BARÇA INNOVATION HUB
Universitas

PHYSICAL DEMANDS AND INJURY RISKS TEAM SPORTS

Module 3: Application of microtechnology to the prevention of injuries in team sports

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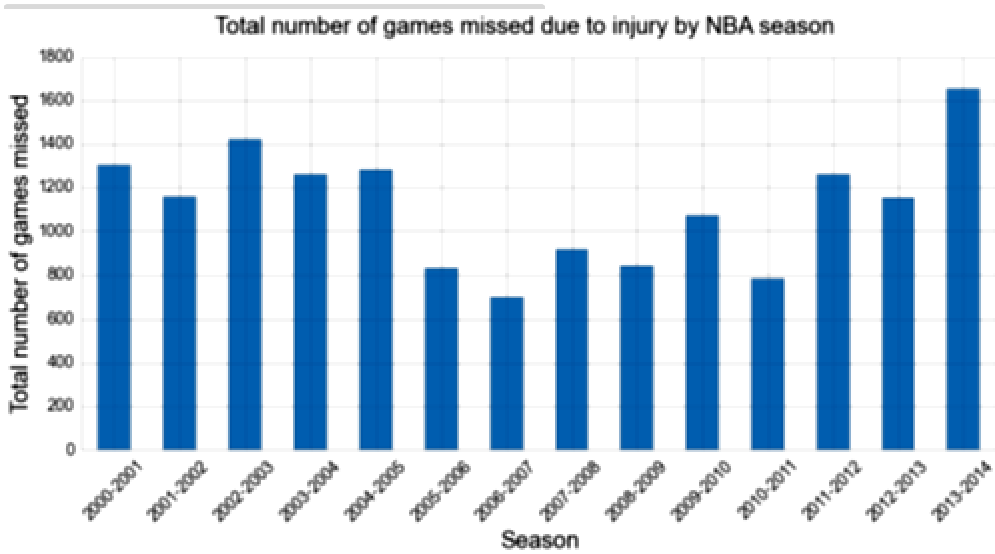
In this module we present a theoretical framework based on scientific evidence that will enable the establishment of strategies and practical applications that minimize the risk of injury in team sports.

In order to work on this issue, we must first establish the relationship between training and/ or competition workload and the risk of injury. This is very important data when it comes to understanding this phenomenon. On the one hand, one of the effects that usually comes up when athletes are injured is the economic loss that this represents for the club and, on certain occasions, also for the player. For example, the Premier League spent € 243 million on salaries of injured players in the 2017-18 season. That season represented an increase of 21% compared to the expenditure of the previous season. The team that suffered the most injuries that season was Arsenal, which had 54 injuries. But the team that spent the most was Manchester City, which had to pay some € 23 million, calculated based on the salaries of its players. In addition, during the period in which the athletes were unable to practice sports, each injury cost an average of approximately € 362,000 per player. The most common injuries were at the knee and muscle level (BBC Sport, 2018).

Another factor that we can use to quantify the influence of injuries on teams is to count the number of games that different teams lost because of injuries. In Figure 1, we can see the evolution of the number of total games lost for each of the NBA teams, from the 2000 season to the 2014 season. The lowest rate was in the 2006 - 2007 season, with just 700 games lost among all, reaching more than 1600 in the 2013 - 2014 season.

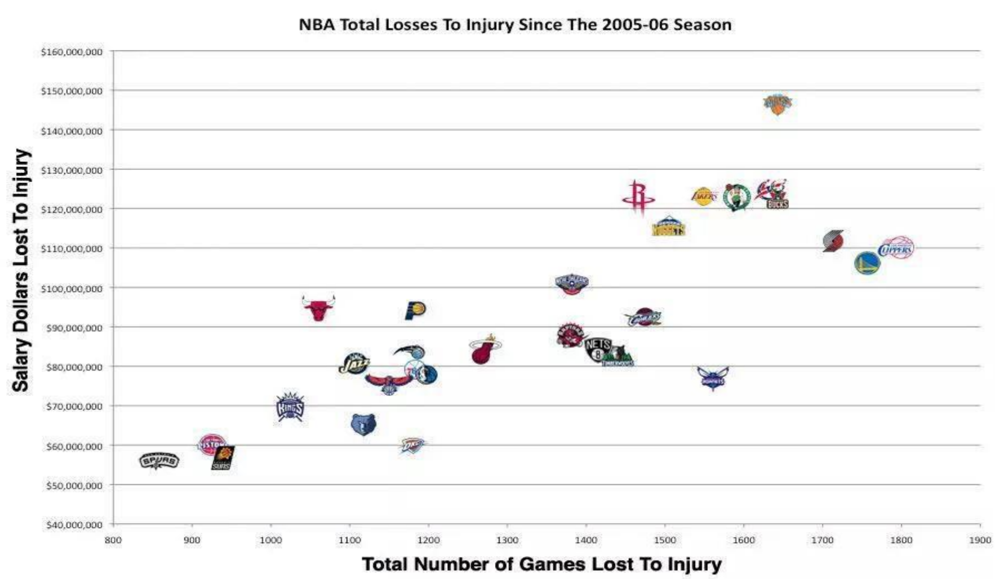
Figure 1: Total number of games lost due to athletes' injuries



Source: Hisham et al., 2016, p. 7.

Another study establishes the total number of games lost due to injury and its relation to the salary received by injured players during their leave of absence. Figure 2 shows the teams that spent the least due to this reason during the 2005 and 2006 NBA seasons (Phoenix Suns and San Antonio Spurs).

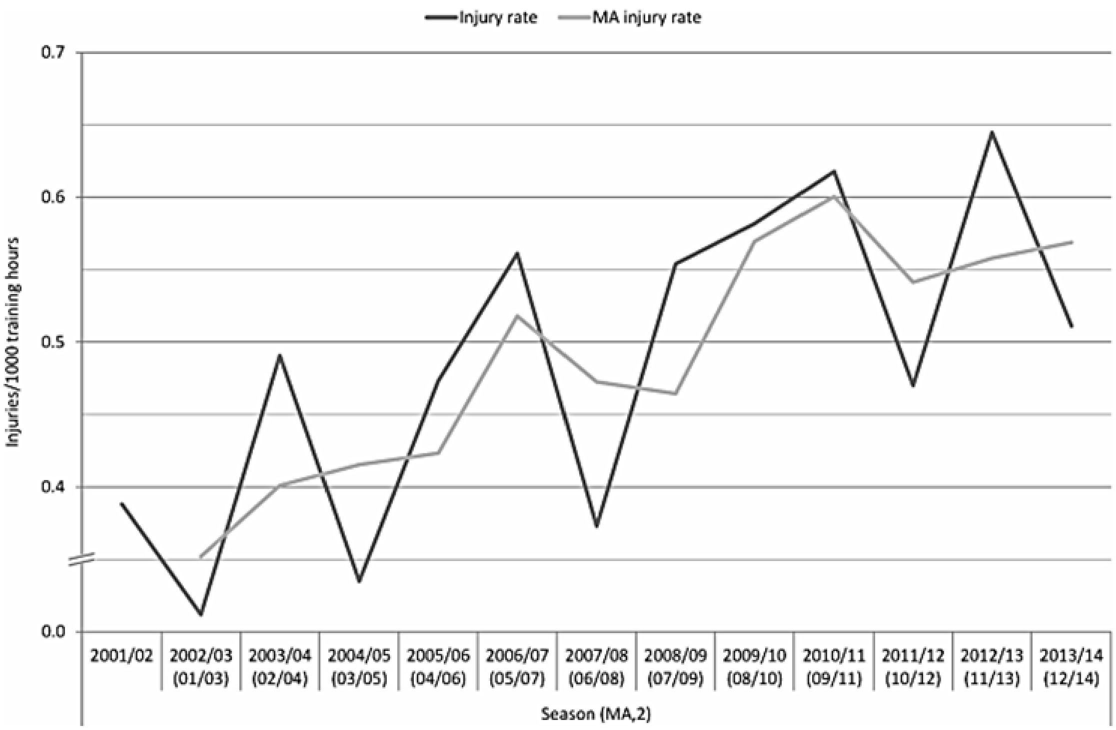
Figure 2: NBA: total number of losses due to injuries since the 2005-2006 season



Source: Moreno, J., 2015, http://www.move2thrive.com/kinein-blog/2015/5/9/hey-nbacant-you-get-your-athletes-bigger-chairs

One of the injuries that has more influence in football is the hamstring injury. This injury causes an average loss of seventeen days both in training and in games. In addition, the subsequent performance of the athlete who suffers the injury decreases, and his recovery costs an average of € 280,000. To better understand injuries and possible prevention strategies, we can start by analysing the data presented in Figure 3. This graphic shows that the injuries suffered at the hamstring level during training sessions have increased by 4% annually, by analysing the period that goes from the 2001 season to the 2013 - 2014 season.

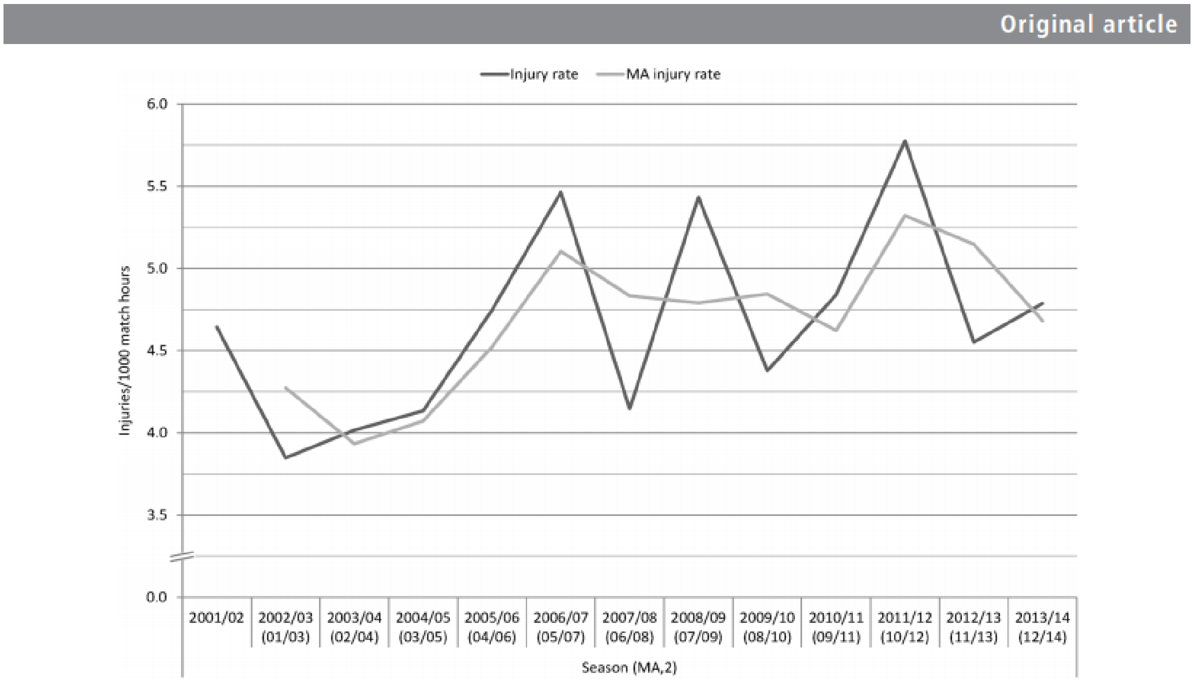
Figure 3: Annual increase in hamstring injuries during training sessions of professional football players



Source: Ekstrand et al., 2016, p. 4.

