4.2 Training load: internal load-external load

The main objectives of high performance team sports are performance optimization and injury risk reduction. As seen in the previous unit, performance optimization is achieved through positive adaptations, once we follow the training principles and conjectures applicable to team sports. There is a lot of information available that can help us to establish optimal training monitoring through quantification of the loads.

In the world of training, the training load has traditionally been understood as the product of training volume because of its intensity:

$$(L = V * I)$$

More specifically, important authors in the field such as González Badillo and Ribas Serna (2002) define the training load as the combination of biological and psychological demands (**internal load**) caused by the training activities undertaken (**external load**).

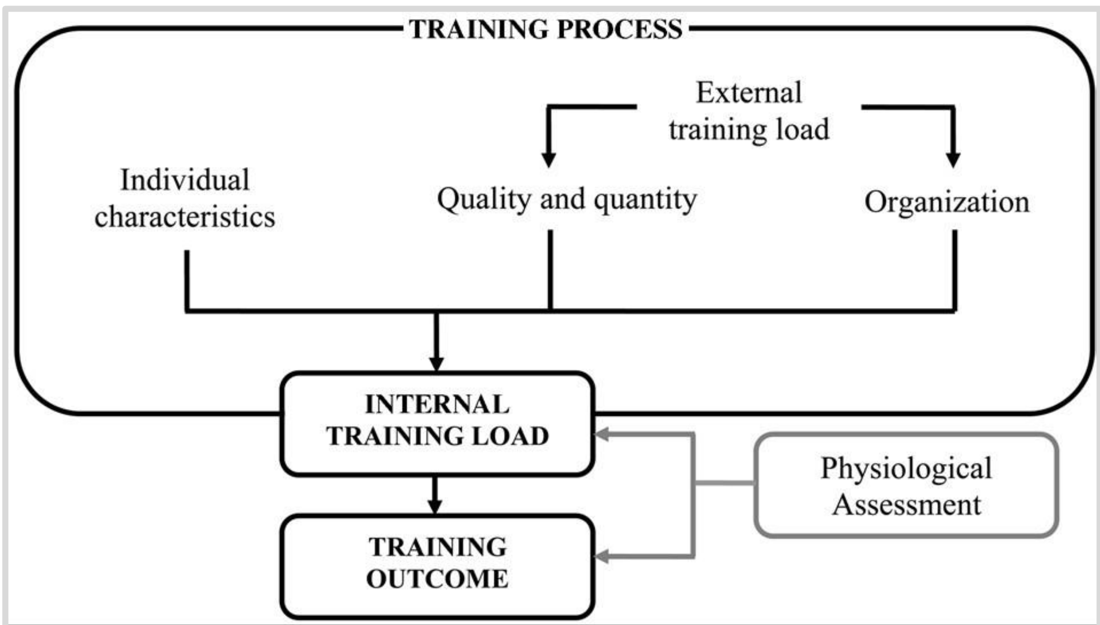
From both loads we can obtain enough information to monitor our athletes and from here we must be able to observe positive or negative adaptations in performance. Associations between internal and external load have been studied extensively in recent research, in order to better understand training process and, therefore, validate some of these internal measures (Mc Laren et al., 2017).

Internal load represents the biochemical (physical and psychological) and biomechanical responses that occur in the athlete. There are four main ways to quantify the internal training load in team sports:

Heart rate (HR)
Maximum oxygen consumption (VO2max)
Rate of Perceived Exertion (RPE)
Blood lactate concentration (BLC)

The external load represents the quantitative conditional workload performed during training or competition. It can be measured using tools such as GPS or multi-camera systems used to monitor training activity or competition, and from there, within team sports, an analysis of different performance variables tracked per day of the week, the microcycle and the season in question can be carried out. Maximum variables such as maximum speed reached, maximum acceleration and deceleration are analyzed in conjunction with other important variables such as total distance covered, high intensity running or high metabolic load distance, etc., which we will examine further later.

