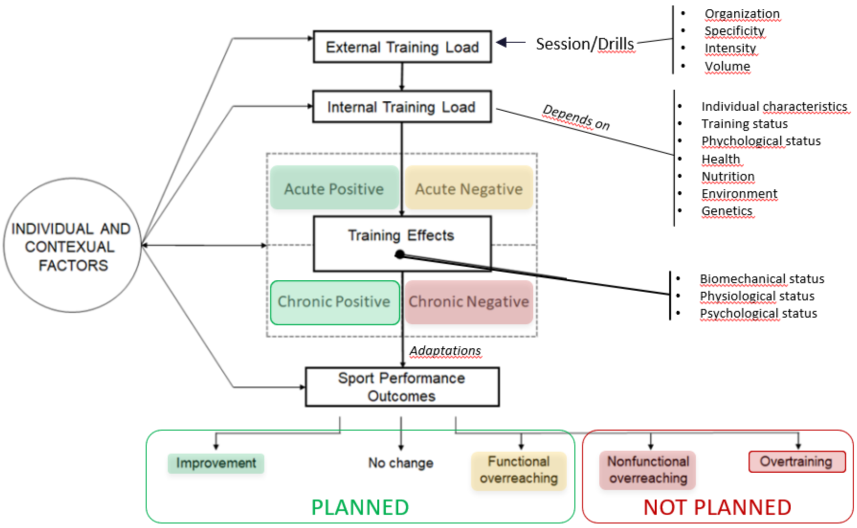
# Module 2. Internal Load Monitoring and Adaptations

## Unit 2.1. Analysis of Internal Load Concepts and Training Adaptations

### 2.1. 1 Analysis of Internal Load Concepts and Training Adaptations

Within the paradigm of the training cycle proposed for a better understanding of what happens to athletes during a stipulated period of time, we differentiate monitoring into three aspects: external load, internal load, and adaptations (Gabbett, 2016).

**Image 1: External load, internal load, and adaptations**

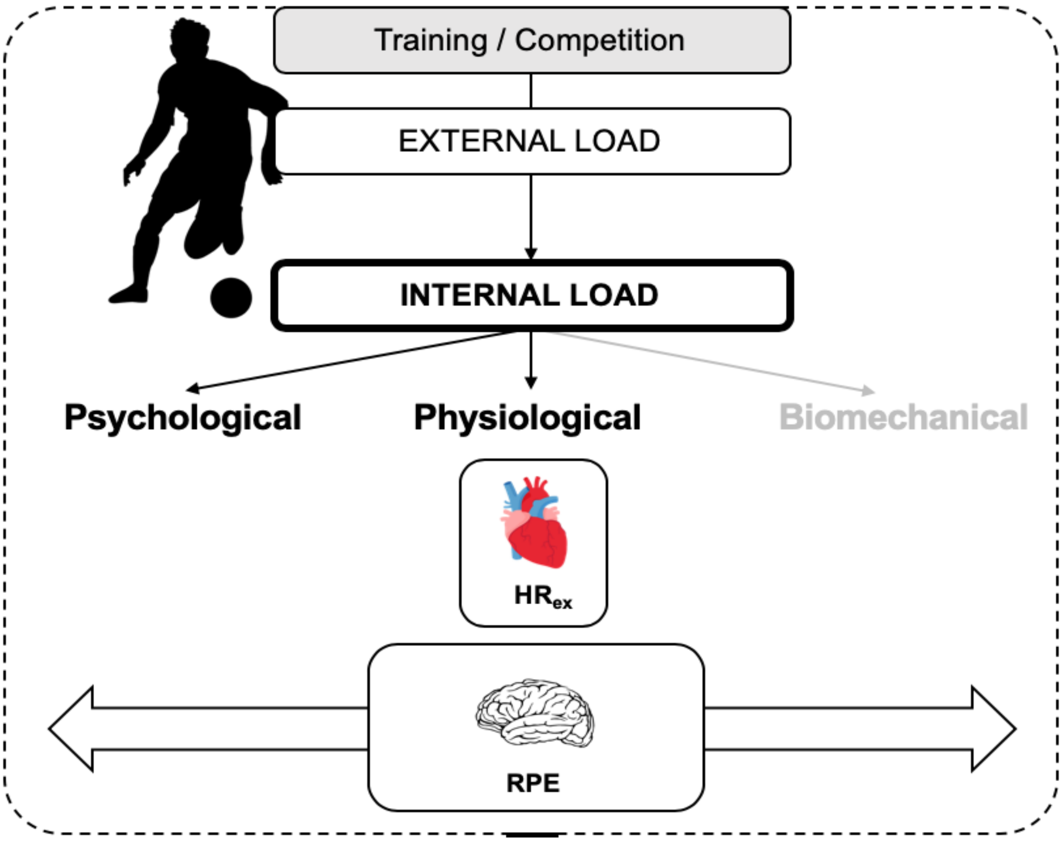



Source: own creation based on Jeffries et al., 2020, p. 3.

External load is defined as the data or variables that describe the movement or activity being performed, for example, the distance in kilometres covered by an athlete, the average normalised power generated in a segment by a cyclist, or the meters of high-speed running that a football player covers in the first 45 minutes.

However, internal load is understood as the response that the players' or athletes' organisms show to the stimuli generated by the sports session, which are monitored and accounted for through external load variables during the activity. These responses are mainly related to physiological processes that occur in the body as a reaction to the loss of homeostasis and activation of the sympathetic nervous system at the beginning of the physical activity. Common measures of this load focus on heart rate, subjective value scales, or blood lactate concentrations. However, it should be clarified that internal load is not limited to being described as the physiological responses generated in the individual, but it is important to emphasise psychological parameters that also encompasses the stress resulting from linking different demanding tasks, the pressure to win matches or to be a starter, in the case of team sports. Biomechanical responses must also be taken into account, since it is highly related to neuromuscular fatigue and efficiency of muscle contraction, which interferes with the performance of the sports gesture or specific movement pattern of each sport modality.