A similar tendency has emerged during matches, with an increase of 15%.

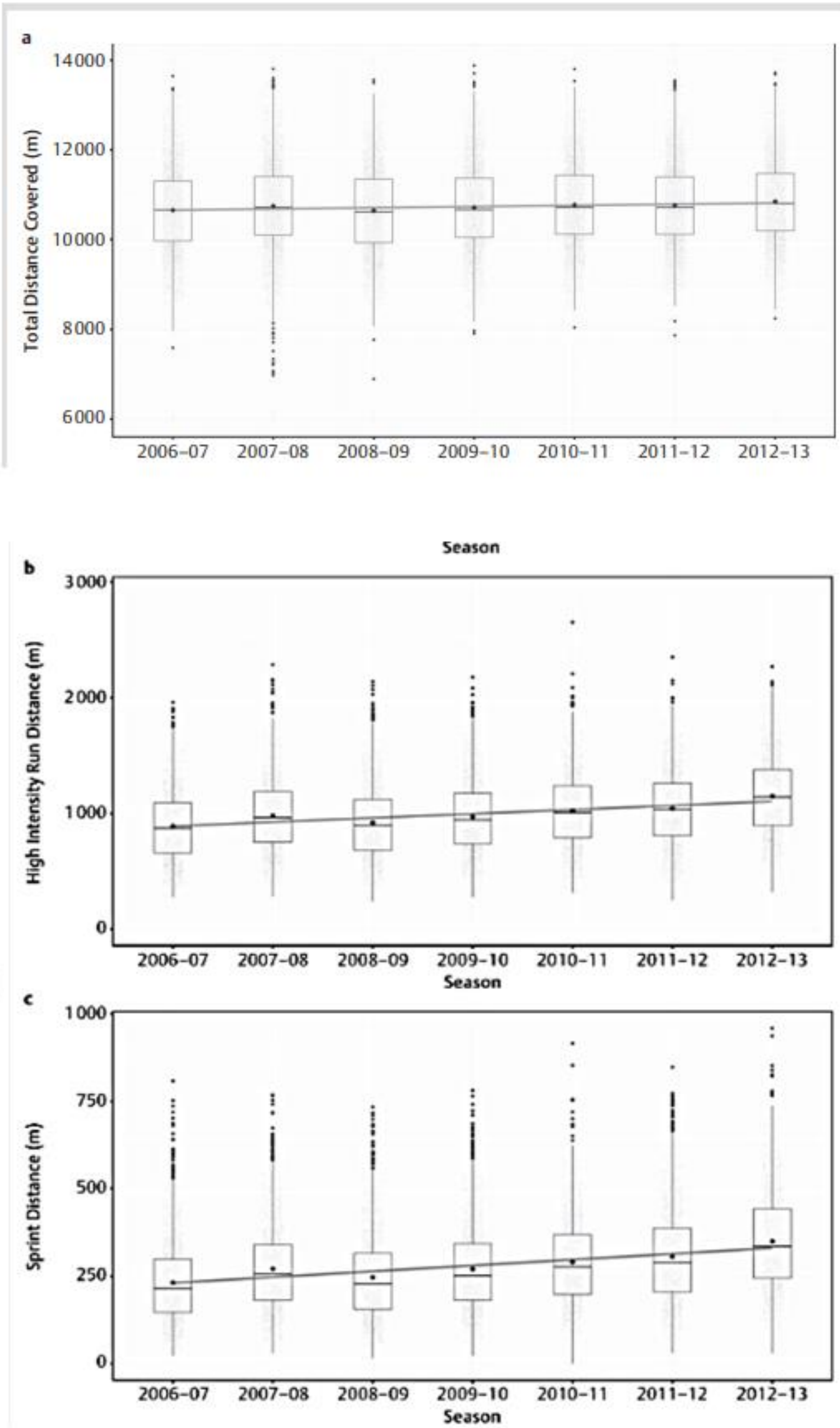
Figure 4: Annual increase in hamstring injuries during matches of professional football players



Source: Ekstrand et al., 2016, p. 5.

When analysing the topic of injury prevention, it is important to mention the study published by Barnes, Archer, Hogg, Bush and Bradley (2014) in which they quantified the technical and physical demands that occurred in the Premier League. In that study, a volume variable (total distance covered) was considered and it was observed that there were not too many differences, and there was only a slight tendency towards the increase. However, if we analyse the distance to high intensity and the sprinting distance, they show a steeper slope in their increasing trend. These data were collected from the 2006 - 2007 season to the 2012 - 2013 season.

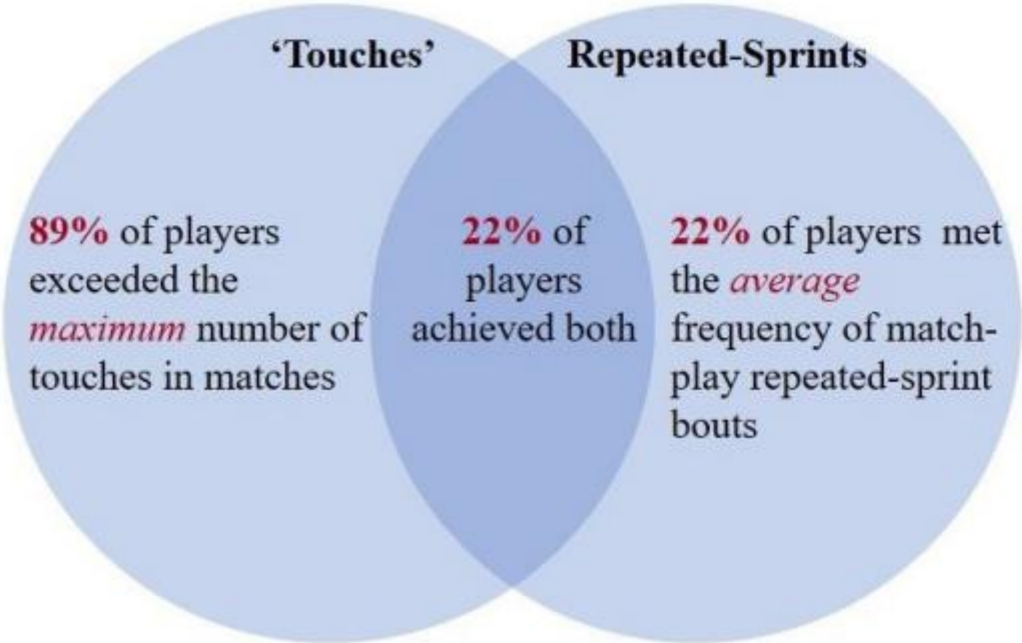
Figure 5: Quantification of technical and physical demands in the Premier League


a
Total Distance Covered (m)
14000
12000
10000
8000
6000
2006–07
2007–08
2008–09
2009–10
2010–11
2011–12
2012–13
Season
b
High Intensity Run Distance (m)
3000
2000
1000
0
2006–07
2007–08
2008–09
2009–10
2010–11
2011–12
2012–13
Season
c
Sprint Distance (m)
1000
750
500
250
0
2006–07
2007–08
2008–09
2009–10
2010–11
2011–12
2012–13
Season

Source: Barnes, 2014, p 1097.

It is also worth analysing the study carried out by Nassis, Brito, Figueiredo, and Gabbett (2019) in which they show that, when playing small side games in football, only 22% of the players reach the requirements they need in competition in relation to repeated sprints (Figure 6).

Figure 6: Comparison on the quantity of touches and repeated sprints in reduced games

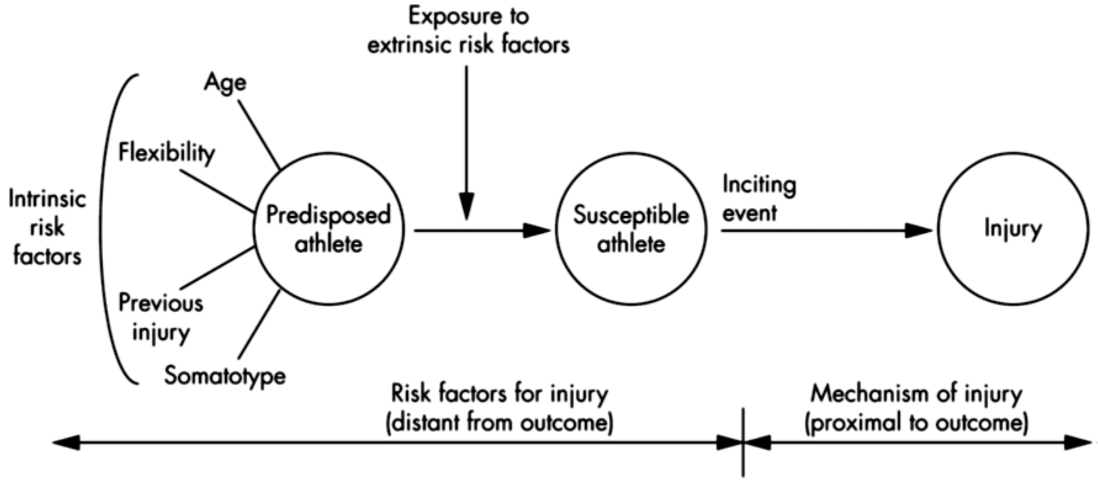


Source: Nassis et al., 2019, p. 1.

However, when analysing reduced games, 89% of the players made more touches than they possibly do during a match. Lastly, in relation to these data, only 22% of the analysed players managed to meet both the requirements of repeated sprints and technical touches that they would perform in a match. Hence, we can conclude that the value of reduced games tasks should be highlighted, but we have to complement them with other types of tasks that will enable us to meet, in this case, the physical demands of sprints both in number and in total distance covered.

