the following drawbacks:

- [GNSS systems] do not work in enclosed facilities, so we can only monitor players in open spaces.

- The signal quality can be affected by weather conditions or covers that may be present in stadiums. In these cases, when the signal is not strong, the accuracy and reliability of the data may not be optimal.

- It is a somewhat invasive technology for the player, as it is necessary to attach a device to them to obtain the data. This technology is becoming less invasive over time, thanks to the reduction in size and weight of the devices.

- [Currently] it only allows monitoring of the athlete, not the ball. (Reche Soto, 2020, p. 20).

Image 6: Components of EPTS

Source: prepared by the authors based on https://wimu.es/es/

Inercial	Inertial
Acelerómetro	Accelerometer
Magnetrómetro	Magnetometer
Giroscopio	Gyroscope
Barómetro	Barometer
Conectividad	Connectivity

Microprocessor: an integrated central circuit that allows the device to perform all logical and arithmetic operations, from the device's operating system to application software.

- **Internal memory:** the device has internal memory to store all the information collected during data collection.
- **GNSS/LPS receiver:** the component that receives signals from GNSS satellites or local positioning systems (if the device has this option).
- **Inertial systems:** an inertial system or IMU (Inertial Measurement Unit) is an electronic system, usually composed of accelerometers, gyroscopes, and magnetometers (one for each axis of movement), with the aim of obtaining measurements of speed, rotation, and gravitational forces. Normally, a pressure sensor (barometer) is also added, although it is not considered an inertial sensor.
- **Connection systems:** some EPTS devices have the ability to connect to other types of sensors, such as heart rate monitors, oxygen saturation measurement devices, or electromyography. The currently functional connection technologies are: WiFi, ANT+, Bluetooth, and ZigBee. Additionally, they also have a micro-USB, which allows connecting the device to a PC for data download or battery charging.
- **Battery:** it allows the device to operate without being connected to any power outlet. It is important to know the exact battery life of the device to avoid it shutting down during training sessions or competition. Usually, batteries last between 4 and 5 hours.

Main variables in football

For a better understanding of objective measures of external load, we must take advantage of all the information that EPTS can provide us. Companies, through algorithms, transform the signals recorded by the sensors into understandable information for the user. This information is translated into a series of variables, some of which better explain the workload volume, while others describe the intensity of the work.

Table 1

Variables related to workload volume		
Distance	Total distance covered	Meters (m)
Player load	Amount of movement recorded by the accelerometer	Arbitrary units (a.u.)

Source: prepared by the authors.

Table 2

Intensity-oriented Variables		
High-Speed Running	Total distance covered above a threshold, usually between 15 and 24 km/h, depending on the company.	Meters (m)
High-intensity accelerations and decelerations	Number or distance of accelerations or decelerations above a threshold, usually between 2 and 3 m/s^2.	Meters (m) or count (c)
Jumps	Number of jumps with an impulse greater than 3 g-force.	Count (c)
Landings	Number of jump landings with an impact greater than 5 g-force.	Count (c)
Impacts	Number of impacts in the horizontal plane with a force greater than 8 g.	Count (c)

Source: prepared by the authors.

There are many more variables. Based on the scientific literature, some will be considered more important than others.

The selection of these variables is as follows:

- Distance is the most well-known and easily understandable variable for all users and athletes.

- Player load is a volume variable sensitive to intensity and also captures the vertical plane, which distance does not.

- High-Speed Running (HSR) is the most studied intensity variable in football due to its relationship with conditional performance and injury incidence. Within the intensity variables, it may represent the lower intensity end.