Figure 1: Physiological assessment of aerobic training in soccer



Source: Impellizzeri, Rampinini, & Marcora, 2005, https://goo.gl/q8wtZe

As an example of the relationship between internal and external loads, Impellizzeri et al. (2005), in their model of physiological assessment of aerobic training in soccer, provide a diagram that summarizes the relationship between the results of the training process, based on the athlete's individual characteristics, and the external load (quantity, quality and organization), with the physiological assessment based on the training results and the internal load.

Methods: Resources for monitoring internal load

Heart Rate (HR)

Heart rate has been one of the most used means to quantify load in team sports, due to it being a low cost, highly reliable and non-invasive method for measuring an athlete's physiological variables during most sport situations.

Heart rate monitoring has been studied and analyzed using two methods, which provide information about internal load control in team sports:

- First, the TRIMP method refers to the increase in heart rate, considering the duration of training multiplied by a factor of intensity, proposed by Bannister, Carter and Zarkadas (1999):

Men: duration (min) x (HRex - HRrest)/(HRmax - HRrest) x 0.64e ^ 1.92x
Women: duration (min) x (HRex - HRrest)/(HRmax - HRrest) x 0.86e ^ 1.67x

e = 2.712, x = (HRex - HRrest) / (HRmax - HRrest), HRrest = Average heart rate during recovery, and HRex = Average heart rate during exercise (Bannister, 1991)

Another method used is the Edwards method (1993) with training zones. This is based on five zones, each of them with a pre-established value for the player, (50-60 % = 1, 60-70 % = 2, 70-80 % = 3, 80-90 % = 4 and 90-100 % = 5), taking into account HR reserve, that is, the HR maximum minus the HR at rest:

Zone 1 = 50-60 % of the HR maximum; Zone 2 = 60-70 % of HR max.; Zone 3 = 70-80 % HR max.; Zone 4 = 80-90 % HR max.; Zone 5 = 90-100 % HR max (Edwards, 1993).

In our own research, the result of the doctoral thesis by Gómez, Pallarés, Díaz and Bradley (2013), we studied different internal load variables in elite soccer players, such as heart rate and rate of perceived exertion. Due to the scientific evidence that a soccer match is played at an average of 85 % of the maximum heart rate, we use this measure to create a variable of high intensity for the quantification of the training load (TTE> 85 % HR max. in minutes):

Figure 2: Average and quantification of the load of preparatory sessions and quantification of official matches (daily mean, weekly mean and weekly total) using heart rate.

	Daily Mean		Weekly Total	
	Elite (n = 21 weeks)	Sub-elite (w = 19 weeks)	Elite (n = 21 weeks)	Sub-elite (w = 19 weeks)
Quantification Preparatory Sessions				
TTT (min)	84.7 ± 13.5	81.4 ±13.9	244 ± 51	284 ± 49*
TTT > 85% HR $_{max}$ (min)	18.2 ± 3.2	28.0 ± 8.2*	66.7 ± 11.9	90.4 ± 34.2*
% of TTT High Intensity (%)	21.8 ± 4.3	34.8 ± 8.8*		
RPE mean	3.5 ± 0.5	3.9 ± 0.7*		
% HR $_{max}$ mean	68.8 ± 1.5	74.8 ± 2.8*		
	Mean per Match			
	Elite (n = 21 weeks)	Sub-elite (w = 19 weeks)		
Quantification Official Matches				
DE match (m)	9.876 ± 404	10.552 ± 582*		
DE match > 19.8 km/h^{-1} (m)	822 ± 131	1.183 ± 112*		

*Significantly different (p <.05) when compared to Elite level results. TTT: total training time; % HR max: percentage of the maximum heart rate; RPE: rate of perceived exertion; DE Match: distance covered in official match.