**Image 2:**




Source: own creation based on Vanrenterghem et al., 2017, p. 3

At the end of the training session, once the athlete finishes the activity, the process of recovery and assimilation of the training load begins, with the consequent activation of the parasympathetic nervous system. In several studies, the importance of athlete recovery during sleep was included, a phase in which the parasympathetic nervous system appears as the main protagonist, in order to restore the different systems altered during exercise and restore balance at a biological level. It is necessary to emphasise the importance of integrating healthy habits during the hours following physical demands, and the use of individualised protocols that encourage optimal recovery of athletes, taking into account physiological, psychological, and biomechanical parameters.

### 2.1.2 Contextualisation of Internal Load Monitoring Based on Sport

Historically, some sports have been more proactive in monitoring athletes' internal load, mainly due to their continuous or progressive effort nature over time. For example, cycling, athletics, especially long-distance runners, triathlon and combined events, mountaineering, cross-country skiing, or trekking. These are sports that have a great deal of experience in monitoring during exercise, especially due to the long or extreme duration of some of the activities. As an example, a long-distance triathlete will plan the race based on internal load variables, such as heart rate in each segment, being aware that if they exceed the prescribed zone at any point during the race, there is a high probability that their performance will be affected as the kilometres or hours go by. Another example could be the lactate measurements through micro puncture in swimmers during different training tasks. This is done to confirm that the swimmer is performing the series at the required intensity and thus correlate the intensity obtained through lactate values with the training rhythms. However, all sports have the same nature in terms of the linearity of effort. It is worth noting intermittent sports, which are those whose actions tend to occur discontinuously over a period of time, and usually the associated intensity is high to maximum. In this group, we have team sports and some individual sports, such as racket sports or combat sports. In these modalities, the usefulness of heart rate, lactate concentration, and $VO_2$max is questioned due to the low systematicity of actions and the multiple association of active and passive actions. In these cases, subjective/perceptual internal load monitoring methods, such as the effort perception scale proposed by Gunnar Borg (1982), are among the main agents involved.

Once the internal load has been contextualised depending on the sport modality, this section aims to explore the fundamental characteristics of the main methods for monitoring such load, separating them into two large groups: physiological methods and perceptual methods.

#### 2.1.2.1 Physiological Methods

Internal load monitoring methods classified as physiological can be defined as those objective variables that we obtain from direct responses of the organs or biological systems of our body. On the one hand, the relative heart rate and oxygen consumption of the cardiorespiratory system must be studied; and, on the other hand, the group of biomarkers, products in the form of hormones and substances that are primarily found in body fluids (blood, saliva, urine), where the main exponent during training is the concentration of lactate in blood. As you progress through the module, you will see the importance of biomarkers in adaptations.

#### 2.1.2.2 Perceptual Methods

The defining aspect of this group is the subjective nature of the values obtained, focusing on questionnaires in which the athlete themselves rate their perception of the activity they are performing or their readiness after a recovery period, usually the day after a training session or competition. These methods are usually classified into two large groups: on the one hand, diaries, on which the athlete has flexibility to record different aspects of monitoring training sessions or competition, as well as other aspects related to sensations, fatigue, nutrition, biomechanics, recovery methods, among others. Likewise, the most standardised use is that of questionnaires with closed questions and usually with a numerical response within a scale. In this case, the athlete must have undergone a familiarisation period so that their response is as objective as possible, and the data are valid as a control of internal load or adaptations to training or competition. Within this group, we find different types of questionnaires: those to evaluate adaptations or assimilations of the load of the previous session; the Wellness questionnaire, which focuses on variables such as sleep quality, level of fatigue, level of stress or level of perceived muscle injury and mood states; the Profile of Mood States (POMS); those that study the recovery process and stress, as well as chronic fatigue in athletes of individual sports, which are Rest-Q and Daily Analysis of Life Demands for Athletes (DALDA); and, finally, those that seek a correlation between the player's performance and their mood state (Individual Zone of Optimal Functioning).

However, the most widespread method for monitoring internal load during training and matches, measured during effort or immediately after, is the perception of effort. This is done using the scale created by Borg (1982), in which perceived exertion is categorised into values of 6 to 20 (in the original scale), with 6 being a state of rest and 20 being maximal exertion. Likewise, there are studies that relate the recorded values to the FC*10 obtained during effort, that is, a 15 on the scale would be equivalent to 150 beats/min. However, it is not possible to generalise or take this concept as a gold standard due to the great variability of this variable in each athlete (Borg et al., 1987). Nevertheless, the use of this scale has been replaced using the scale adapted by the same author with values from 0 to 10, in order to generate greater ease in choosing values at times when the athlete is performing efforts at moderate to maximum intensities. Finally, we must mention the use of RPE-min, a method of load monitoring in which the RPE of each task is used as the internal load variable and the minutes performed as the external load variable. The results obtained are the result of multiplying the RPE value per minute. For the final RPE of the session, it is necessary to perform a sum of the RPE-min of all tasks (Mallol et al., 2019).

**Image 3: View of the RPE questionnaire mobile app**


Source: own creation

### 2.1.3. Contextualisation of Monitoring Adaptive Processes in Sports

Every adaptive process requires a prior loss of balance among the components that make up the system. In sports terms, the adaptive process par excellence focuses on improving performance through the dynamic loading to which the athlete is subjected, which alters the homeostasis of the physiological systems involved so that the body seeks balance again through adaptations to the new conditions presented (Rivera-Brown and Frontera, 2012; Hawley et al., 2014).

Historically, the most common process, due to its relative ease of monitoring, was the control or tracking of loads during training. Time or distance completed during the training session; average power of the session; maximum sustained power in a defined interval; flight time in a jump test; kilograms moved in a strength training session; among others, are recurrent variables in external load monitoring. Meanwhile, variables such as the average heart rate of the session, maximum heart rate, blood lactate concentration, volume of oxygen used in a certain interval, and perceived exertion define the internal load to which the player or athlete is subjected to (Impellizzeri et al., 2019).