Apart from this issue, it is very important to analyse the aetiology models of the injuries. For example, in 1994, Meeuwisse published a study in which he established a change in the analysis of causes. He went from analysing a single factor as the cause of the injury to an analysis of more factors that could affect the injury (multifactorial analysis), in addition to proposing the implementation of multivariate rather than univariate analyses. Such analysis provides a better understanding of the origins of injuries.
Figure 7 summarizes the factors that were used to understand the risk of injury. On the one hand, internal risk factors were studied, that is, the player's intrinsic factors (age, flexibility, previous injuries and the somatotype of each athlete, among other factors). But since these players were immersed in an environment, the extrinsic risk factors that made them susceptible to injury were also analysed. In this way, we basically differentiate two areas: the risk area for the injury (the individual risk factors and the exposure to external factors) and the area of the injurious mechanism (possible cause of the injury).

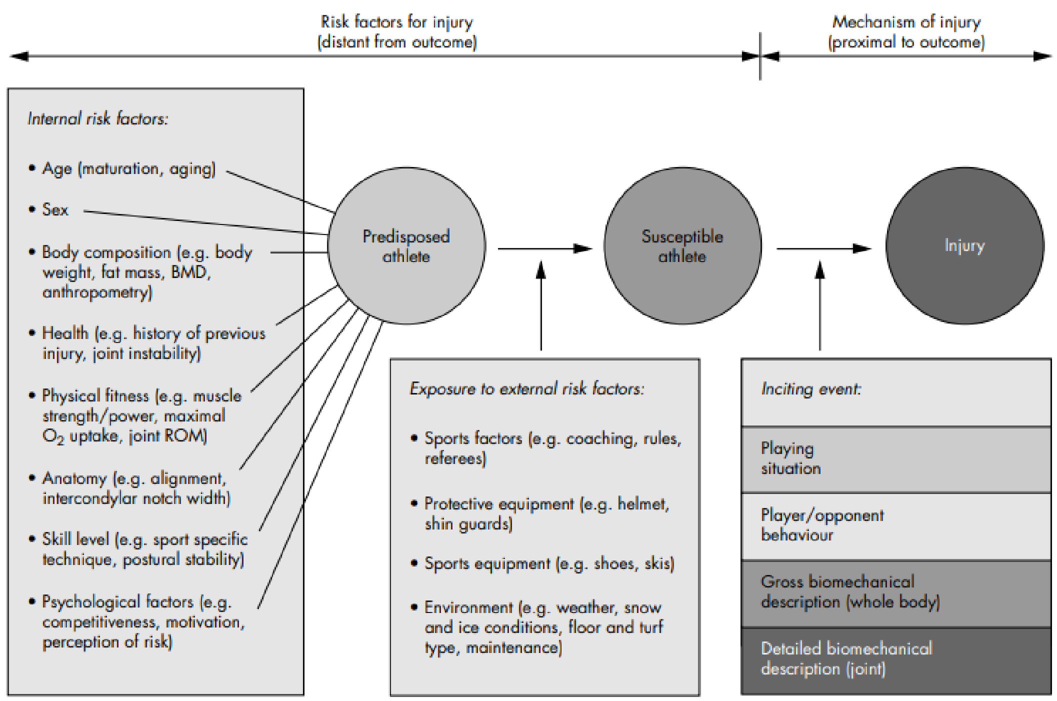
Figure 7: Multifactorial model of sports injuries aetiology



Source: Meeuwisse, 1994, p. 168.

A few years after the publication of this study, Bahr and Krosshaug (2005) broadened its scope. Based on the previous approach, the authors showed a series of more detailed intrinsic factors: age, sex, body composition, body fat, total weight, health, subject's skill level, and psychological factors, such as competitiveness, motivation, and stress. They added possible joint instabilities, physical conditioning-oxygen consumption, range of motion - and whether there were differences in joint alignment, among other factors. In addition, the extrinsic factors of the environment, which had previously only been mentioned, were further analysed. Some of the risks of external factors that were taken into account were: sports factors (the rules, the referees who participated in the competitions), equipment for protection (whether a helmet is worn, the type of ground surface), sports equipment (the type of footwear, for example) and the environment (whether the sport was carried out in outdoor conditions, and whether there was snow, rain, etc.). And, finally, the harmful mechanisms were determined in such detail that they included the game situation, the behavior of both the player and his opponent and also a complete biomechanical analysis of movement (at the global level of the body but also at the local level). All these factors resulted in an improved analysis of harmful mechanisms.

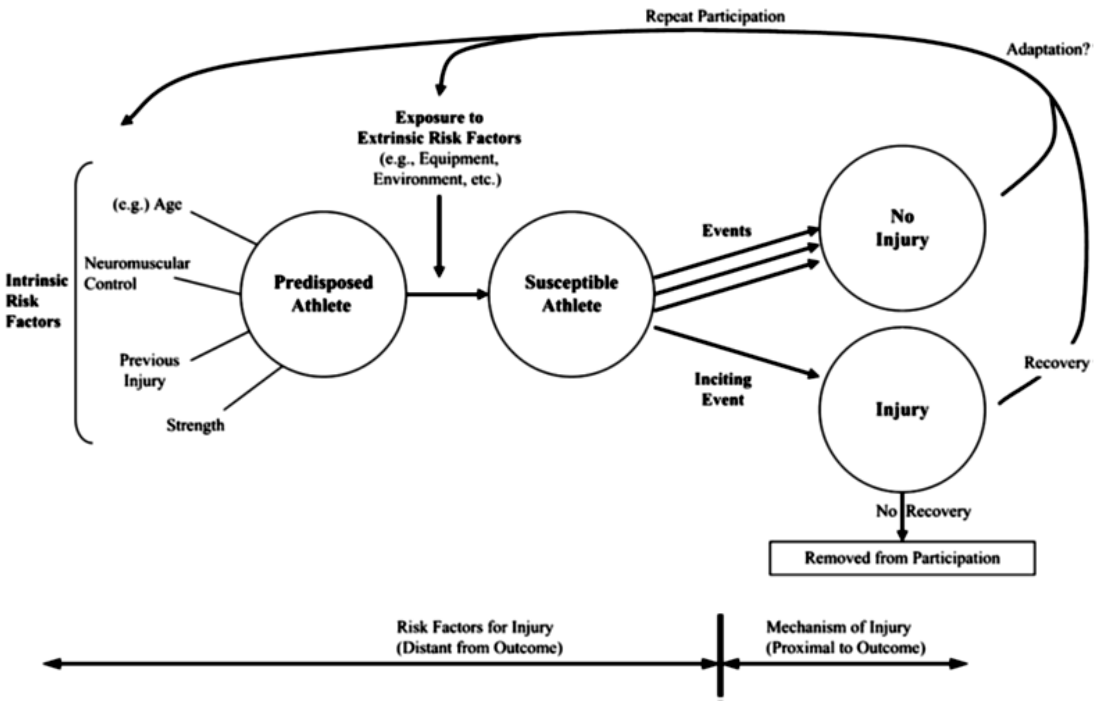
Figure 8: Integral model of injuries causalities



Source: Bahr and Krosshaug, 2005, p. 327.

A third step outlined by Meeuwisse, Tyreman, Hagel, and Emery (2007) could be summarized as a dynamic linear approach to the process. Until then, there were a series of internal and external risk factors, a damaging mechanism, and the focus of research was only on the injury. From the moment this article was written onwards, practitioners began to consider that a mechanism may or may not lead to injury. If it does not, it is possible that this non-injury generates positive adaptations in the player's internal risk factors due to training. For example, the training session could improve the player's neuromuscular control. If the injury does occur, the player will need a recovery that tackles the intrinsic risk factors in a directs way, since from that moment on, that injury will become a risk factor.

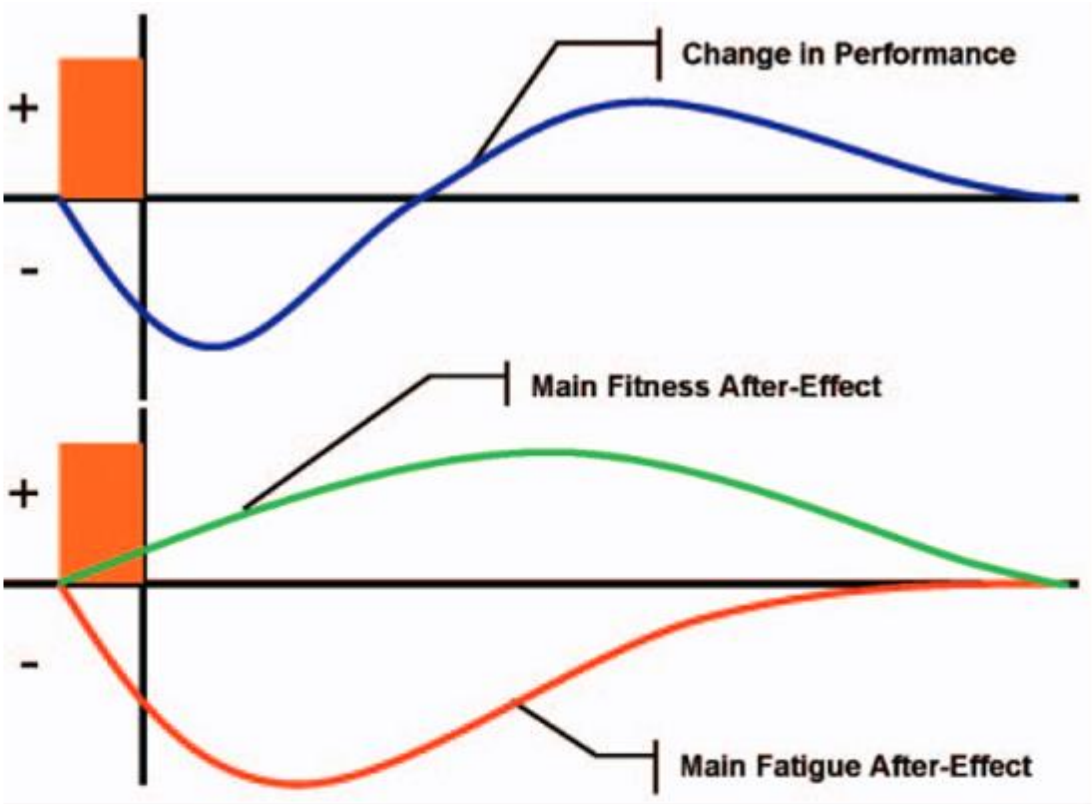
Figure 9: Dynamic and recursive model of aetiology of sports injuries



Source: Meeuwisse et al., 2007, p. 217.