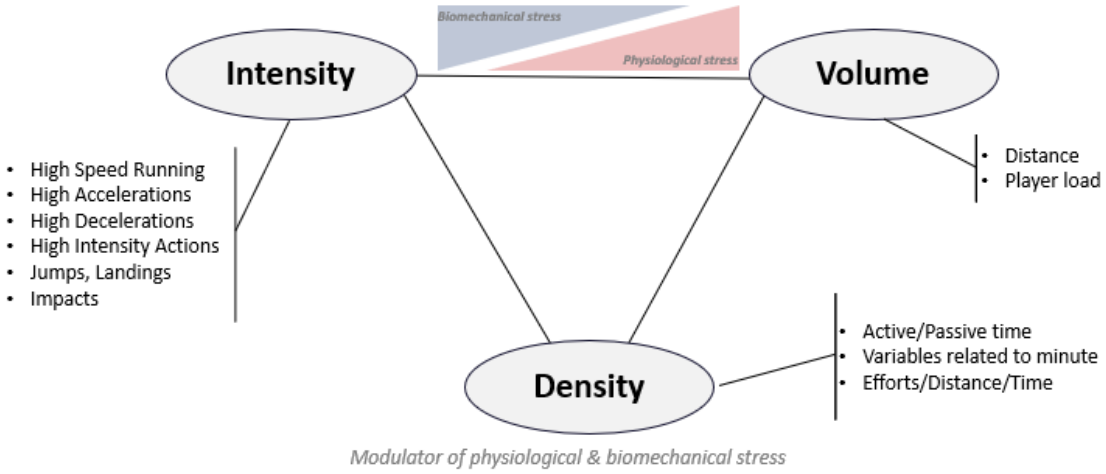
- High-intensity accelerations and decelerations reflect **very** high intensity. Along with HSR, they may be more related to muscle soreness during the adaptation processes in football.

- Jumps and landings are high-intensity variables in the vertical plane.

- High-intensity impacts reflect collisions and falls of players with high force levels.

In the image below, density variables are also shown. These variables modulate the physiological and biomechanical impact caused by volume and intensity variables. Primarily, the number of actions or meters per minute is analysed, as well as the number of efforts, distance, and duration.

Image 7



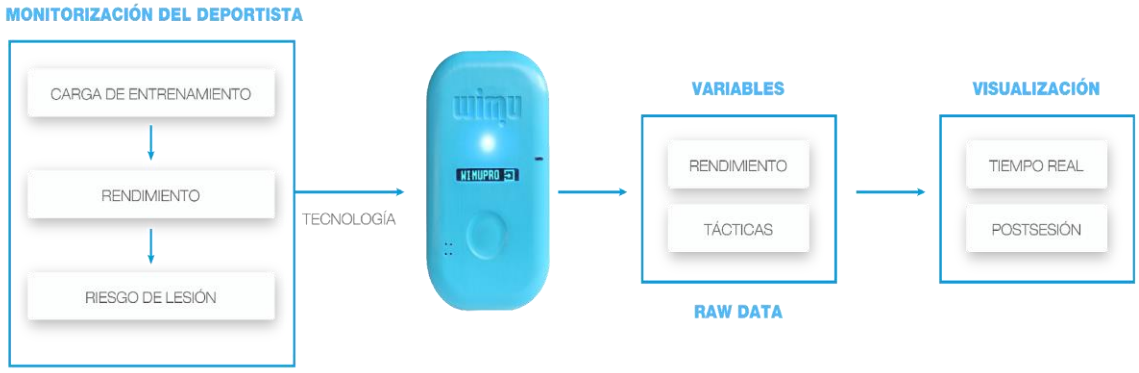
Source: prepared by the authors.

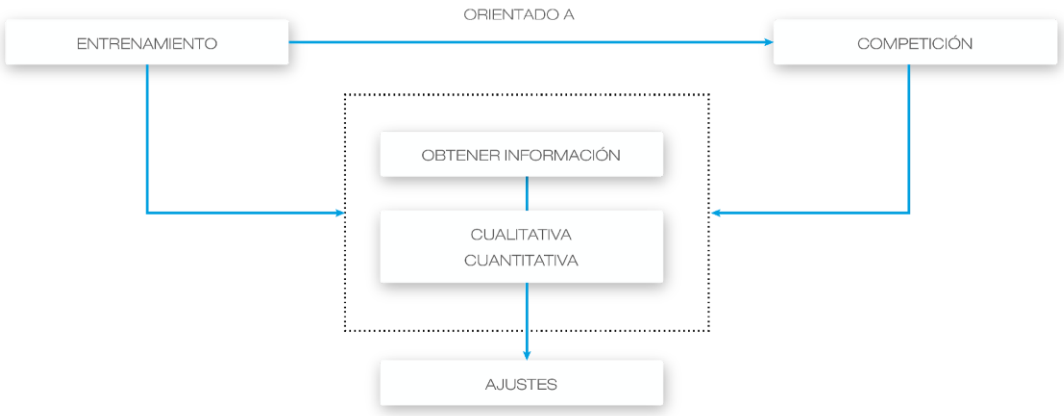
Analysis of objective measures of external load

The main objectives of objectively monitoring external load are three:

- Understanding what is happening during training sessions and competitions.
- Optimising conditional performance by modulating workloads.
- Reducing the likelihood of injury.