However, in recent years, the density of competitions has increased exponentially, so it seems essential to analyse the responses of athletes in the period between the stopping of the activity or exercise and the moment they must resume the next training session or competition. Currently, more sports scientists, coaches, and physical trainers give greater importance to monitoring recovery or return to the athlete's basal state; analysing what the player/athlete's responses are during the hours following the stress resulting from physical exercise; and observing the assimilation of that stress and the willingness to face the next training or competition load.

In general terms, adaptations in athletes can be divided into two major groups: short-term adaptations, those that occur immediately or after the training session or competition, or adaptations that occur in a limited period of time—for example, a microcycle—and adaptations that occur in the medium to long-term resulting from a cumulative process of planned loads over months, even over seasons.

Regarding the variables currently related to adaptations in sports sciences, they can be divided into different groups depending on their nature and the timing of their monitoring. One of them is biomarkers, which are variables directly and strictly related to the functioning of the player's physiological system. Within biomarkers we should highlight the biochemical and cardiopulmonary ones.

Biochemical biomarkers, known as substances, secreted by our endocrine system in response to the nervous system's imbalance of homeostasis produced by physical activity, have been studied in recent years. Everything indicates that there are certain common chemical biomarkers in different sports, while others are more specific to certain sports. For example, hormones or biomarkers that are more sensitive to high load volumes, such as endurance sports, or biomarkers that are more sensitive to interval exercises at maximum intensities.

Based on Lee et al. (2017), these substances can be classified in relation to the function they describe during or after physical activity. On the one hand, we have biomarkers related to nutritional status and metabolic health; those related to hydration status and muscle status; those that influence cardiovascular endurance or capacity; another group related to the risk of injury; those related to the inflammatory response; and finally, those related to possible food allergies.

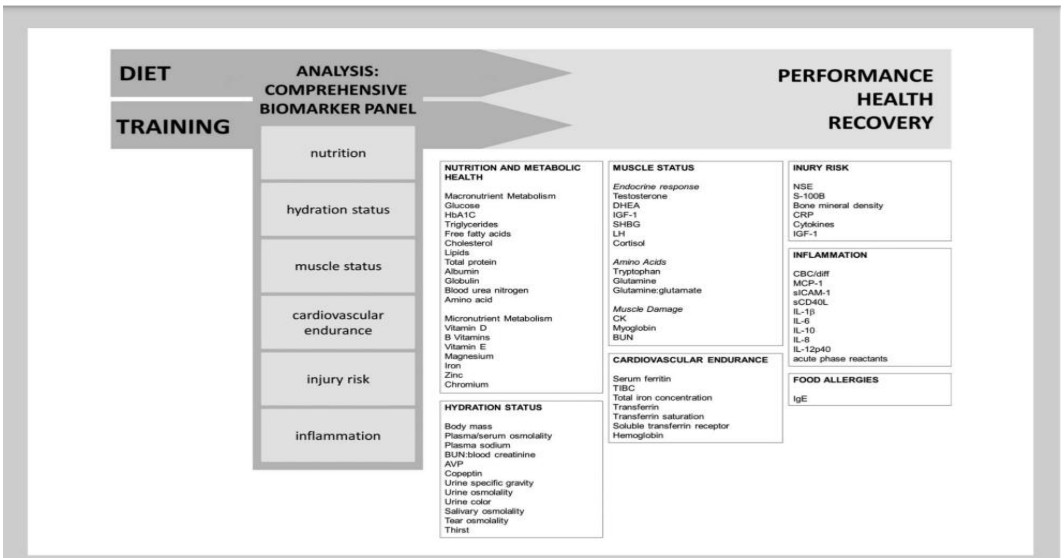



**Figure 1.** Comprehensive approach to biomarker analysis. Assessing multiple aspects of biological function allows coaches and athletes to track performance, recovery, and health in an individualized, practical manner. Relying on multiple validated biomarkers increases sensitivity, allowing athletes to detect potential impacts of training, recovery, diet, etc., long term. Data from long-term biomarker analysis will enhance preventative detection of injury or negative effects on performance. Examples of options for well-studied biomarkers in each category are provided as suggested components of a customized panel.

**Image 4: Concept map of**

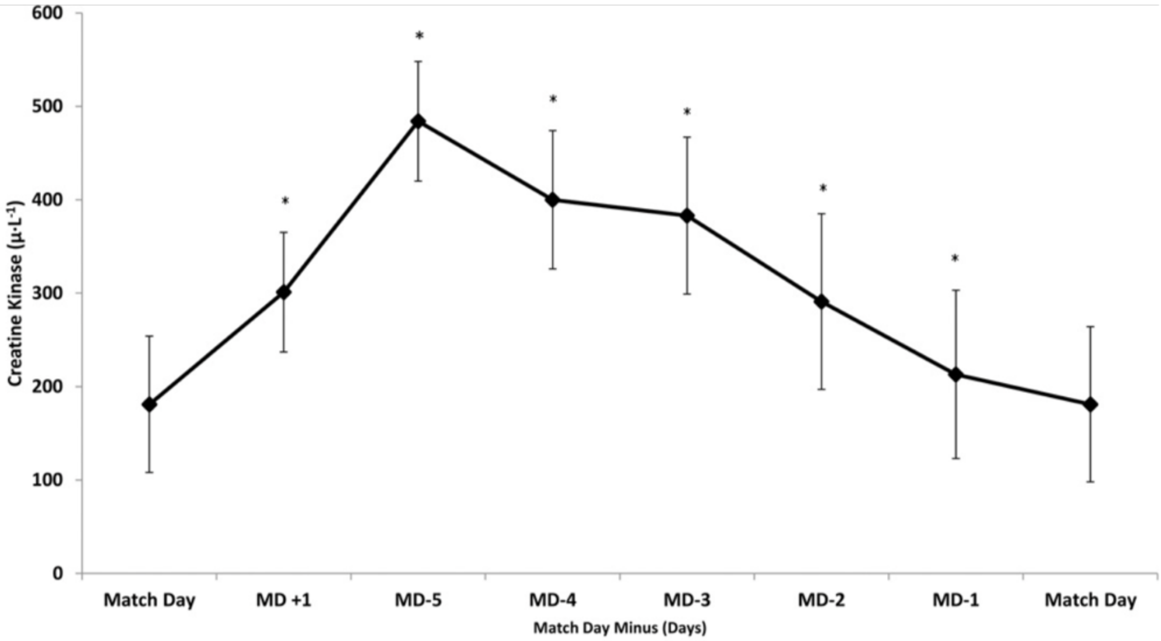
**relevant biomarkers in physical exercise**

Source: Lee et al., 2017.