Now that we have reviewed the different models, we should focus on the training workload. Loren and Bradford's (2003) article reviews Banister's study, in which he analysed the dose and response in training, but only in relation to performance: he did not analyse or predict their effect on the chances of suffering injuries. In Figure 10 we see how, according to the bifactorial theory, a stress (training workload) occurs that produces a series of negative effects manifested in the form of fatigue and a series of positive effects related to fitness that can lead to overcompensation that allows the subject to be above the pre-stimulus level. There is a moment when the positive effects outweigh the negative ones; at that time "supercompensation" manifests itself, as Banister showed in his performance analysis models.

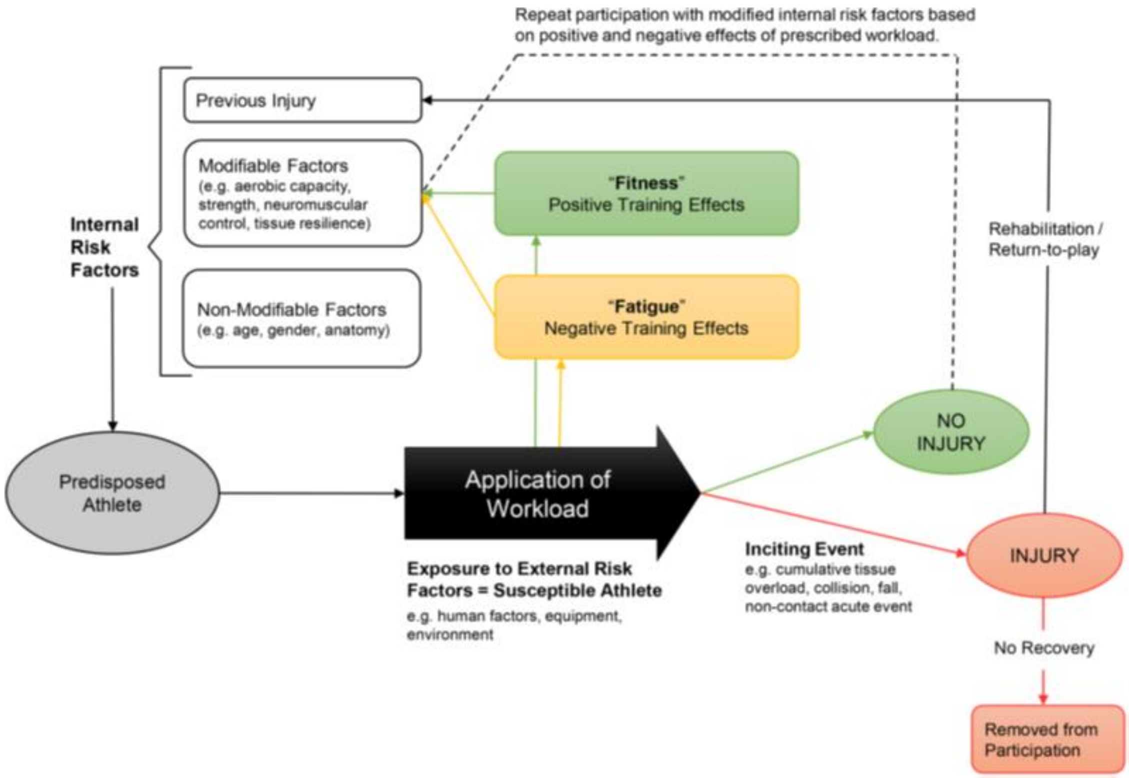
Figure 10: Fitness - Fatigue theory



Source: Loren, 2003, p. 43.

However, injuries have not been analysed following this approach. When an anterior cruciate ligament injury occurs, it is customary to think of the damaging mechanism first. However, what could have happened in the preceding moments is not generally taken into account, that is, the workload the athlete endured the previous day, the previous week, etc. These aspects, which are related to the training workload, may also be relevant. Training workload is not an intrinsic risk factor nor an extrinsic one; it is the means through which sports injuries may occur.
Windt and Gabbett (2016) proposed to locate the training and/ or competition workload within the analysis of the model of the aetiology of sports injuries. These authors also distinguish between intrinsic and extrinsic risk factors as well as the positive or negative effects that the workload will have on the athlete. If no injury occurs, internal risk factors will be affected in one way or another after that workload. If an injury does occur, as in the previous model, there will be an impact, since the athlete will be more susceptible to suffering future injuries.

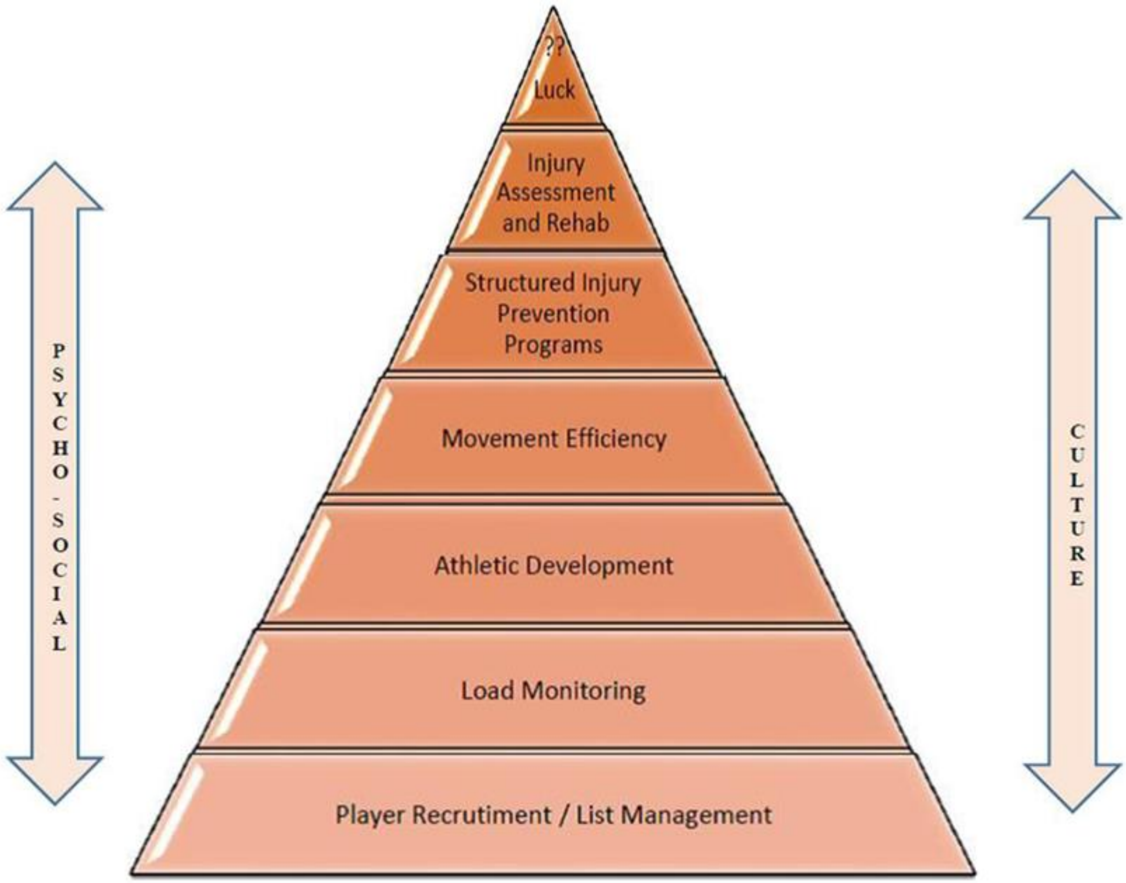
Figure 11: Aetiology model of the origin of sports injuries



Source: Windt and Gabbett, 2006, p. 6.

Physical training can produce positive adaptations in the player's physical condition. These adaptations will be associated with an improvement in modifiable internal risk factors, such as aerobic capacity, skill level, or the player's body composition. Finally, the negative effects of weight training, that is, its negative consequences associated with training mainly through fatigue, will also affect modifiable risk factors. This will cause a decrease in certain functions (such as neuromuscular control) that will produce greater vulnerability in a potentially harmful situation. It is important to point out that, despite the fact that the origin of the injuries is approached from a multifactorial perspective, scientific evidence indicates that the workload is a factor that should be considered in the prevention of injuries and, therefore, we must include it in our analysis, in the same way as Windt and Gabbett did in their model.
In order to determine the risk of injury, pyramids are generally used to show categories such as the athlete's strength level, workload monitoring, among others. However, none has yet displayed the information shown in Figure 12.

Figure 12: Pyramid for preventing injuries



Source: Coles, 2017, p. 2.

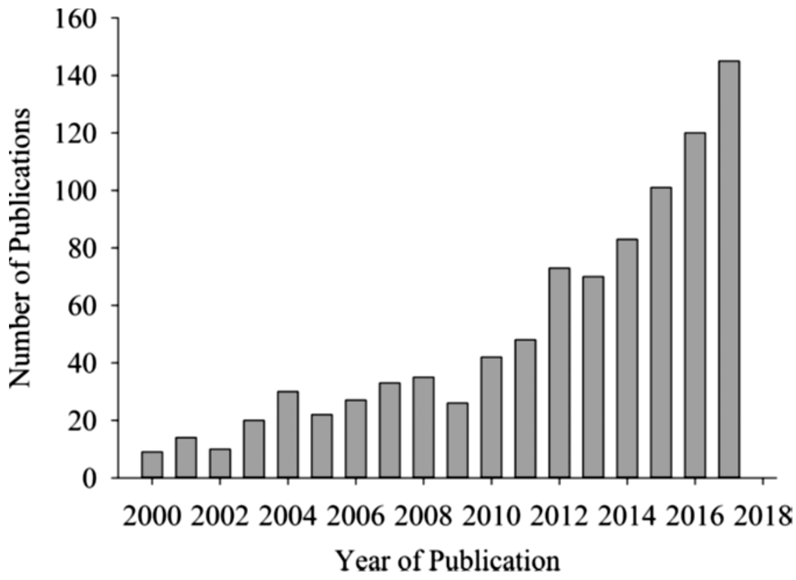
This Figure was drawn by one of the doctors of the NBA San Antonio Spurs. It shows that the base of the pyramid are the players in the team. The probability of injury in a football team with an average age of 40 years will not be the same as that of a team with an average age of 23 years. Since age is one of the intrinsic risk factors, the younger team will have less risk. The making of the team is a fundamental element in the prevention of injuries; this is something that has not been reflected upon with enough clarity in the past..

The pyramid continues in ascending order with load monitoring, the development of physical conditioning, the efficiency in the patterns of the different movements that the player could perform on the field, the structured injury prevention plans, the rehabilitation after the injuries and finally the luck factor.