Images 8 and 9





Source: prepared by the authors.

Monitorización de deportista	Athlete Monitoring
Carga de entrenamiento	Training Load
Rendimiento	Performance
Riesgo de lesión	Injury Risk
Tecnología	Technology

Variables	Variables
Tácticas	Tactics
RAW DATA	RAW DATA
Visualización	Visualisation
Tiempo real	Real time
Postsesión	Post-session
Entrenamiento	Training
Obtener información	Information gathering
Cualitativa	Qualitative
Cuantitativa	Quantitative
Ajustes	Adjustments
Orientado a	Aimed at
Competición	Competition

These objectives can be achieved through the following general purposes, which may overlap (Torres-Ronda et al., 2022):

- Describing
    - The first step in any analysis is to understand what we have and what demands football imposes. Each team and player will have individual demands. While scientific literature provides information on the demands in football, it is important not to extrapolate findings from research articles

to the reality of one's team and players, as both domains can be very different.

- Planning

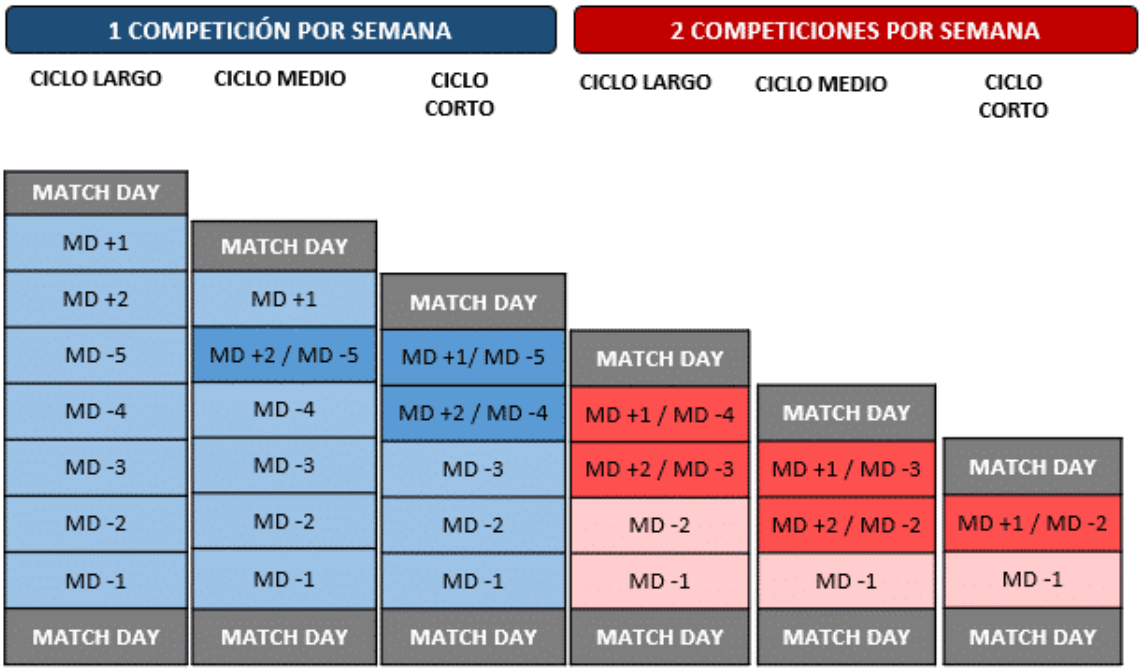
    - Once the demands are known, following the principles of adaptation processes, typical microcycle plans are developed based on training days and the stage of the season. There are several proposals on how this planning should be, and probably all of them are valid as long as they adapt to the team's context and players. Sessions -3 and -4 are usually high-intensity training sessions, while sessions -1 and -2 are low-intensity training sessions (Martín-García et al., 2018). The optimal load level for the player to get in good conditions for the competition will be determined by the monitoring of the training cycle. In the initial phase of planning, the basic principles of training theory should be followed to determine recovery timings based on physiological and biomechanical demands. Once there is a sufficient volume of data and more individualised analyses can be conducted, training loads can be modulated during the week based on the players' adaptation processes.