Source: Gómez Díaz, A. J., Bradley, P. S., Díaz, A., & Pallarés, J. G. (2013)

Figure 3: Correlation between the main study variables

1	2	3	4	5	6	7
1. TTT (min)	.52**	-.08	.78**	-.04	.17	.23
2. TTT > 85% HR_{max} (min)		.80**	.82**	.55**	-.03	-.51**
3. % of TTT High Intensity (%)			.45**	.63**	-.20	.44*
4. RPE mean				.32*	.20	.43*
5. % HR_{max} mean					.40*	.65*
6. DE match						.77**
7. DE match > 19.8 km/h^{-1}						

* p < .01; * * p < .001. TTT: total training time; % HR $_{max}$: percentage of the maximum heart rate; RPE: rate of perceived exertion; DE Match: distance covered in official match.

Source: Gómez Díaz, A. J., Bradley, P. S., Díaz, A., & Pallarés, J. G. (2013)

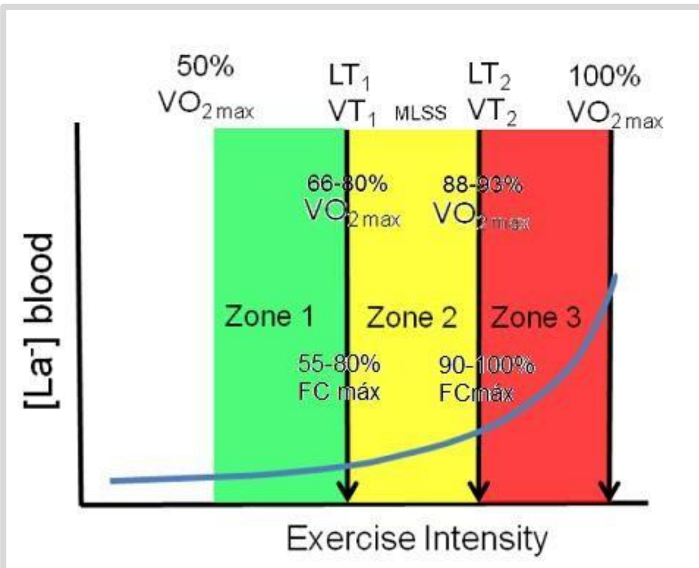
Correlation between the main study variables

From this study and its data, we can observe a high correlation of internal load parameters TTE> 85 % HR max. with other internal load variables such as RPE and also external load parameters such as distance traveled at high intensity in competition, among others.

Maximum oxygen consumption (VO2 max)

The traditional methods used to measure VO_2 max make its everyday use in training impossible. Furthermore it is currently impossible to use in competitive settings in team sports. Some authors have determined that HR monitoring is an adequate indicator of exercise intensity due to its close relationship with VO_2 max (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Likewise, this parameter has been commonly used to measure intensity in team sports:

Figure 4: Training Zones



Source: Muñoz, 2014, https://goo.gl/dKp6Dt

In the same way that the average HR in a soccer match is estimated to be 85 % of the maximum HR, the average oxygen consumption in a soccer match can be indirectly estimated to be 70 % of VO_2 max.

However, team sports present some specific characteristics such as the intermittent and submaximal nature of actions. This intermittent structure of the game, together with thermal or emotional stress that may occur during the competition, could alter the linear relationship between HR and VO_2 (Casamichana, San Román, Calleja, and Castellano, 2015).