On the basis on the aforementioned article, we need to point out that the work of the physical trainer can fundamentally affect the following levels of the pyramid: prevention

programs, the development of strength through physical conditioning, the efficiency of movement patterns and the monitoring of training and/ or competition loads.
In order to establish an injury prevention strategy, we need the contribution of all the members of the staff: the coach, the medical staff, the physical trainer and, of course, that of the player himself, who is part of that process. The work and interaction of this group of people will allow a better approach to reducing the probability of injury.
In the same way that the scientific literature has grown exponentially in the publication of articles related to IMU's and GPS positioning systems, there has been an exponential growth in publications related to the probability of injury from the year 2000 to the present day. And apparently, this will continue.

Figure 13: Growth in research that include keywords such as "training" and "injury" since 2000.

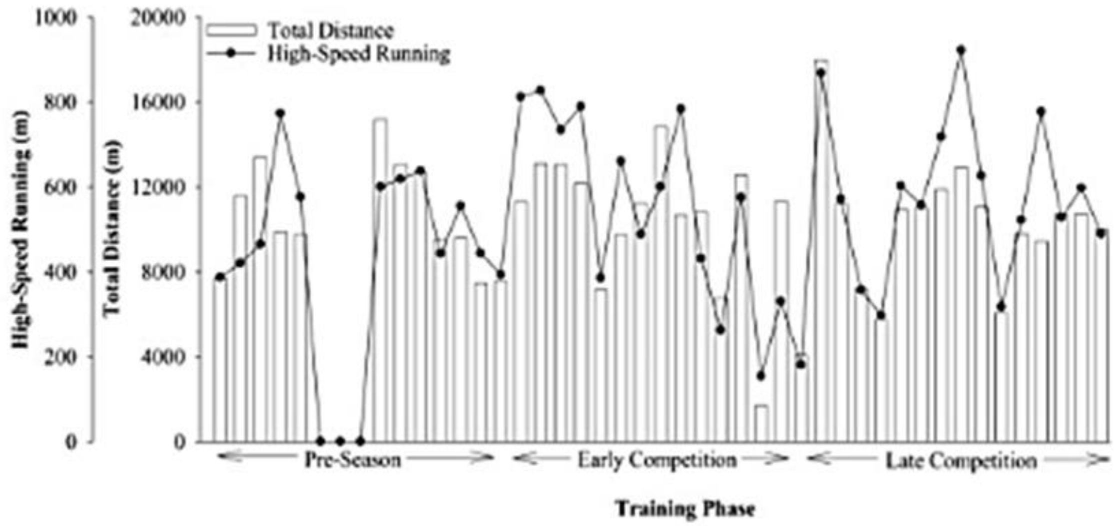


Source: Gabbett, 2018, p. 1.

To rigorously and more efficiently diminish the probability of injury, we must find the optimal training dose that produces the intended performance effects. In general, the elite teams train to improve performance and win in competition. Therefore, their objective is to increase performance to achieve victory, but the optimal dose to achieve it should be found; otherwise, an excess, for example, can generate a greater probability of injury. This is already a practical application of monitoring training and/ or competition loads. Finding that adequate, optimal load is essential.

In relation to monitor loads, Tim Gabbett (2012) established the total distance and the distance to high intensity covered by rugby players in the different microcycles during one season. The results showed that whenever players ran an additional nine meters per session at more than 25 km/h, they increased the probability of suffering a soft tissue injury without contact by 2.7 times.

Figure 14: Total weekly training distance and distance covered to high-speed running over the course of a professional rugby league season



Source: Gabbett, 2012, p. 956.

Along these same lines, it is worth mentioning the article on Australian football published by Colby, Dawson, Heasman, Rogalski and Gabbett (2014). The authors concluded that the probability of injury increased to 5.5 when a greater distance was accumulated every three whole weeks during pre-season and that the ratio was 3.7 when this distance was greater in sprinting. During the season, the probability of suffering an injury increased by 2.5 when the force load variable was greater in three weeks and the probability multiplied by 2 when the rate of change in speed increased every four weeks.

Figure 15: Workload data on different years of experience in the Australian football system at different stages of the season

	Preseason	In-season	Whole-season
Distance (m)			
1–2 y	350,674 (313,731–387,616)	344,088 (299,321–388,855)	694,762 (629,839–759,685)
3–6 y	375,136 (339,277–410,995)	373,924 (354,243–393,605)	749,060 (705,808–792,312)
>7 y	356,431 (316,662–396,200)	‡320,417 (262,034–378,800)	676,848 (597,150–756,547)
V1 distance (m)			
1–2 y	§‖99,883 (90,090–109,676)	99,574 (81,572–117,577)	199,458 (180,025–218,890)
3–6 y	§120,903 (111,984–129,822)	106,281 (96,846–115,716)	227,184 (211,123–243,245)
>7 y	§113,757 (100,480–127,034)	92,534 (78,612–106,457)	206,292 (182,857–229,727)
Sprint distance (m)			
1–2 y	‖4,322 (2,756–5,888)	5,753 (3,770–7,735)	10,075 (6,645–13,506)
3–6 y	7,480 (6,048–8,930)	7,170 (6,330–8,010)	14,660 (12,649–16,671)
>7 y	5,848 (4,900–6,796)	¶4,076 (2,819–5,332)	9,924 (8,393–11,454)
Force load (AU)			
1–2 y	26,890 (23,474–30,307)	26,787 (23,090–30,483)	53,677 (47,792–59,563)
3–6 y	28,043 (25,370–30,716)	29,814 (27,067–32,560)	57,857 (53,445–62,269)
>7 y	27,613 (23,322–31,904)	26,798 (20,973–32,622)	54,411 (45,668–63,154)
Velocity load (AU)			
1–2 y	31,608 (27,192–36,025)	31,446 (27,078–35,814)	63,055 (56,000–70,109)
3–6 y	36,475 (33,386–39,565)	36,117 (34,011–38,224)	72,593 (68,545–76,641)
>7 y	35,898 (31,536–40,260)	32,281 (26,404–38,159)	68,180 (59,331–77,029)
RVC (AU)			
1–2 y	365 (324–407)	385 (321–450)	751 (663–839)
3–6 y	386 (321–452)	440 (396–384)	827 (733–920)
>7 y	345 (290–399)	¶347 (251–443)	692 (567–817)

*AU = arbitrary units; RVC = relative velocity change.
†Data are expressed as mean (95% confidence intervals).
§Preseason load significantly greater than in-season ($p \le 0.05$).
‖1–2 y significantly lower load than 3–6 y ($p \le 0.05$).
¶>7 years significantly lower load than 3–6 y ($p \le 0.05$).

Source: Colby et al., 2014, p. 2247.

To prevent injuries, it is also important to prepare our players in the requirements of the competition.
Figure 16 provides practical and real data from our team. The data was collected during different sessions of one season. The first column indicates the distance covered per minute (team average) and the second column corresponds to a specific player in that session.

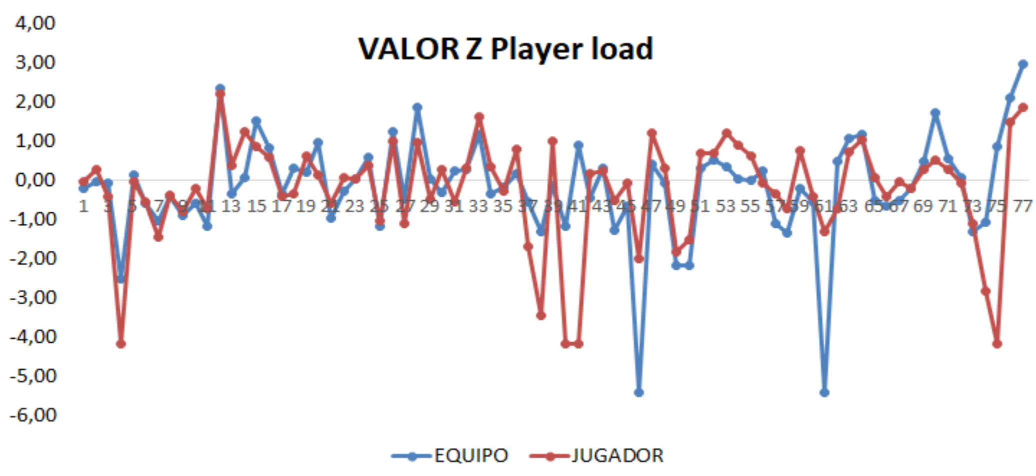
Figure 16: Comparison of own team data with data of a particular own player

35,93	34,39	-1	-0,62	-1	-0,75	-4%
32,41	32,57	-1	-1,08	-1	-0,96	0%
37,26	42,49	-1	-0,45	0	0,16	14%
33,45	34,79	-1	-0,95	-1	-0,71	4%
35,97	34,99	-1	-0,62	-1	-0,68	-3%
31,55	34,65	-1	-1,20	-1	-0,72	10%
57,78	49,97	1	2,24	1	0,99	-14%
37,63	33,65	-1	-0,40	-1	-0,83	-11%
40,84	38,57	0	0,02	-1	-0,28	-6%
51,51	55,36	1	1,42	1	1,60	7%
46,48	37,4	1	0,76	-1	-0,41	-20%
37,58	32,12	-1	-0,41	-1	-1,01	-15%
42,62	22,89	1	0,25	-1	-2,04	-46%
41,88	37,75	0	0,16	-1	-0,38	-10%
47,45	43,36	1	0,89	1	0,25	-9%
32,94	30,23	-1	-1,01	-1	-1,22	-8%
38,28	36,02	-1	-0,31	-1	-0,57	-6%
40,47	41,42	0	-0,03	0	0,04	2%
44,71	40,43	1	0,53	0	-0,07	-10%
31.39	27.29	-1	-1.22	-1	-1.55	-13%

Source: Own elaboration

In this study, the data was analysed using the minimum detectable change between all sessions to establish whether or not that variable presented significant changes in that session, compared to the other sessions. But that was not enough because we needed to know the magnitude of that change. So, the Z value was calculated. Thus, for example, we can go from 0.62 to 1.08 (fourth column) and reach in some cases up to 2.24. The sixth column shows the Z value for an individual player. The last column refers to the calculation of the variation rate.