      Having predefined standard weeks can help both physical trainers and coaches focus on the important aspects of training and competitions, thinking just on what to work on rather than spending too much time on how to structure a task or exceed the conditional or technical/tactical content.

- Monitoring

    - Once the plan has been created, monitoring guides the way and helps in decision-making. In the scientific contextualisation module, the one on internal load and this one provide a summary of how to carry out the entire monitoring process.

Image 10



Source: prepared by the authors.

Competiciones por semana	Competitions per week
Ciclo largo	Long cycle
Ciclo medio	Medium cycle
Ciclo corto	Short cycle

- An important aspect of monitoring that has not been mentioned before is the temporal analysis of this monitoring, to know which variables to focus on and what assessments to make at each moment.
    - Long-term. It provides a vision of the season or multiple seasons, allowing us to see the long-term impact of daily activities.

- Medium-term. During the season, there are periods when we need to perform analyses or evaluations that cannot be done on a daily basis, but are important for guiding us along the way. These can include stress tests, biochemical tests, etc.

- Weekly. It forms the basis for work during the season, game by game. Short-term decisions will be influenced by competitive results and the players' conditioning.

- Daily. Understanding the daily impact of training helps identify which players are following the plan and which ones may require modifications to their load to ensure they reach the desired moment in optimal condition.

- Training tasks. Understanding the demands of tasks is vital to make optimal proposals based on the training day and the desired objectives.

- Temporal scenarios during training. They usually last 1 minute (Martín-García et al., 2018). Football, being an intermittent sport, does not always have the same demands throughout the entire task or competition. It is important to identify scenarios of high or maximum demand during a match in order to propose tasks that resemble those scenarios, provided that the conditional objective of the task aligns with them.