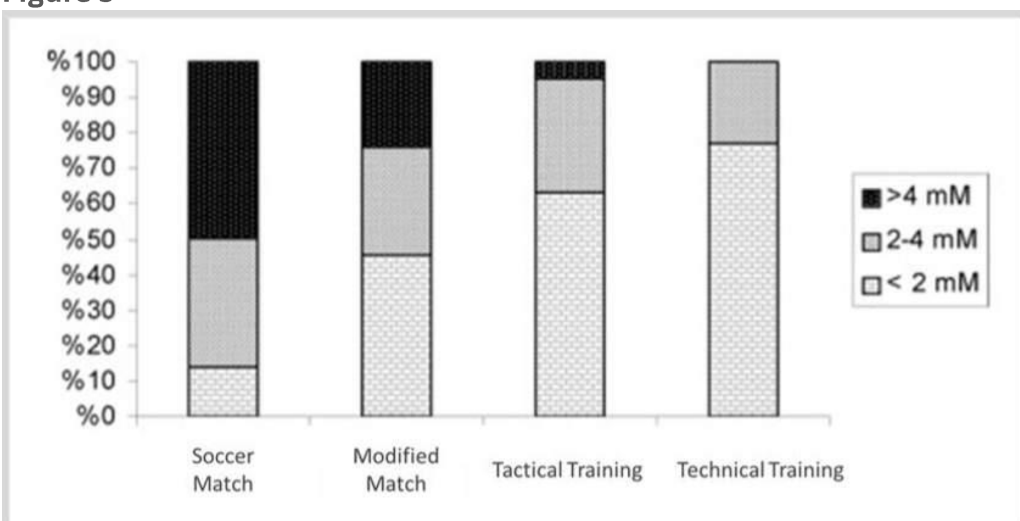
Blood lactate concentration

Another measurement taken to quantify the athlete's internal load is blood lactate concentration, normally measured using different portable analyzers, that have made its evaluation during training and competition possible.

In general terms, both the variables of VO_2 max and sanguineous lactate anaerobic threshold can be used to explain performance in endurance sports, but can also be used in team sports. Since sanguineous lactate is associated with the physiological load, this can be correlated with an athlete's heart rate to assess the internal load.

Bearing in mind that scientific studies (specifically in soccer) have shown that lactate concentrations are between 4 and 6 mM during a match, the 2 mM lactate line is normally used as an aerobic threshold, while the 4 mM lactate line is used to indicate the start of the anaerobic threshold. From these assessments there are different internal load magnitudes for different contents in training sessions and matches:

Figure 5



Source: Eniseler, 2005, page 801. Journal of Strength and Conditioning.

Percentage of heart rates recorded below, between and above the heart rates corresponding to the 2- and 4-mM reference lactate lines during different soccer training activities.

Rate of Perceived Exertion (RPE)

RPE is probably the most economical and easy to use, non-invasive method that collects individual information from the player during or at the end of the sporting activity itself. RPE scales (Borg, 1982) are quantified by athletes attributing a subjective perception of physiological stress based on perceived exertion.

Traditionally, the Borg-RPE scale included scores between 6 and 20. However this was modified to a scale of 1-10 for better understanding, once results and academic assessments became more familiar with it.

Figure 6: Relationship between rate of perceived exertion and training zones

RPE TRAINING ZONES

BORG RPE	MODIFIED RPE	BREATHING	TRAINING ZONE	% of MHR	TYPE
6	0	No exertion	1	50% - 60%	Warm-Up
7		Very light			
8	1				
9					
10	2	Notice breathing deeper, but still comfortable. Conversations possible.	2	60% - 70%	Recovery
11					
12	3				
13		Aware of breathing harder; more difficult to hold conversation	3	70% - 80%	Aerobic
14	4				
15	5	Starting to breathe hard & getting uncomfortable	4	80% - 90%	Anaerobic
16	6				
17	7	Deep & forceful breathing, uncomfortable, don't want to talk	5	90% - 100%	VO2 Max
18	8				
19	9	Extremely hard			
20	10	Maximum exertion			

Source: Daley, 2011, https://goo.gl/cDUcui

Through this method's subjective analysis, necessary information is provided by the player as they use said scale, which consists of asking the player to score numerically (from 0-10 when using the modified Borg Scale) how hard the session was for them. Using that score, the training load is then easily calculated by multiplying this subjective value of exertion by the duration of the session in minutes.

As an example, we will provide information about a soccer match, in which a player indicates (quantitatively) a level of fatigue/tiredness with a RPE of 10, and at training on day -3 with a RPE of 6. As shown below, based on the same duration, different loads are calculated:

Match = 95 min x 10 RPE = 950 load units
Training -3 = 95 min x 6 RPE = 570 load units
(60 % of match load)

The Borg scale is also used to identify the type of work that has been done during the session, as it can be used to classify the intended focus and preferences throughout a given session. Thus:

The first three levels of the scale correspond to a preferably aerobic training.