Regarding nutritional, metabolic, and hydration status, we can subdivide into defining markers of macronutrient metabolism to glucose, triglycerides, free fatty acids, proteins, and amino acids as the main substrates for the different energy pathways used depending on the sports demand; and micronutrients, which include essential vitamins and minerals for muscle contraction and the development of functions during exercise. Also, plasma, saliva, or urine osmolality; comparison of body mass as an indicator of water loss before and after a competition; or the amount of creatinine in blood are indicators of the player's hydration status.

Biomarkers related to muscle status can be divided into three subgroups: concentrations of creatine kinase, myoglobin, and BUN (blood creatinine) that provide information about the muscle injury caused by certain activity. Depending on the increase in these concentrations, the fibrillar rupture would be more significant.

**Image 5: Evolution of creatinine kinase along a microcycle in professional football players**



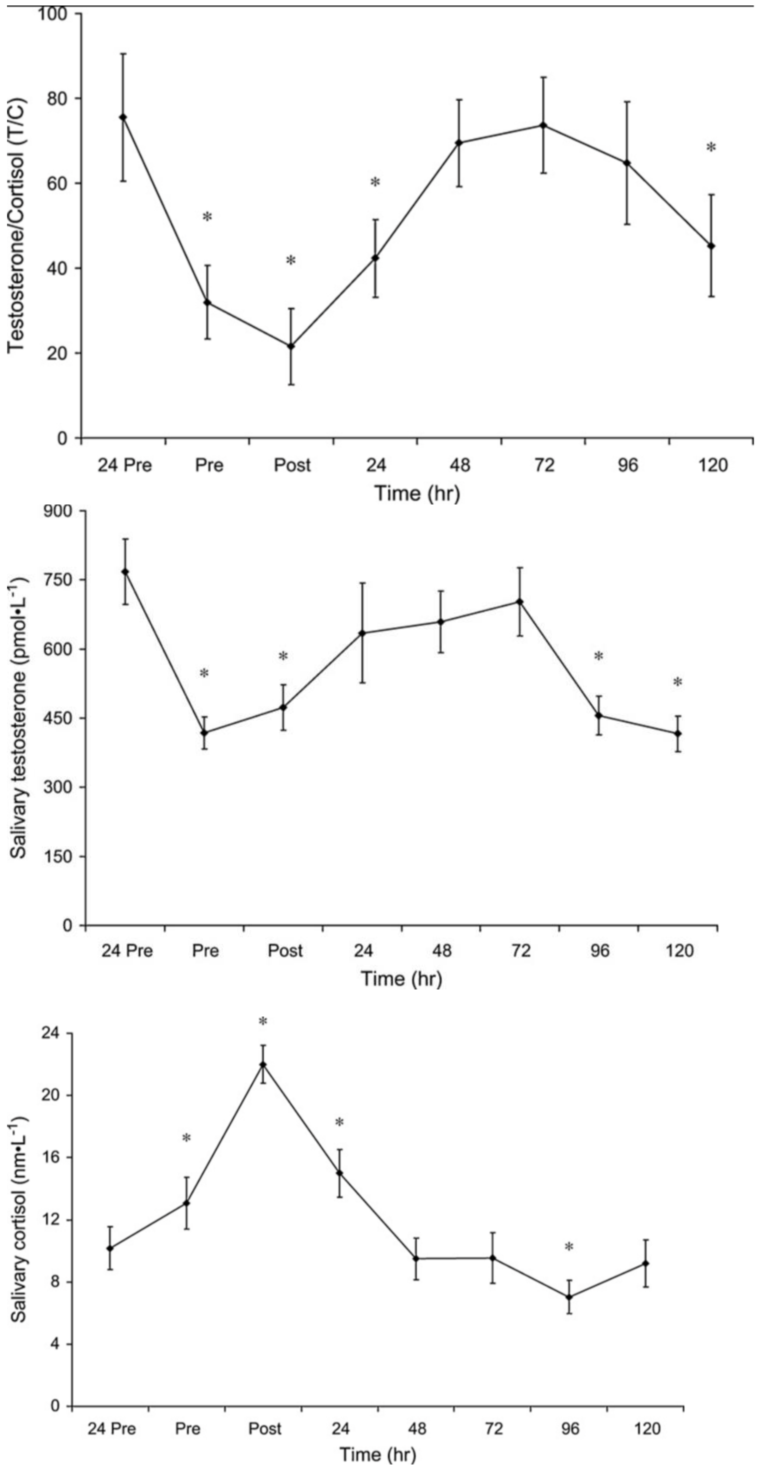

*Significantly different from match day (all $p \leq 0.05$)

Source: Malone et al., 2018.

Similarly, in the case of amino acids present in protein resynthesis, we observe that an increase in concentrations of tryptophan, glutamine, and the glutamine: glutamate ratio defines a greater need to resynthesise protein components that have been damaged. Finally, endocrine responses are not only defining of the generated muscular stress but also comparable to the balance between stress-recovery with variables such as testosterone, whose concentration rises after loads that have generated significant stress —such as after a hypertrophy training or a match. Also, cortisol, as an indicator of general stress, both psychological and physiological, presents a great variability, so it may present different values depending on the time of day and the conditions in which it is collected since it is a hormone that presents a circadian rhythm, being generally its concentration highest in the early hours of the day and decreasing throughout the day until reaching the lowest values at night. The testosterone: cortisol ratio seems to be an indicator of anabolic-catabolic processes or the body's ability to withstand the stimulus during exercise. In this way, it activates the sympathetic nervous system (SNS) and has the capacity to subsequently activate the parasympathetic nervous system (PNS), thus favouring optimal recovery.

It should be noted that these concentrations can describe both the stress-recovery balance after a match (acute) or throughout a season (chronic).