Image 11

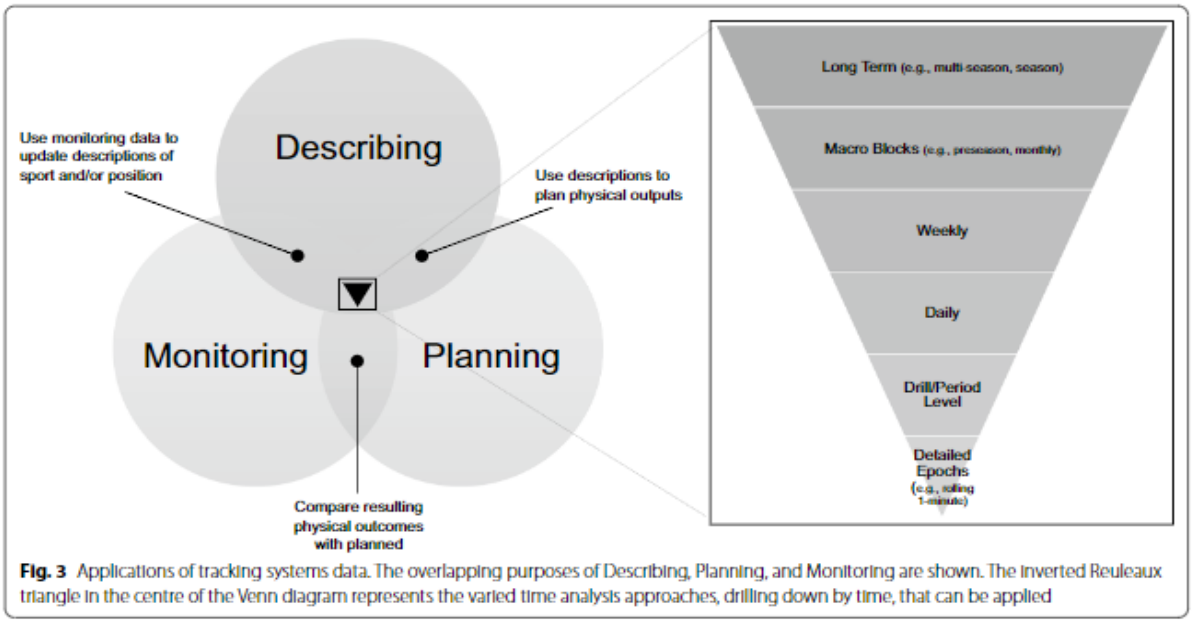


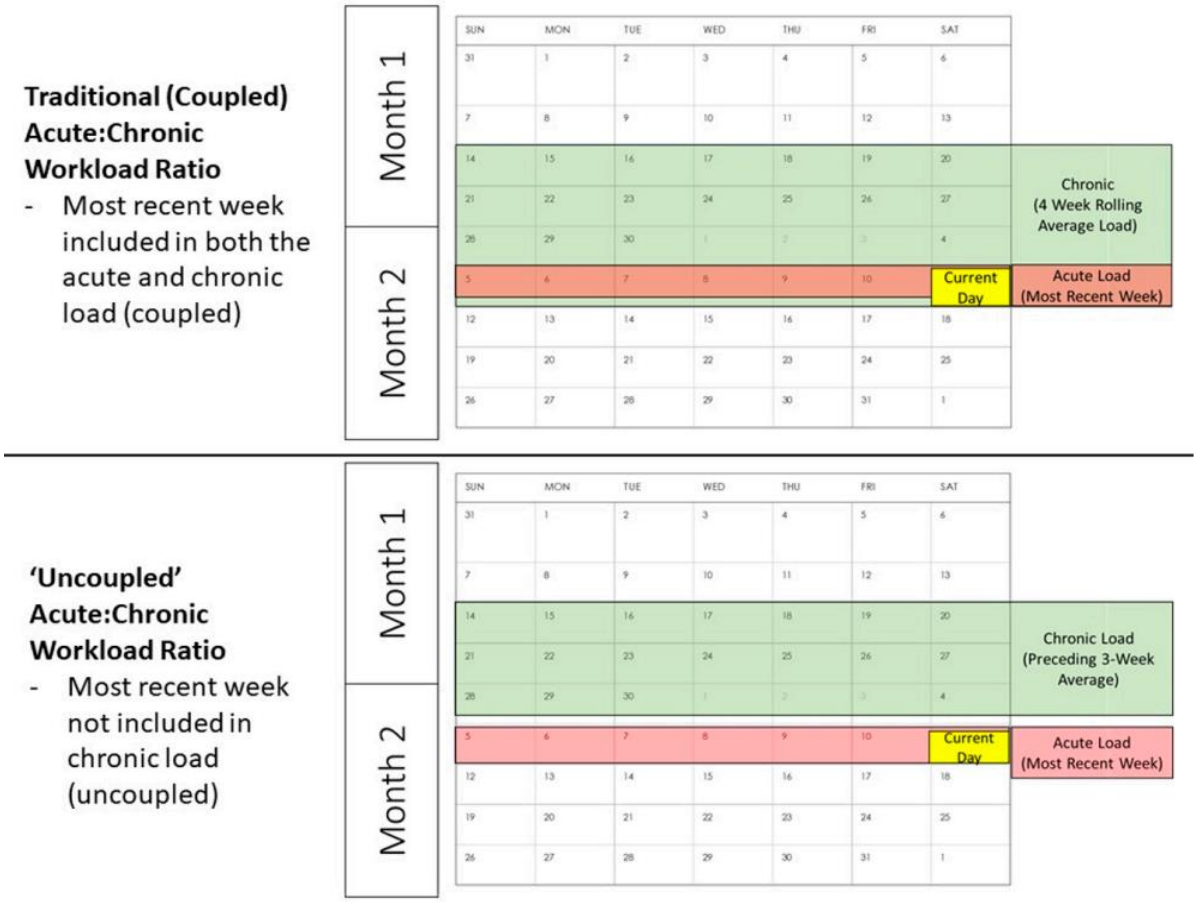
Fig. 3 Applications of tracking systems data. The overlapping purposes of Describing, Planning, and Monitoring are shown. The inverted Reuleaux triangle in the centre of the Venn diagram represents the varied time analysis approaches, drilling down by time, that can be applied

Source: Torres-Ronda, Beanland, Whitehead, Sweeting and Clubb, 2022, p. 5.

The Acute:Chronic Workload Ratio

A concept that has become popular in recent years is the acute:chronic workload ratio. This ratio is simply a mathematical calculation between the workload performed in the last week and the average of the last 4 weeks. There are two ways to calculate it: coupled or uncoupled. It simply differs in whether the acute week is included or not in the calculation of the chronic period (Windt and Gabbett, 2018).