Below the aerobic threshold, between three and seven is considered the mixed zone (between the aerobic and anaerobic thresholds).

From a score of seven onwards, the training is predominantly anaerobic.

Self-Perception of Health (SPH)

Wellbeing questionnaires have become relevant in team sports and high performance sports. Increasingly there is greater interest in the athlete's self-perception and how this relates to training and competition stimuli. Recent research in these sports demonstrates that there is a close relationship between the impact of training and the athlete's state of well-being and mood.

McLean, Coutts, Kelly, McGuigan and Cormack (2010), in rugby, and Morgan, O'Connor, Ellickson and Bradley (1998), in athletics, researched wellbeing questionnaires. They evaluated five main sections in the questionnaires: athlete's perception of fatigue, sleep quality, muscle soreness, stress levels and mood. For the assessment of each, they used a scale from 1 to 5 (lower to higher wellbeing):

Figure 7: Example of a wellbeing questionnaire

	5	4	3	2	1	Record Score
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired	
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
GENERAL MUSCLE SORENESS	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down	

Source: Morgan, O'Connor, Ellickson, and Bradley (as cited in Andoni, 2016, https://goo.gl/pWy5aV).

Methods: Resources for monitoring external load

Currently, GPS technology and accelerometers have been used in team sports to quantify the movement demands on athletes in training and competition situations. These devices are non-invasive, small and light-weight, they are individual and are not excessively expensive. Thus they continue to be highly successful at monitoring conditional capabilities in the field.

In an effort to classify and clarify the different variables that are obtained using said technologies, in a recent study (Fernández, Medina Leal, Gómez, Arias Vicente, and Gavaldà Mestre, 2016) in the area of athletic performance at FC Barcelona the variables were divided into the following groups, which in turn can be used for all team sports:

Table 1: Description of the selected physical variables divided into three groups: locomotor, metabolic and mechanical

Locomotor variables:
Distance covered (DIS)
Sprints (SPR)
High speed running (HSR)
Max speed (MAX)

Metabolic variables:
Average metabolic power (AMP)
High metabolic load distance (HMLD)
High metabolic efforts (HEF)
Energy expended by the player per second per kg, measured in W/kg
Distance traveled by the player when the metabolic power is> 25.5 W/kg
The number of movements or efforts undertaken in producing HMLD
Total distance covered during a session or matches
Number of times over 5.5 m/s for more than 1
Meters covered when speed is > 5.5 m/s
Maximum speed reached by the player

Mechanical variables:
Fatigue index (FAI)
Dynamic stress load (DSL)
Total loading (TLO)
Accelerations (ACC)
Decelerations (DEC)
Step balance (STE)
Accumulated DSL from the total session volume, in terms of speed (DSL/SPI)
Total number of impacts, based on the total number of impacts, based on accelerometer values over 2 g
The total of the forces on the player over the entire session based only on accelerometer data
Number of increases of speed during at least 0.5 s (> $3m/s^2$)
Number of decreases of speed during at least 0.5 s (> $3m/s^2$)
Ratio of left step impacts to the sum of left and right step impacts

Source: Description of physical variables. (Adapted from Fernández, Medina Leal, Gómez, Arias Vicente, and Gavaldà Mestre, 2016)

Based on these variables, reports are created about training exercises, training sessions, microcycles and evolution by player or group of players.

Figure 8: Example Wimu Conditional session and training exercises report

Source: Prepared by the author

Other external load monitoring resources can be obtained using multi-camera system video recording. Normally, each of the players is assigned a point prior to training or competition, and from there a series of variables that can be conditional and also technical-tactical in the case of team sports are studied.

As a summary, in the following table we outline the main variables looked at in our soccer competition matches using the multi-camera system.