Figure 17: Analysis of the Z value during different sessions for a player and for the average of the analysed team

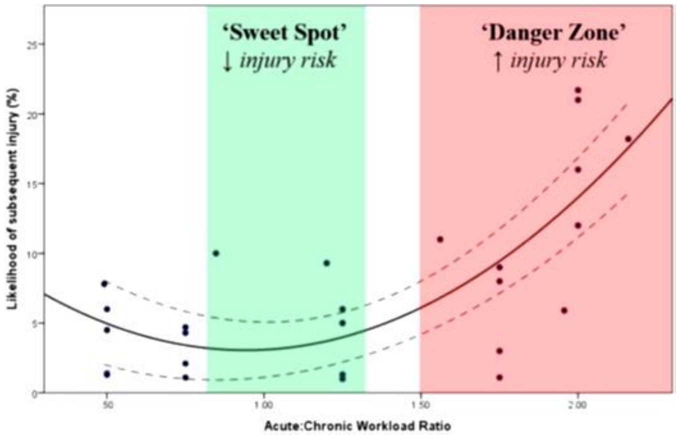


VALOR Z= Z Value
Equipo= team
Jugador= player

Source: Own elaboration

Other concepts that it is important to consider are the acute load (short period of time) and the accumulated or chronic load (longer period of time). The relationship between these two concepts, acute and chronic load through the ratio between acute load and chronic load, provides the ratio of acute-chronic load. From this we can derive that, when establishing a certain ratio (Figure 18), an area with a lower risk of injury (green area) is also delimited. Moreover, the probability of injury increases (red zone) when a certain ratio is exceeded.

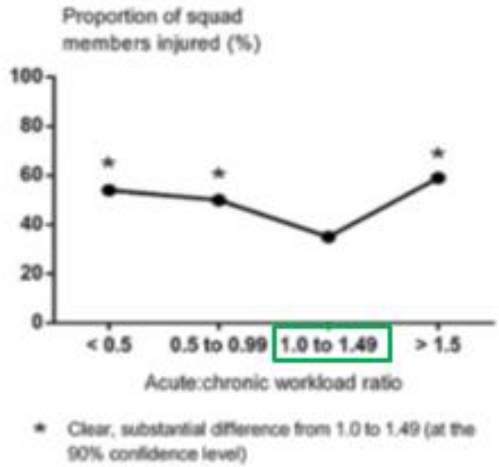
Figure 18: Guide to interpret and apply acute-chronic workload data



Source: Gabbett, 2016, p. 6.

If we want to analyse this relationship in basketball, we should turn to Weiss, Allen, McGuigan, and Whatman's (2017) article. In this study, the authors indicated that the percentage of injured players on the team analysed varied as load ratios changed. Areas with a higher risk of injury appeared compared to an optimal area that was established between the ratio of 1 to 1.49.

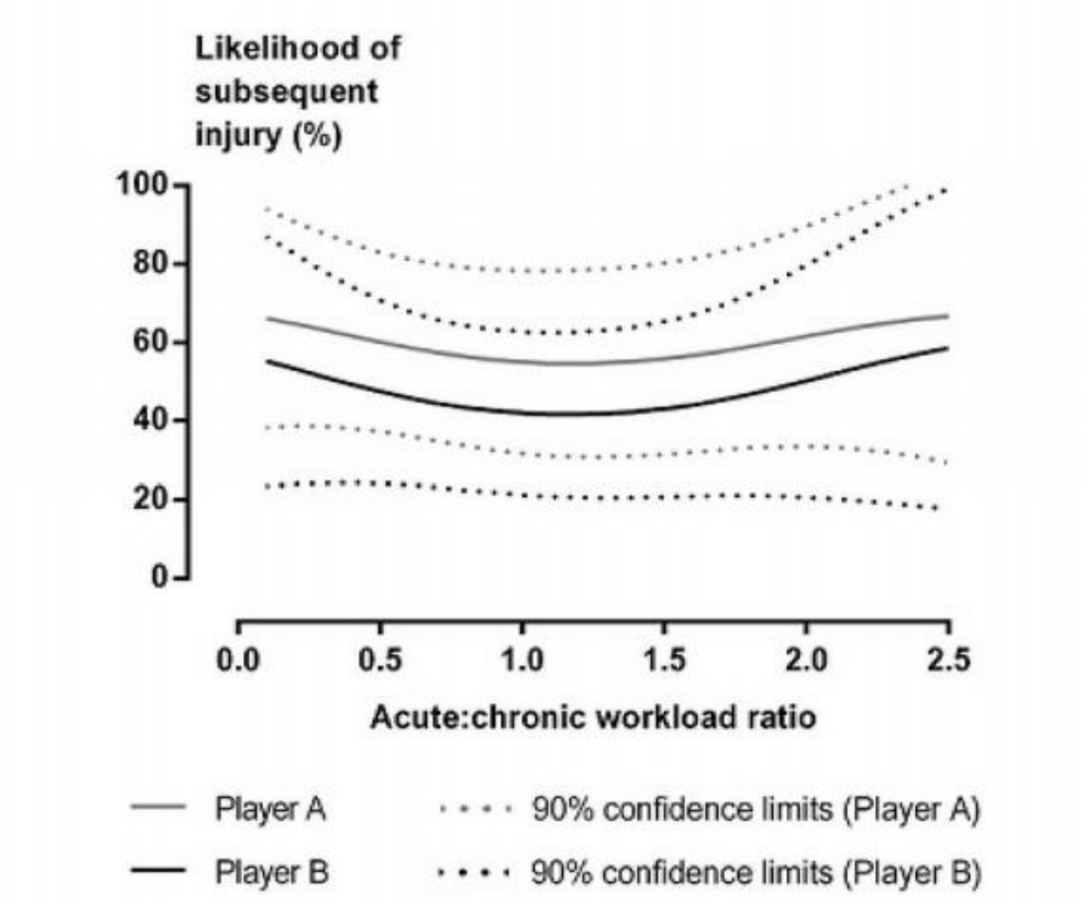
Figure 19: Acute-chronic load ratio in basketball players



Source: Adapted from Weiss et al., 2017.

In this sense, individualization is essential. Figure 20 shows how two players from the same team have a different probability of suffering an injury when facing the same acute-chronic load ratio.

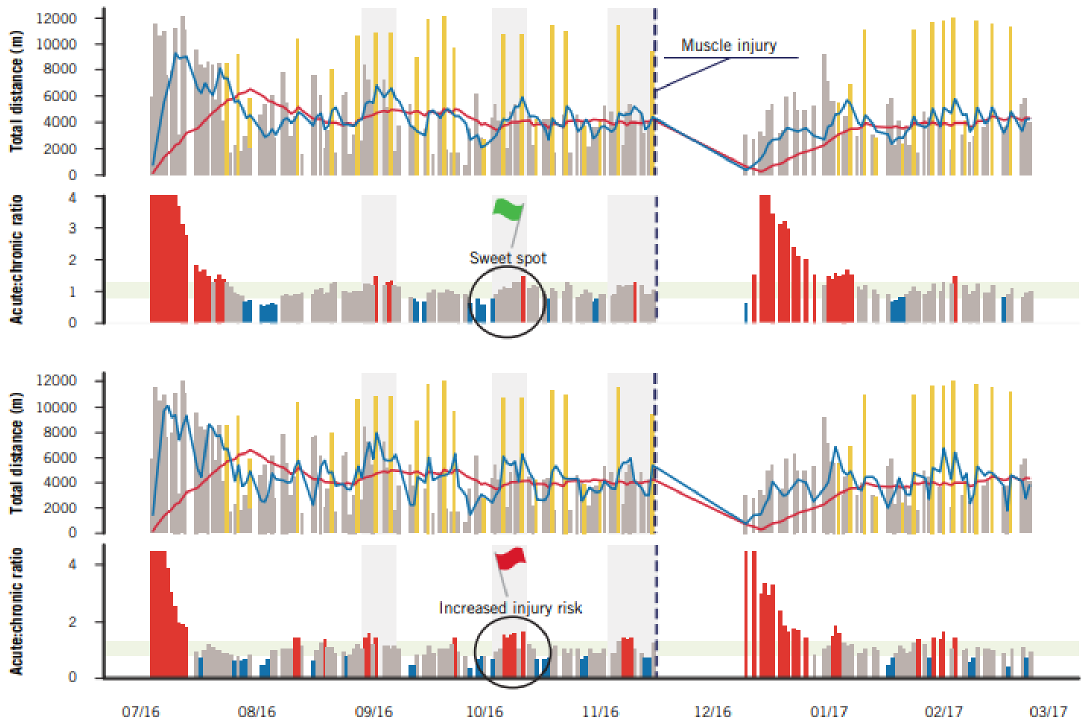
Figure 20: Comparison between two athletes in relation to their probability of injury)



Source: Weiss et al., 2017, p. 20.

That is, the acute-chronic load ratio is also individual. So, we can ask ourselves, do the ratios we choose actually matter? Is it the same to choose as acute load four days or one week, and as chronic load, three or five weeks? Lacome, Simpson and Buchheit's (2018) article shows that the four-day acute load and the eighteen-day chronic load were more sensitive in predicting a greater risk of injury than the seven-day ratio for the acute load and twenty-eight, for the chronic load. This tool is also useful as a strategy to prevent injuries.

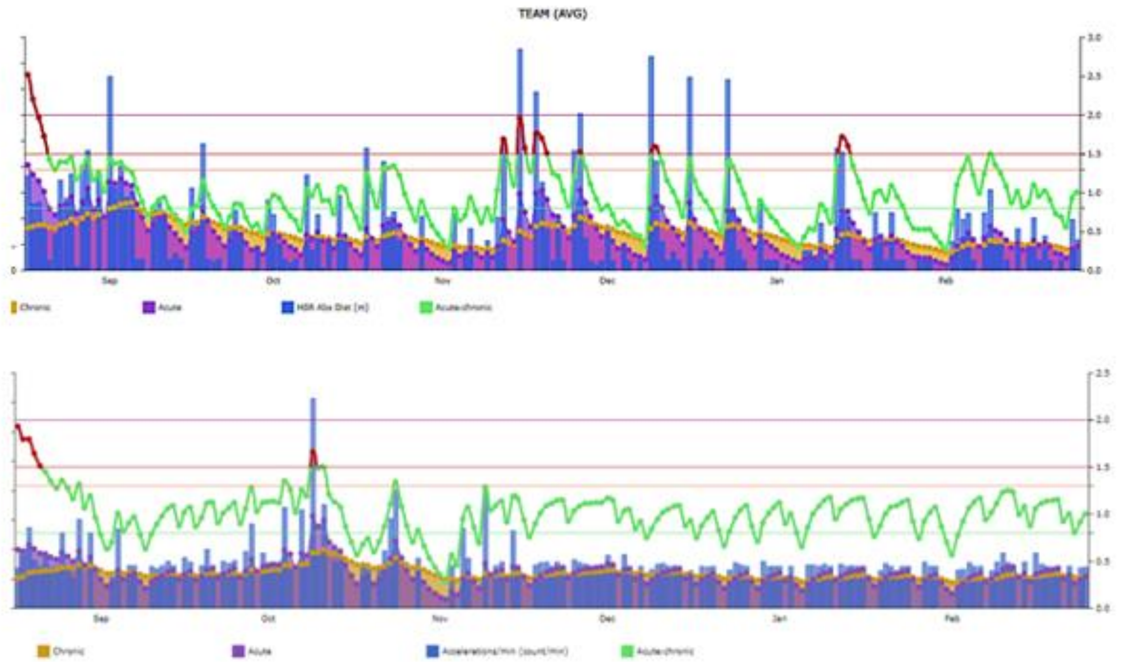
Figure 21: Changes in total distance (in meters) for an elite football player over a period of seven months



Fuente: Rodríguez, 2011, p. 55 o adaptado de Rodríguez, 2011. ("adaptado" significa que se toma como referencia a otro autor, es decir, que la imagen no es textual, sino adaptada).