**Image 6: Testosterone, cortisol and tersotoreno7cortisol ratio pre- and post-match of the Rugby League**




Source: McLellan et al., 2010.

Several authors emphasise the lack of assimilation of training or competition load with reductions in the testosterone: cortisol ratio greater than 30% (Adlercreutz et al., 1986;

Mujika et al., 1996; Elloumi et al., 2003). Meanwhile, hormones such as dehydroepiandrosterone (DHEA), insulin-like growth factor 1 (IGF-1), sex hormone-binding globulin (SHBG), and luteinizing hormone (LH) are markers that, if their concentrations chronically decrease, are related to overtraining. Other hormones, such as α-amylase, whose usefulness can be related to acute physiological stress (during a limited period of time); or the group of immunoglobulins, specifically immunoglobulin A (IgA), whose concentration can be related to load assimilation and the state of the immune system during periods of intensified training, should also be noted.

However, there is no unanimity on which markers are most effective for describing the athlete's state, so further study is necessary.

To conclude, we must mention new variables that focus on genetic and epigenetic biomarkers and those from omic technologies (transcriptome, metabolomics, and proteomics) to achieve a better understanding of the athlete's physiology and create an individualised profile. This ultimately aims to prevent injuries or states of non-assimilation of training loads (Quintas et al., 2020; Sellami et al., 2021; Ginevičienė et al., 2022).

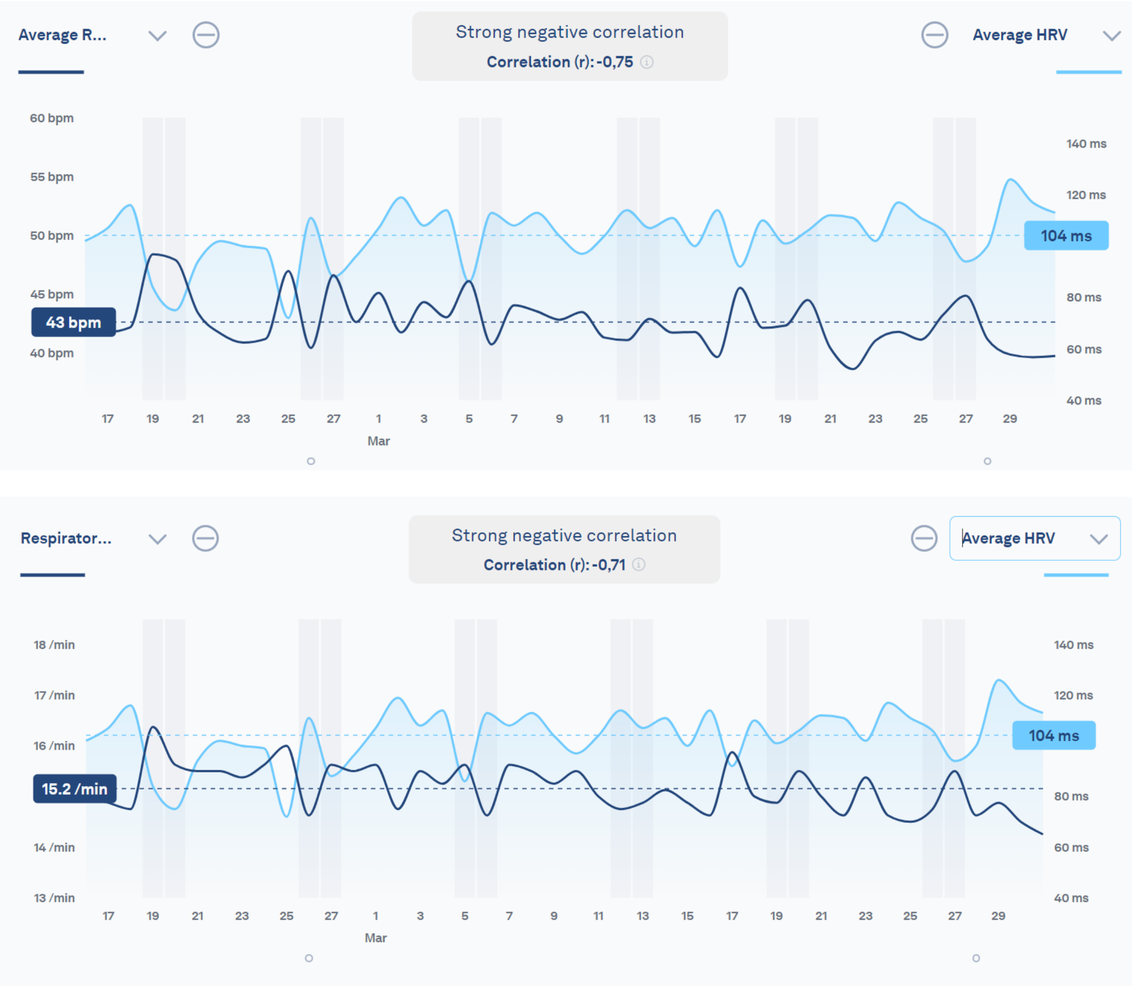
The most relevant and current cardiopulmonary biomarkers for monitoring adaptations focus on the use of heart rate variability, basal or resting heart rate, and respiratory rate. This is due to the emergence of various devices that allow these variables to be measured during sleep or in a state of limited consciousness, which facilitates the obtaining of baseline values.

Heart rate variability (HRV) is defined as the difference or variation in time between heartbeats. It is a variable sensitive to the reaction of the autonomic nervous system in response to stressful situations, such as training load (Altini and Plews, 2021). In terms of the variables analysed in HRV, they are divided by their frequency domain: the peak frequency of the low frequency band (LF peak, Hz); the peak frequency of the high frequency band (HF peak, Hz); or the absolute power of the low frequency band (LF power, ms2) and high frequency band (HF, ms2). Additionally, there are temporal domain variables, such as the standard deviation of NN intervals (SDNN) or RR intervals (SDRR) in ms, and the percentage of successive RR intervals that vary by more than 50 ms (PNN50) in %. However, most publications related to athletic performance agree that the rmssd variable, the square root of the mean squared differences of successive RR intervals, would be the recommended variable (Plews et al., 2017).