Figure 9: Example of Mediacoach individual player report Eventing, accumulated technical data

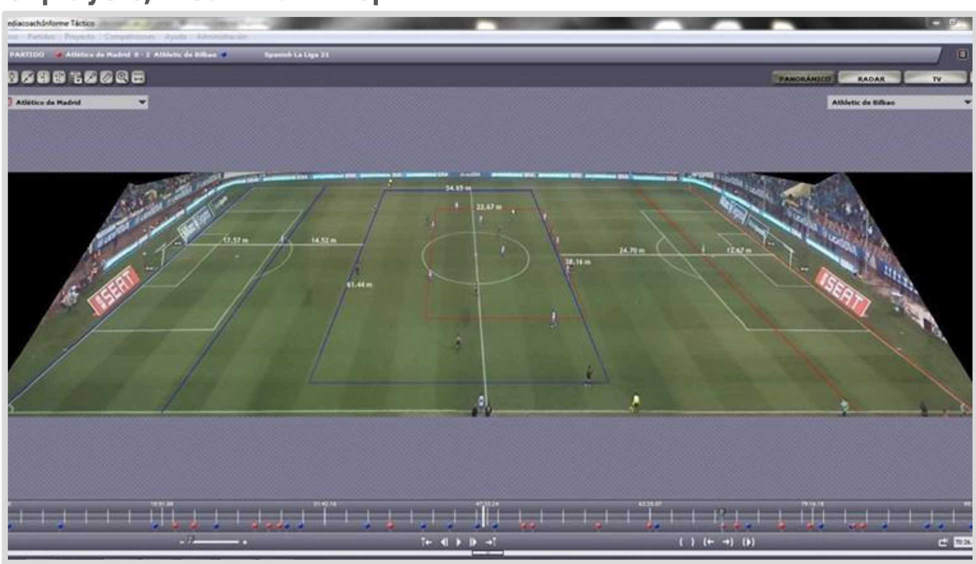
Eventing

Summary of accumulated data

	Mean	Total		Mean	Total
Goals scored	0,09	1	Shots	0,54	6
Goal assist	0,00	0	Shot assists	0,63	7
Total passes	69,58	777	Good passes	61,52	687
Recovered balls	5,73	64	Lost balls	12,54	140
Fouls received	1,88	21	Fouls committed	0,99	11
Yellow cards	0,00	0	Red cards	0,00	0
Off-sides	0,00	0	Standings	0,00	0

Source: Prepared by the author.

Figure 10: Example of Mediacoach tactical report Distances between lines of players, breadth and depth



Source: Prepared by the author.

Adjuvant Training. Monitoring strength training

In the theory and practice of high performance team sports training, there are two established training methods within structured training.

Firstly, there is *optimizing training*, which covers the programming, design, execution and control of training tasks, and aims to optimize the performance of the athlete in all competitions that they participate in throughout their athletic life.

Secondly, there is *adjuvant training*, which works as a complement to the former. This includes all the practices that allow the athlete not only to achieve a state of success and to protect their health–which means the tasks set by the optimizing training each day can be carried out (Seirul-lo, 2017)–but also to strengthen the elements, structures and systems required by each specialty and that facilitate the athlete progressing towards the desired level of performance. This training is as important as optimizing training, however, sometimes its practice is underestimated, as it does not directly affect the athletes' performance.