Image 12

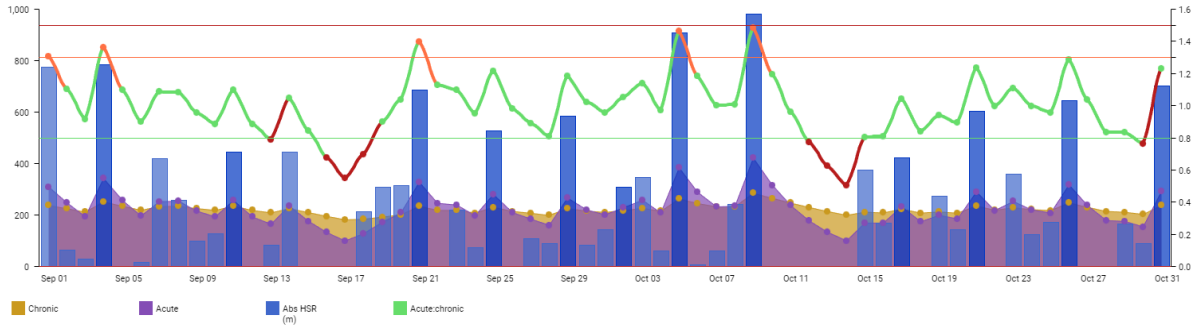


Source: Windt and Gabbett, 2018, p. 1.

Our opinion is that the uncoupled approach is more appropriate for physiological and mathematical reasons, which we won't go into detail about.

This ratio is useful to quantify whether the workload performed in the last week is above or below what the player has been doing in the past month. Publications have been made regarding the degree of increase or decrease in this ratio, relating it to the likelihood of injury. Although we do not agree with following this proposal in a strict way, we must understand that if we have done a significantly higher amount of work in the last week compared to the previous 4 weeks, we can push the player towards overload, overtraining, or even risk injury for these reasons.

Image 13



Source: prepared by the authors.

Within the adaptation processes, as seen in the scientific contextualisation module, analysing the acute:chronic ratio, combined with the analysis of internal load and training responses and adaptations, will optimise the decision-making process to improve player's and team's performance.

Subjective Monitoring of External Load

With objective monitoring, we have precise information and know the amount of work that has been done, but we don't know the quality of it.

Therefore, in this section, subjective monitoring is proposed, taking into account the specificity of football, a concept that has been addressed in the structured training modules.

Based on the basic training load formula (Solé, 2008):

$$External\ load = Volume * Intensity$$

$$External\ load = Time * Specificity$$

We define volume as total time and intensity as specificity, meaning the approximation to competitive reality (Schelling and Torres-Ronda, 2016). Below is a table proposed as an example with 10 levels of approximation. Ideally, this table should be adapted to the actual context for better understanding, not only by the physical trainer but also by the coaching staff.

Depending on the level of detail, levels of approximation can be established per task or per session. If done per task, the load of each task should be added up for load computation. If done per session, an estimated level of approximation is established based on the predominance of tasks.

Table 3

Orientation	Approximation level	Brief definition
Competitive	X	Official game
	IX	Friendly game
	VIII	Simulation game
	VII	Complex decision-making tasks. Collective tàctics. More players participating
	VI	Complex decision-making tasks. Collective tàctics
Special	V	Complex decision-making tasks. Real opposition. Emphasis on tactical concepts
	IV	Complex decision-making tasks. Level of opposition increased
Guided	III	Tasks without opposition or very passive. Simple decision-making. More players participating
	II	Tasks without opposition or very passive. Simple decision-making
General	I	Movents paterns similars with sport. Non decision-making or very simple
	0+	Non dynamic similarities with sport. Movement patterns more specific than 0-. No decision-making.
Generic	0-	Non dynamic similarities with sport. No decision-making.

Source: prepared by the authors.

Once the external load has been calculated, to determine the training load, we should simply multiply it by the internal load, which can be represented by the RPE in case a heart rate sensor is not available.

$$Load = External\ load * Internal\ load$$

$$Load = Volume * Intensity * RPE$$

The ideal proposal is to combine objective and subjective measurements, where external load variables are provided by tracking devices, internal load by RPE or heart rate, and a corrective factor for specificity should be taken into account. This is important in team sports like football, where, as explained in the structured training explanation, the human being is composed of a series of structures that should be considered and analysed to achieve optimal performance.

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