There are no reference values for rmssd since HRV is an individual value for each athlete. It should be noted that the analysis of this variable is advisable to be performed by measuring the trend over time individually. Its fluctuations are highly related to the activation and action of the sympathetic and parasympathetic nervous systems, so it is a useful tool for observing or describing the state of acute adaptation or recovery of athletes or players.

For its part, basal or resting heart rate and respiratory rate are other components that facilitate the understanding of the adaptations or recoveries of the athlete in post-exercise moments. The trend of RHR over an accumulation of records draws the assimilation of the load from the previous day. Generally, RHR tends to increase after a stressful stimulus and returns to basal values when the athlete has recovered from that stress. Respiratory rate behaves very similarly when calculated as the number of breaths per minute.

**Image 7: Trends and correlations of variability of heart rate with the resting cardiac frequency and respiratory frequency**




Source: Oura, 2022.

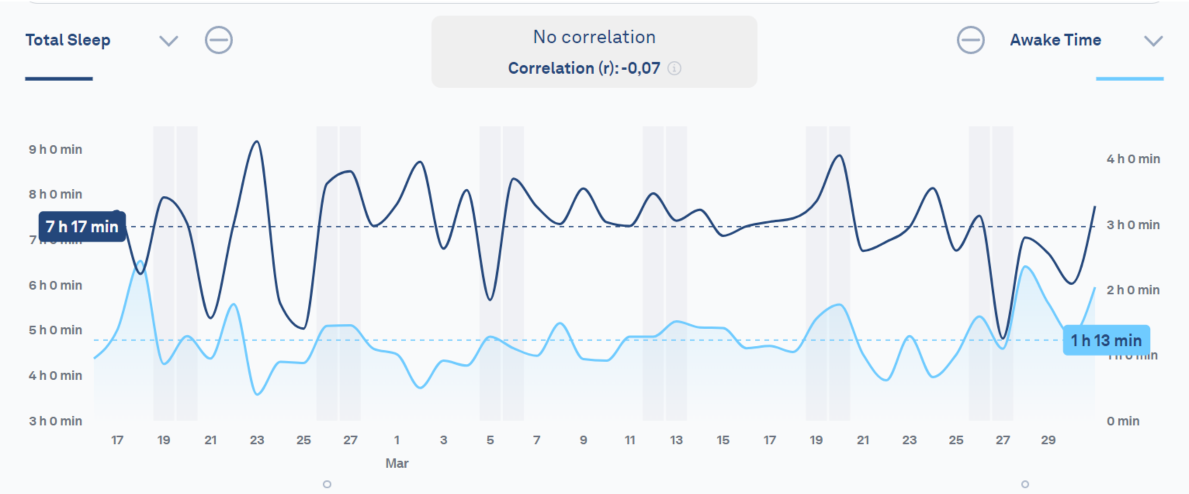
Additionally, in certain sports modalities, the average heart rate (HR average) and maximum heart rate (HRmax) during warm-up or in designated tasks during physical activity could act as indicators of adaptation to a certain stressful load to which the athlete is subjected to.

### 2.1.3.1 Assessment of the adaptation through sleep variables

As mentioned in previous paragraphs, the commercialisation of devices that record physiological and sleep data during the night, with minimally invasive methods, facilitates the understanding and description of athlete recovery. With reference to values of HRV, RHR, and respiratory rate, the analysis of variables such as total time in bed, total sleep time, total wake time, and the number of disturbances during the night can become indicators of the level of fatigue generated by training or competition.

Currently, work is being done on validating data on the analysis of sleep phases. Once high precision is obtained in data collection, it will be a plus in understanding the recovery state depending on the time the subject has spent in deep sleep and REM sleep phases.

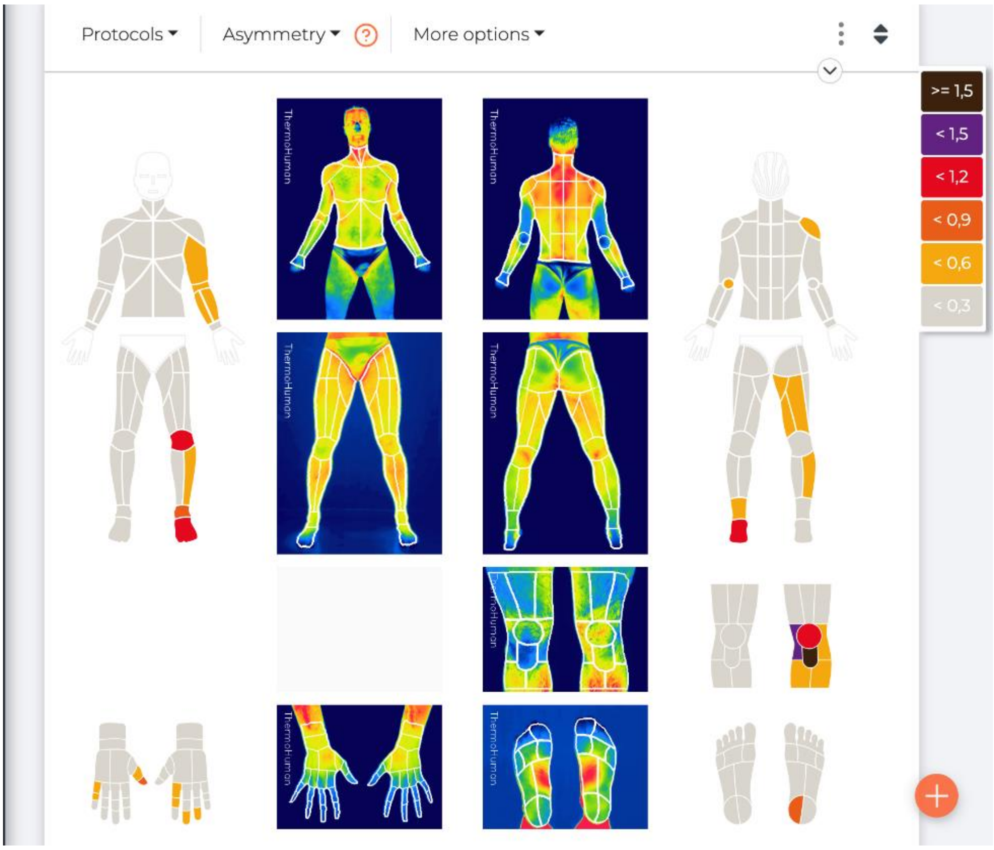
**Image 8: Trend of the variables of total sleep time during the night and total wake time**




Source: Oura, 2022.