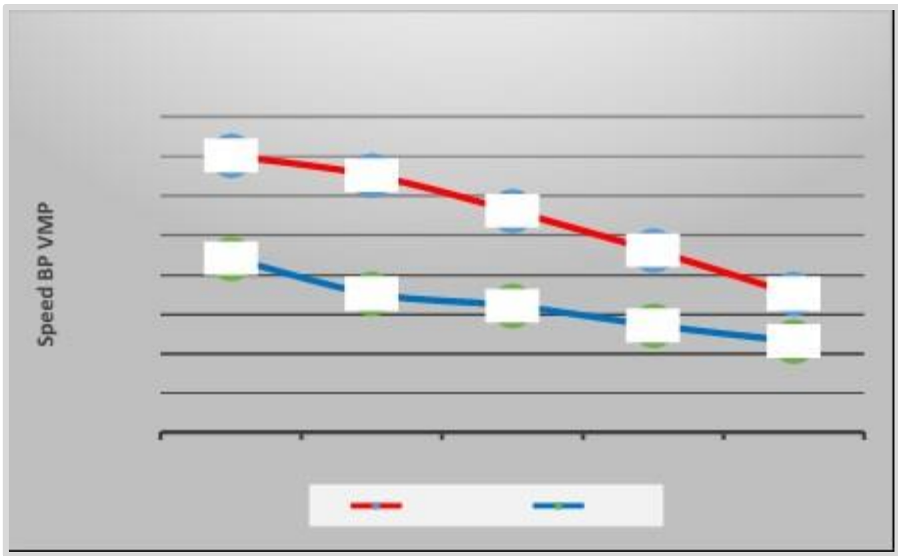
VBST (*velocity based strength training*) is used as part of adjuvant training and to monitor strength training. VBST utilizes different technology, such as accelerometers or linear or inertial *encoders* to measure the speed of movement in an exercise. From the information on the speed of movement, both the coach and the athlete can observe performance immediately and obtain specific and real *feedback*, in order to adjust the training.

Traditionally, strength training has been monitored using absolute weight (in kg) or relative weight (based on repetition maximum or % 1RM). However, in a more recent trend, researchers such as Sánchez Medina and González Badillo (2011) state that coaches should prescribe strength training based on the speed of movement focusing mainly on two variables:

The average velocity of the first or best repetition.
The maximum percentage of velocity loss for a repetition with regards to the best repetition of the set. Example: If the percentage of loss within a set is greater than 15%, the feedback is not positive and the set should end. This is very important, since it allows us to observe and limit the athlete's fatigue during any movement.

In the end, with regards to high performance, the player's improvement is achieved by optimizing strength and, therefore, the speed of execution and power. If we want athletes to move a load faster (an external load or their own body weight), then more strength is being applied in less time and, consequently, that improvement in the speed of execution will be accompanied by an improvement of strength and power.

Figure 11: Difference between two training tests with different loads for the same exercise (half squat HS) in a professional soccer player

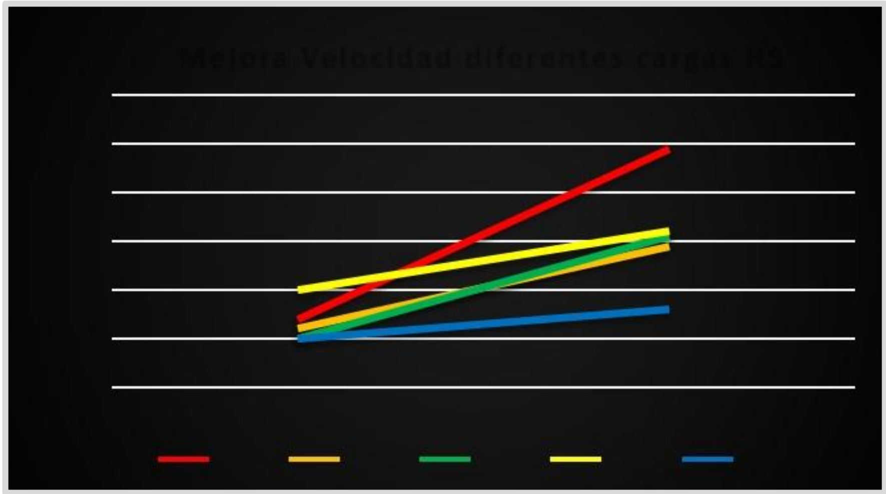


Source: Gómez, 2017 (prepared by the author)

Ultimately, and according to Jovanovic and Flanagan (2014), a series of benefits will be obtained from monitoring velocity in strength training:

- Develop an individual load-velocity profile per athlete and movement.
- Use this load-velocity profile to predict and monitor changes in maximum strength.
- Use velocity monitoring to control the effects of fatigue in strength training.
- Use velocity monitoring for immediate performance feedback to reach the maximum level of effort in certain exercises and utilize it as a training stimulus to achieve greater adaptation.