Figure 22 shows data related to our team. The acute load ratio established at seven days and chronic load ratio established at twenty-eight days appear for the variables of distance >18 km/h covered and for the number of accelerations during several months of the season.

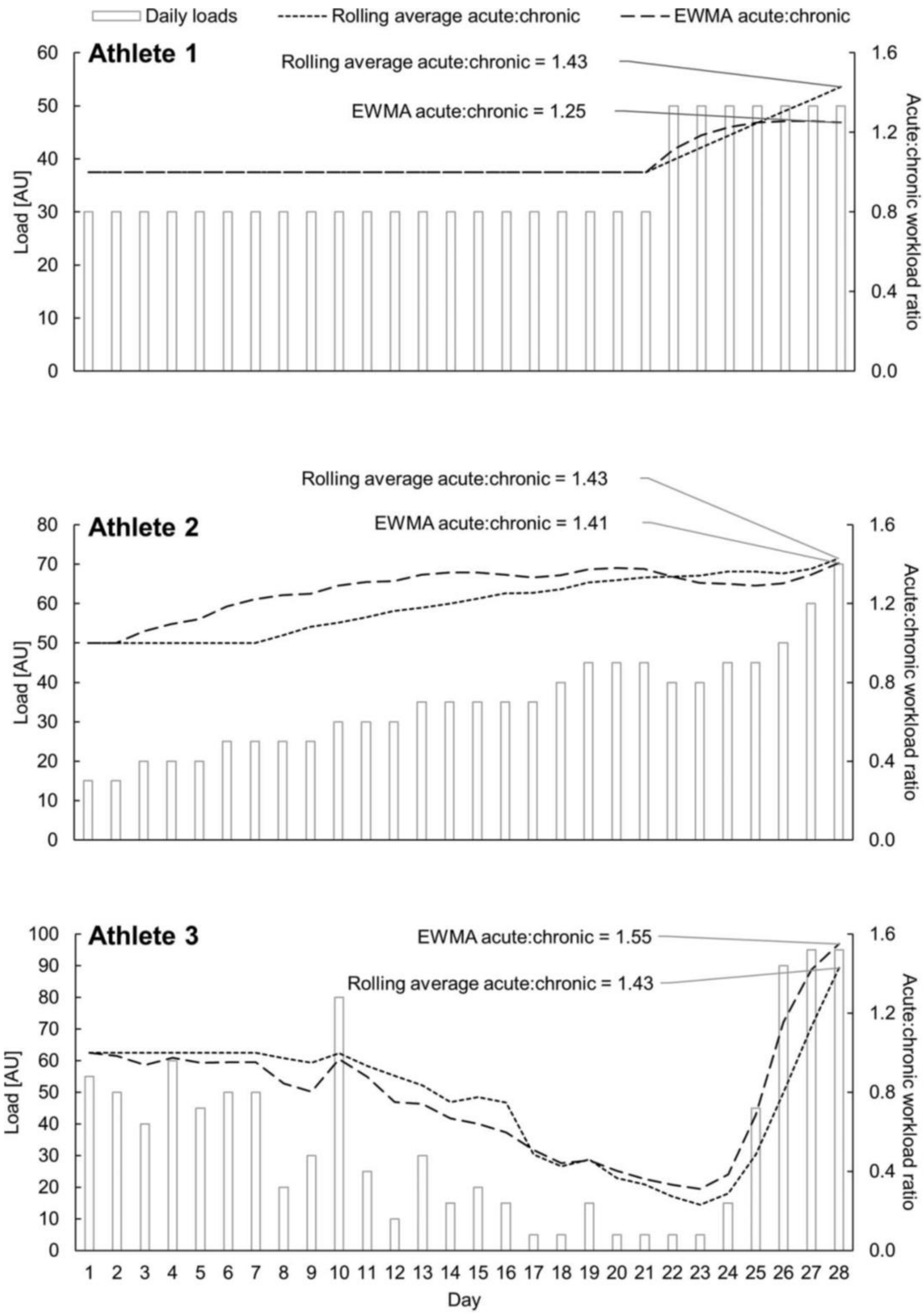
Figure 22: Load control and acute-chronic load ratio of the FC Barcelona first basketball team



Source: Author's elaboration through the use of WIMU devices, Realtrack Systems S.L.

Another aspect to take into account in relation to this ratio is the calculation used to obtain it: the rolling average or moving averages. But this is not the only way to calculate the ratio, it can also be calculated, unlike the data presented above, from an exponential analysis of moving averages. This process allows for a greater importance and relative weight to the most recent data, that is, to the closest training sessions in time. The following Figure shows the evolution of the ratio in three athletes comparing the rolling average analysis and the exponential moving average analysis (EWMA).

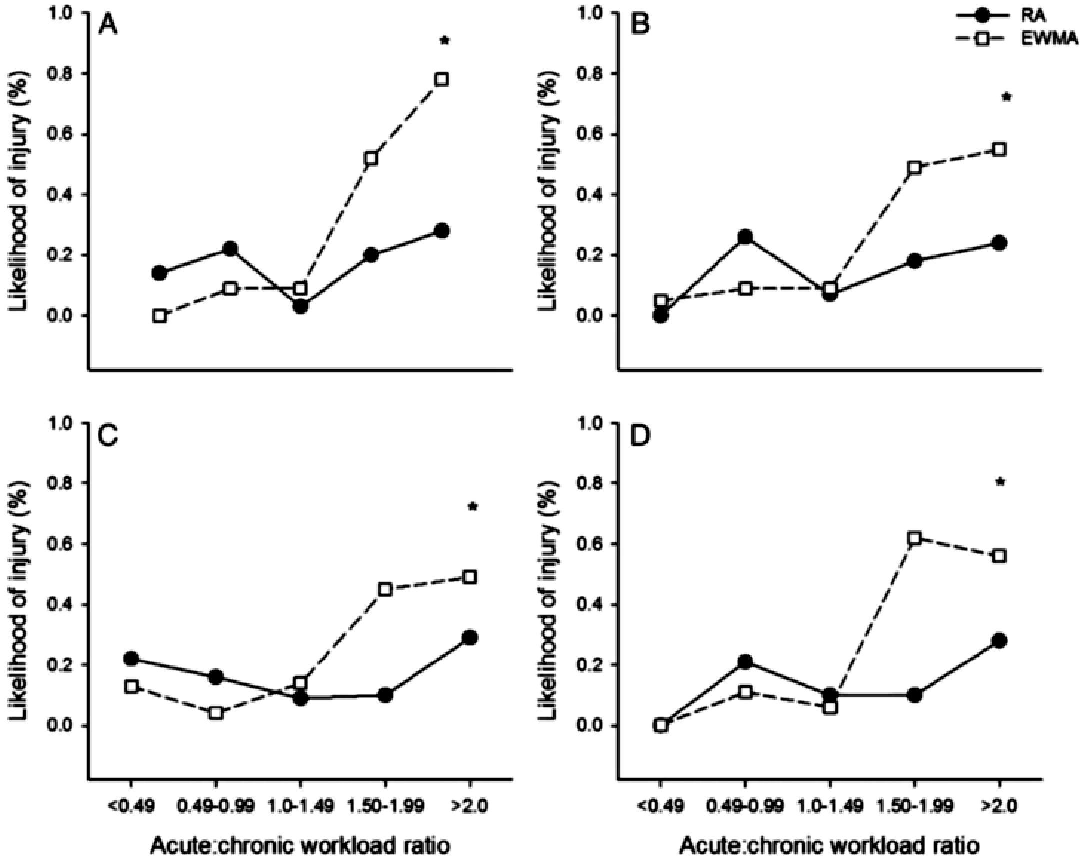
Figure 23: Different acute-chronic workload ratio values produced using exponentially weighted moving averages and moving averages methods


Daily loads
Rolling average acute:chronic
EWMA acute:chronic
Athlete 1
Rolling average acute:chronic = 1.43
EWMA acute:chronic = 1.25
Athlete 2
Rolling average acute:chronic = 1.43
EWMA acute:chronic = 1.41
Athlete 3
EWMA acute:chronic = 1.55
Rolling average acute:chronic = 1.43
Load [AU]
Acute:chronic workload ratio
Day

Source: Williams, 2017, p. 210.

Figure 23 shows the difference between the two analyses, reaching values of 1.25 and 1.43 in the case of athlete 1. And values of 1.41 and 1.43 in the case of athlete 2. In relation to the load dynamics of athlete 3, in which there is a large fluctuation between the latest data and the previous ones analysed, the exponential analysis generates a ratio of 1.55, higher than the one previously found. Thus, we could establish that the analysis of exponential moving averages is more sensitive, especially in high ratios.
The article published by Murray, Gabbett, Townshend and Blanch (2016) calculated the ratio for the total distance covered, the already high moderate distance, and the player load. The study showed significant differences between the two methods in the four variables when the ratio was high (Figure 24). These data corresponded to the pre-season, and the same behaviour occurred in the season phase.

Figure 24: Probability of injury in each ACWR range during the pre-season period for the current day in total distance, distance at moderate speed, distance at high speed and player load



Source: Murray et al., 2016, p. 4.

A third method is the coupled and uncoupled method. The coupled analysis means that for an example of four weeks the acute-chronic calculation includes the four weeks as chronic load and the last week as acute. However, the uncoupled method takes the first three weeks as chronic load and the last week as acute. That is, it eliminates the last week of the analysed chronic load.

In general, we can establish that acute spikes in the workload for multiple variables should be avoided, due to the fact that they are associated with an increased risk of injury. The moving averages model is based on scientific evidence and supported by the literature to quantify the probability of the risk of suffering an injury. All in all, the exponentially weighted moving averages model has a higher sensitivity to detect increases in the risk of injury in greater ranges of the acute-chronic ratios.