Thermography is understood as the technique that allows to determine the athlete's temperature, focusing on the variations and differences between different areas, as well as identifying asymmetries between different muscle groups throughout microcycles or weeks, using thermographic cameras. It is a method that can be useful for monitoring adaptations in the sports world.

**Image 9: Use of thermography in the analysis of asymmetries**

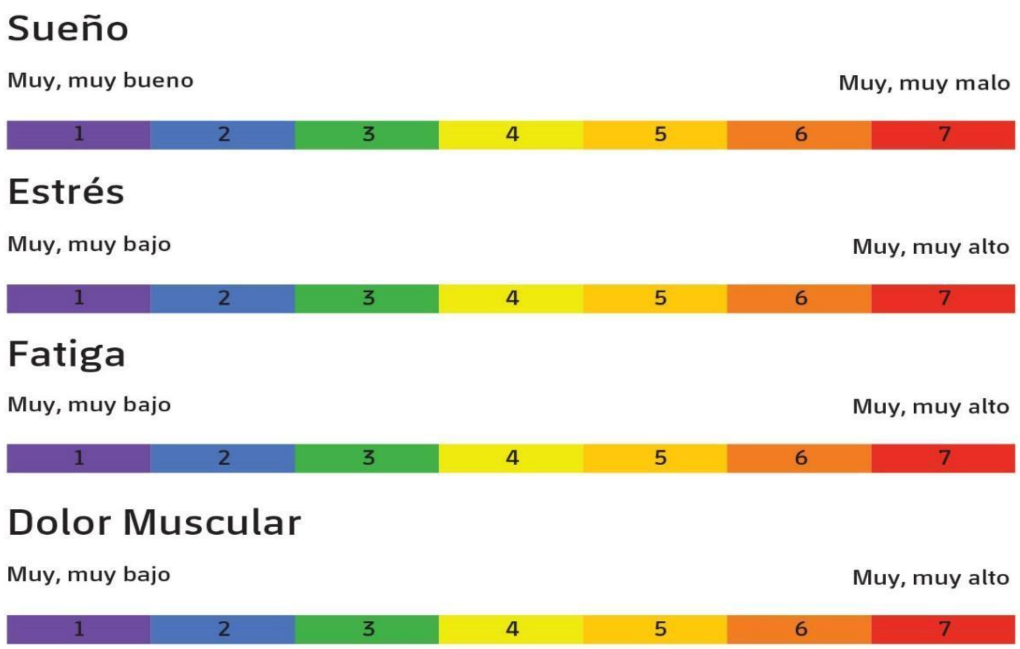



Source: ThermoHuman, s. f.

### 2.1.3.2 Perceptual Markers

Finally, the use of subjective questionnaires focused on the athlete's sensations in response to the load supported the previous day and the perception of their recovery is widespread in sports where access to other methods may be limited due to their nature, competitive density, or economic constraints. The Wellness questionnaire stands out among these. It focuses on a list of items such as levels of fatigue, stress, mood, energy levels, sleep quality, sensation of muscle injury among others, and that are valued by the athlete on a scale of 0 to 10 (Borg, 1998) or 0 to 7 (Hooper and Mackinnon, 1995).

**Table 1: Wellness Questionnaire**




Source: own adaptation from Hooper and Mackinnon, 1995; and Fessi et al., 2016.

| | |
|---|---|
| Sueño | Sleep |
| Muy, muy bueno | Very, very well |
| Estrés | Stress |
| Muy, muy bajo | Very, very low |
| Fatiga | Fatigue |
| Muy muy bajo | Very, very low |
| Dolor muscular | Muscle pain |
| Muy, muy bajo | Very, very low |

#### 2.1.3.2 Neuromuscular fatigue markers

Another type of evaluation to observe the evolution of peripheral fatigue in the player, specifically related to the body segments that are protagonists in each sports modality throughout the different microcycles that make up a season, is doing neuromuscular assessments. Analysing fluctuations in power, absolute strength, and accelerations, among other biomechanical variables, can be a useful indicator of the athlete's state and assimilation of loads. The posterior chain test to evaluate the fatigue of the posterior muscle groups, specifically the hamstrings, can become an effective tool to analyse the muscular fatigue resulting from a football match; and, as a second objective, to try to prevent possible injury risks resulting from a significant loss of strength in the area.

**Image 10: Posterior chain test with force platform**

Source: Matinlauri et al., 2019.

Other assessment tests may focus on 10 or 30-meter sprints, bench press tests for upper extremities; power tests with conical pulley in open or cross exits; force platform or contact force jump tests; or radar launch tests.