Figure 12: Velocity improvement with different loads for the same exercise (half squat HS) in a group of professional soccer players



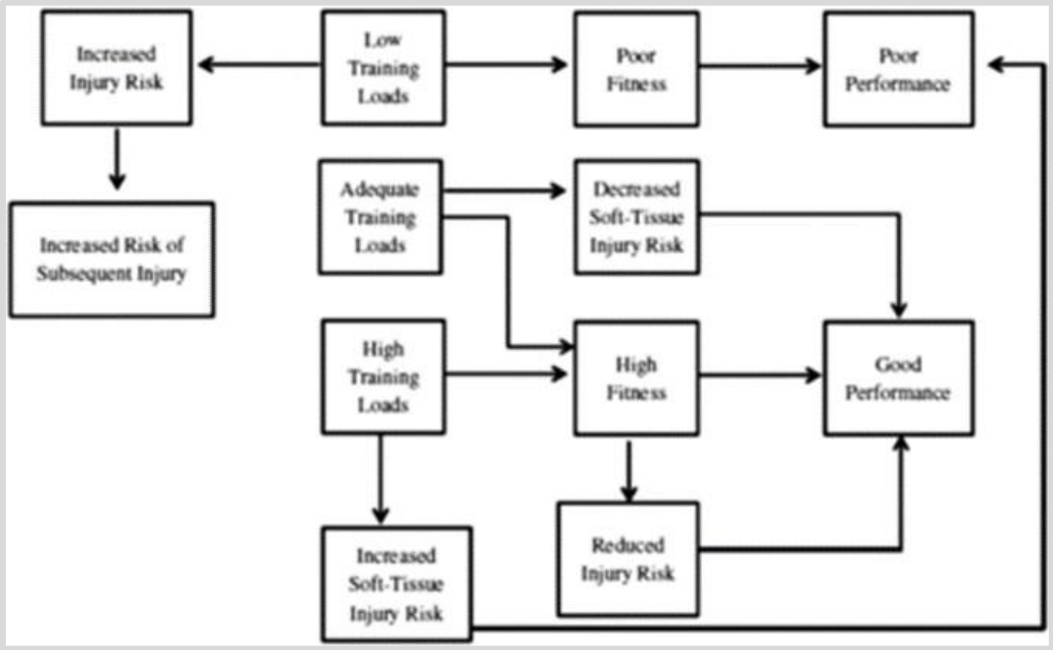
Source: Gómez, 2017 (prepared by the author)

Objectives: optimizing performance and reducing injury risk

As discussed at the start of this unit, the main objectives of high performance team sports are performance optimization and injury prevention. Professional soccer teams with fewer injuries per season perform better in national leagues, in the top leagues in Europe and in European Cup competitions (Hägglund et al., 2013). Hence we have to take into account factors that facilitate injury prevention.

In our opinion, the best prevention comes from a good state of physical preparation, appropriate load control and an optimal dose of competition. In this regard, well-known researchers in this field such as Tim Gabbett (2016), from Australia, provide the evidence and implication of preventive work in load control, outlining the following conclusions on the relationships between the level of physical condition, training load and injury risk in team athletes:

Figure 13: Relationship between physical qualities, training load and injury risk in team sports players



Source: Gabett, 2016, https://goo.gl/ThPfUe

It seems that a high chronic load has a positive influence on injury prevention.

An adequate level of physical fitness is associated with reduced injury risk. Insufficient training increases injury risk, in addition to facilitating a loss of physical fitness.

Reducing workloads is not always the best way to protect against injuries. Non-contact injuries may be caused by an inappropriate training program. Excessive and rapid increases in training loads are likely responsible for a high percentage of soft tissue injuries.

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