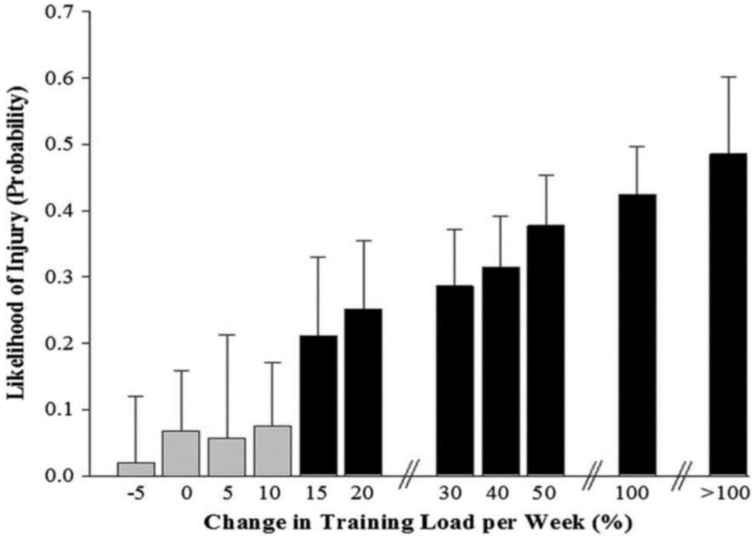
However, more evidence must be provided on the different methods of acute-chronic loading and the calculation of the risk of injury. This will allow professionals involved in fitness training of elite players to systematically and more effectively prescribe training loads to improve the physical qualities required in competition while minimizing the risk of load-related injuries.

In general, these articles indicate that high chronic loads provide the athlete with better preparation and predisposition to withstand some of the sharp training peaks, in part, due to adequate physical conditioning that, in turn, allows them to better withstand the requirements of competition. Therefore, a good level of physical conditioning can contribute to better incorporate loads and therefore, reduce the probability of injury.

The percentage of change of the load between the different weeks should also be analysed.

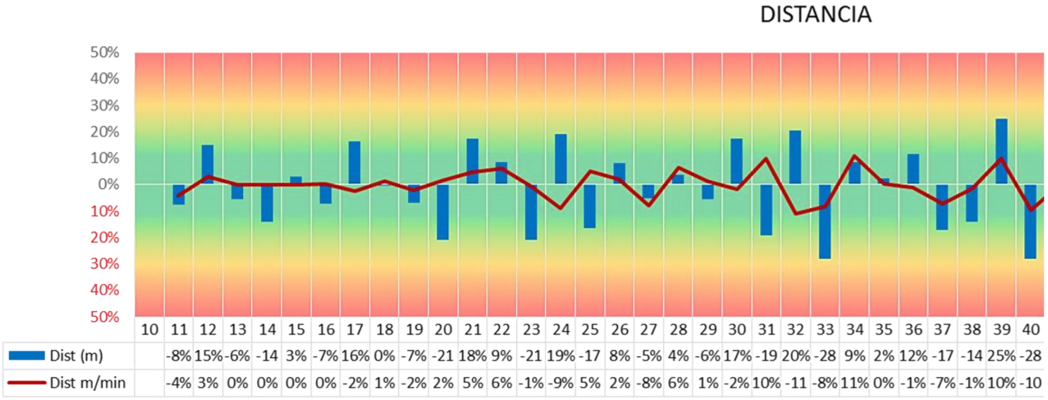
For example, if there is a certain increase in the percentage, compared to the previous week, the probability of suffering an injury also increases (Figure 25).

Figure 25: Probability of suffering injuries with different changes in training load



Source: Gabbett, 2016, p. 5.

Figure 26: Evolution of the change in percentage between weeks of the distance in the F.C. Barcelona



Source: Own elaboration

Another aspect to take into account to minimize the risk of injury is the control of the distance to high intensity to which our players are subjected. We will consider the article published by Williams, Trewartha, Cross, Kemp and Stokes (2017). The authors sought to establish the most important variables when analysing the load. To do this, they carried out an analysis of the main components of ten variables in four teams.

They established that there were three main components that explained 57% of the variation as acute, 24% as chronic load, and 9% as change between microcycles. From this analysis, they concluded that the acute load was fundamentally represented by the load endured in one day.

Another essential aspect to consider is fatigue. Various articles have compared different physical demands between the first part and the second part in football and between the different quarters in basketball. Linke, Link, Weber and Lames (2018) showed that football players covered 99 meters per minute in the first half, and 78 meters per minute in the second half. This entailed a decrease of 21% between the first and the second part. But if we control and normalize breaks, the difference is lowered to just 6.6%. Therefore, we must ask ourselves, or reflect upon the following issue: whether fatigue is the cause of this slight decrease in distance covered or if contextual factors can influence this result.

Finally, it is important to point out that machine learning can help us better understand and better prevent injuries. We should not dismiss the player's internal responses to the external load (heart rate and heart rate variability, for example). It will also be important to approach injuries from a complex dynamic systems perspective, so as to gain a better understanding of strategies in the field of injury prevention.

All this information should be taken into account to minimize the risk of injury in team sports.

Referencias

Bahr, R. & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine*, 39(6), 324–329. doi: https://doi.org/10.1136/bjsm.2005.018341

Barnes, C., Archer, D. T., Hogg, B., Bush, M. & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine,* 35(13), 1095–1100. doi: https://doi.org/10.1055/s-0034-1375695

British Broadcasting Corporation (2018). Premier League clubs paid £217m in wages to injured players in 2017-18. Retrieved from https://www.bbc.com/sport/football/45045561

Colby, M. J., Dawson, B., Heasman, J., Rogalski, B. & Gabbett, T. J. (2014). Accelerometer and GPS-Derived Running Loads and Injury Risk in Elite Australian Footballers. *Journal of Strength and Conditioning Research,* 28(8), 2244–2252. doi: doi:10.1519/jsc.0000000000000362

Coles, P. A. (2017). An injury prevention pyramid for elite sports teams. British Journal of Sports Medicine, 52(15), 1008–1010. doi: https://doi.org/10.1136/bjsports-2016-096697

Edwards, W. B. (2018). Modeling overuse injuries in sport as a mechanical fatigue phenomenon. Exerc. Sport Sci. Rev., 46(4), 224–231.

Ekstrand, J., Walden, M. & Hagglund, M. (2016). Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. *British Journal of Sports Medicine*, 50(12), 731–737. doi: https://doi.org/10.1136/bjsports-2015-095359

Gabbett, T. J. & Ullah, S. (2012). Relationship Between Running Loads and Soft-Tissue Injury in Elite Team Sport Athletes. *Journal of Strength and Conditioning Research*, 26(4), 953–960. doi: 10.1519/jsc.0b013e3182302023

Gabbett, T. J. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine.* doi: 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*. doi: https://doi.org/10.1136/bjsports-2018-099784

Hisham, T., Thomas, V., Geoff, F., Camden, H., Juan, H., Aparna, K. & Shawn, S. (2016). *Preventing in-game injuries for NBA players.* Paper presented at the Sports Analytics Conference. Paper ID: 1590.

Lacome, M., Simpson, B. & Buchheit, M. (2018a). Monitoring training status with player-tracking technology. Still on the road to Rome. Part 1: Traditional practices and new concepts. *ASPETAR: Sports Medicine Journal,* 7, 55-63. Retrieved from https://www.researchgate.net/publication/327142176_2018_Monitoring_training_status_with_player-tracking_technology_Still_on_the_road_to_Rome_Part_1

Lacome, M., Simpson, B. & Buchheit, M. (2018b). Monitoring training status with player-tracking technology. Still on the road to Rome. Part 2: Increasing coach "buy-in" with good data visualization. *ASPETAR: Sports Medicine Journal*, 7, 64-66. Retrieved from https://www.researchgate.net/publication/327142262_Monitoring_training_status_with_player-tracking_technology_Still_on_the_road_to_Rome_Part_2

Linke, D., Link, D., Weber, H. & Lames, M. (2018). Decline in Match Running Performance in Football is affected by an Increase in Game Interruptions. *Journal of Sports Science & Medicine,* 17(4), 662–667. Retrieved from https://www.researchgate.net/publication/329247433_Decline_in_Match_Running_Performance_in_Football_is_affected_by_an_Increase_in_Game_Interruptions

Loren, Z. F. Chiu, L. & Bradford, J. (2003). The Fitness-Fatigue Model Revisited: Implications for Planning Short- and Long-Term Training. *Strength & Conditioning Journal*, 25, 42–51. doi: https://doi.org/10.1519/1533-4295(2003)025<0042:TFMRIF>2.0.CO;2

Meeuwisse, W. H. (1994). Assessing Causation in Sport Injury: A Multifactorial Model. *Clinical Journal of Sport Medicine*, 4(3). Retrieved from https://journals.lww.com/cjsportsmed/Fulltext/1994/07000/Assessing_Causation_in_Sport_Injury__A.4.aspx

Meeuwisse, W. H., Tyreman, H., Hagel, B. & Emery, C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine*, 17(3), 215–219. doi: https://doi.org/10.1097/JSM.0b013e3180592a48

Moreno, J. (2015). NBA Total Losses To Injury Since The 2005-2006 Season. Retrieved from http://www.move2thrive.com/kinein-blog/2015/5/9/hey-nbacant-you-get-your-athletes-bigger-chairs

Murray, N. B., Gabbett, T. J., Townshend, A. D. & Blanch, P. (2016). Calculating acute: chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. *British Journal of Sports Medicine*, 51(9), 749–754. doi: 10.1136/bjsports-2016-097152

Nassis, G. P., Brito, J., Figueiredo, P. & Gabbett, T. J. (2019). Injury prevention training in football: let's bring it to the real world. *British Journal of Sports Medicine*, bjsports-2018-100262. doi: https://doi.org/10.1136/bjsports-2018-100262

Weiss, K. J., Allen, S. V, McGuigan, M. R. & Whatman, C. S. (2017). The Relationship Between Training Load and Injury in Men's Professional Basketball. *International Journal of Sports Physiology and Performance,* 12(9), 1238–1242. doi: https://doi.org/10.1123/ijspp.2016-0726

Williams, S., West, S., Cross, M. J. & Stokes, K. A. (2017). Better way to determine the acute: chronic workload ratio? *British Journal of Sports Medicine*, 51(3), 209 LP – 210. doi: https://doi.org/10.1136/bjsports-2016-096589

Williams, S., Trewartha, G., Cross, M. J., Kemp, S. P. T. & Stokes, K. A. (2017). Monitoring What Matters: A Systematic Process for Selecting Training-Load Measures. *International Journal of Sports Physiology and Performance*, 12(2), 2101–2106. doi: https://doi.org/10.1123/ijspp.2016-0337

Windt, J. & Gabbett, T. J. (2016). How do training and competition workloads relate to injury? The workload—injury aetiology model. *British Journal of Sports Medicine*, 51(5), 428–435. doi: 10.1136/bjsports-2016-096040