### 2.1.4 Internal load monitoring variable and adaptations in women's football

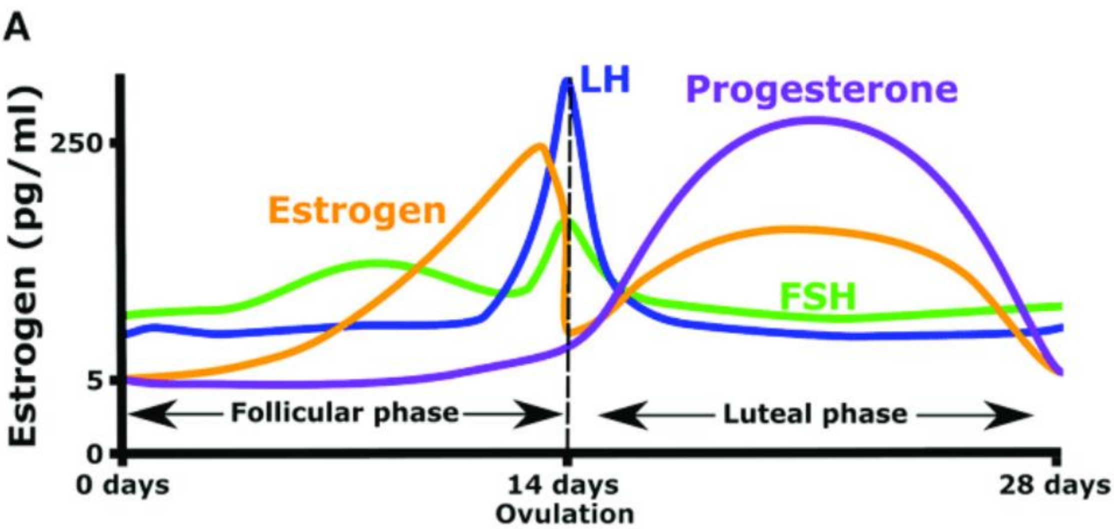
As a summary and after analysing the nature of women's football, we can propose a plan for monitoring internal load during training and its subsequent adaptations by the player.

Regarding internal load and what happens during training or a match, the use of the Subjective Perceived Exertion Scale (RPE) by the player is a highly recommended tool, provided that the player is familiarised with the method beforehand. In this way, automated responses without a prior introspective analysis of perceived sensations are avoided. Also, using heart rate during training, complementing external load variables, can provide a real-time view of how the player responds to different tasks. It would be interesting to investigate HRR behaviour during breaks between tasks, to analyse the physical demands of different tasks and the individualised recovery capacity of each team member. At more specific moments, such as after very specific tasks in preseason, the analysis of resulting blood lactate concentrations would help locate players and have an idea of their conditioning profile to then individualise training depending on their needs.

At the adaptation level, they could be grouped into assessments within the microcycle and assessments in specific periods throughout the season. For example, pre-season, early in the year, and in the months of April and May, just before the start of more competitive mesocycles and relevant matches.

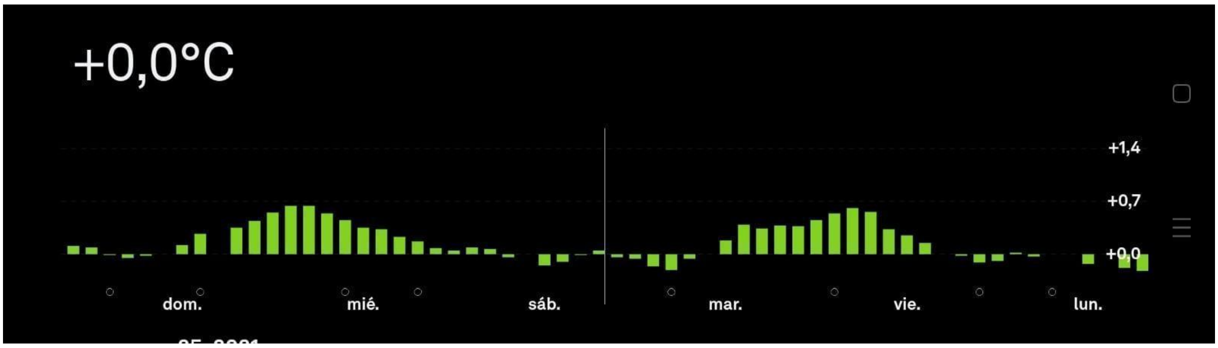
The first assessments, performed periodically in each microcycle, correspond to the less invasive methods. Monitoring cardiorespiratory variables (mainly HRV and RHR); and analysing the amount and quality of sleep through versatile and comfortable devices, using LED lights and PPG lights for data recording, are highly interesting options. Thermography is also a relevant method for observing muscle behaviour and post-match residual fatigue. It is important to highlight the importance of common work between the different members of the technical staff to obtain correct feedback on events that occur. Likewise, performing a Wellness-type perceptual questionnaire in the morning, just after waking up and while having breakfast, is useful to see the levels of readiness or attitude to face that day. Additionally, in the case of women's football, it is interesting for each player to respond to a questionnaire with questions related to the menstrual cycle, simply notifying whether the athlete is menstruating or presenting any type of premenstrual or menstrual symptoms. Thus, the need to objectify said cycle arises, taking into account that the most recent scientific literature (Romero-Moraleda et al., 2019; Blagrove et al., 2020; McNulty et al., 2020; Bruinvels et al., 2021; and Keay et al., 2021) emphasises the importance of individualising training loads according to the phase of the cycle the athlete is in. Analysis over a prolonged period of temperature variations, currently carried out through most devices that analyse other physiological variables (Bruinvels et al., 2021); and concentrations of oestrogen and progesterone, essential hormones in the menstrual cycle, are important in these cases.

**Image 11: Theoretical fluctuation of oestrogen and progesterone in the menstrual cycle**




Source: Chidi-Ogbolu and Baar, 2019.

**Image 12: Trend of the temperature variability over the menstrual cycle**




Source: Oura Smartphone, 2022.

Another periodic measurement within the microcycle, especially during shorter periods without conducting them throughout the entire season but rather during the most critical months in terms of demand and competitive density, would be the use of salivary biomarkers to describe the assimilation of loads by each player and thus individualise recovery. The testosterone: cortisol ratio, free testosterone, and cortisol, as well as IgA, define the stress-recovery balance and the immune system status of the player, respectively.

However, a more thorough analysis of the biomarkers mentioned above would be advisable at three or four moments during the season, as it creates a biochemical profile of each team member.

Depending on the demands and group status, neuromuscular assessment tests should be scheduled more or less frequently. For example, in a period where the Wellness presents results of muscle injury and doctors and physiotherapists report a high tendency for posterior chain discomfort, it may be interesting to monitor on MD+1 or MD+2 to rule out significant strength decreases. Likewise, conducting an acceleration-speed profile for each player would help detect non-habitual patterns and emphasise deficiencies.

In the next modules, knowledge about assessments and their timing will be expanded.

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