Module 2. Acute:chronic load ratio: concept and method of calculation

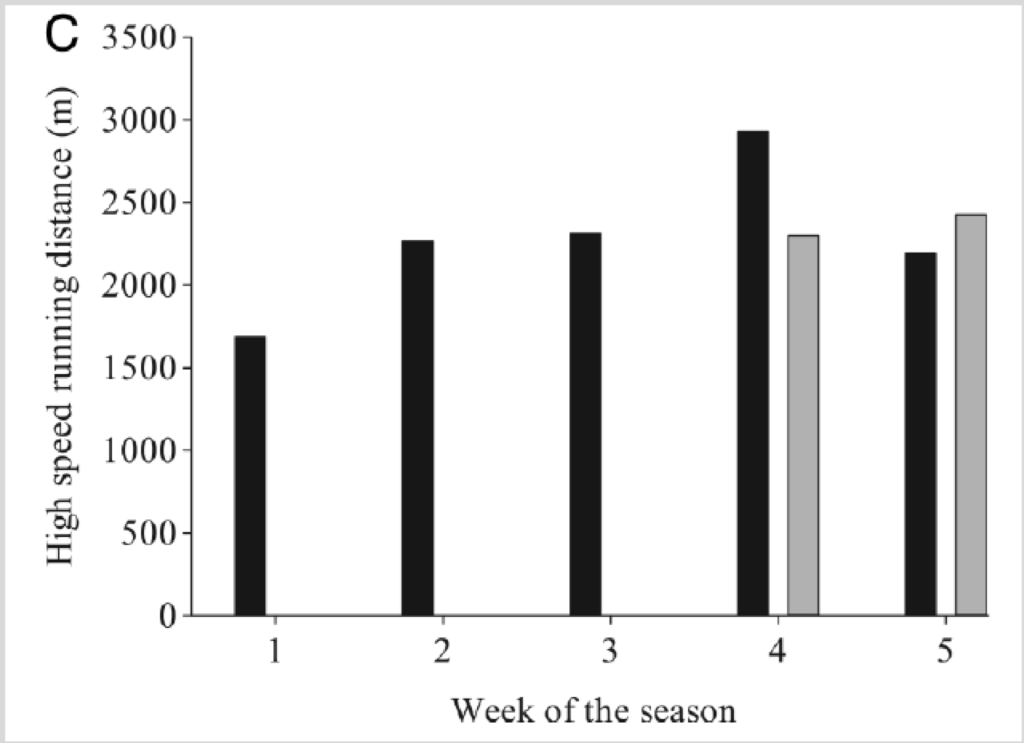
2.1 Introduction to the acute:chronic load ratio

The quantification of loads is not only considered essential for maximizing the probability of obtaining optimal performance from athletes at particular points during the season (Drew & Finch, 2016). Knowledge on training volume and how it applies to the acute: chronic workload (A:C) relationship has generated a great deal of interest in recent years in relation to predicting injury risk in a wide variety of team sports (Blanch & Gabbett, 2016; Gabbett, 2016).

Banister, E. W.; Calvert, T. W.; Savage, M. V. & Bach, T. (1975) proposed that "an athlete's performance in response to training can be estimated based on the difference between a negative function ('fatigue') and a positive function ('fitness')". It was later suggested that the ideal training stimulus is one that maximizes performance by using the correct training load while limiting the negative consequences of training, such as injuries and fatigue (Morton, 1997). Hence, it is important that experts understand and control training loads to be able to measure past and present physical fitness levels in their athletes. This means taking previous training logs into account, or in other words, considering what athletes are prepared for or accustomed to. The relation between what they have already done (acute load, fatigue) and what they are prepared for (chronic load, physical condition) can be examined using the A:C load ratio.

The concept of the A:C load ratio is defined as the absolute load developed during a short period of time, which represents the acute load (usually a particular week is used, such as the current week), and its relation to the workload average during a longer temporal structure, which represents the chronic load (usually the average for the 4 previous weeks) (Hulin, Gabbett, Blanch, Chapman, Bailey, & Orchard, 2014). This comparison between both workloads provides us with a value called the A:C load ratio, which can dynamically represent an athlete's preparation and influence the athlete's likelihood of injury (Malone, Owen, Newton, Mendes, Collins, & Gabbett, 2017). A week of training seems to be the logical and convenient unit in the majority of competitive contexts to determine acute loads, while chronic loads represent the average of the last 3-6 weeks of training (Gabbett, 2016).

Figure 1: Acute and chronic load at different weeks for the distance covered at high speed (m) variable. The black bars represent acute load (load for the week) while the gray bars represent chronic load (load average for the previous 4 weeks, including week being studied).



Source: Gabbett, 2016, p. 2.

Chronic training loads are analogous to an adequate level of physical fitness, while acute training loads are equivalent to a fatigued state (Banister et al., 1975). The relationship between both loads within the ratio contributes information on the workload that athletes have performed with respect to the workload for which they have been prepared (Hulin et al., 2014), emphasizing the positive and negative consequences of their training (Gabbett, 2016).

2.2 Calculating the acute:chronic load ratio

There are two models that have been used and studied in scientific literature in recent years: the traditional A:C load ratio and the exponential A:C load ratio. The exponential model was proposed as a solution to some of the limitations of the traditional model for the calculation, which does not differentiate in terms of when training load was accumulated. Thus, the session completed the previous day is accounted for in the same way (with the same weight) as the session completed 4 weeks prior. With that in mind, the main difference between the two models has to do with the weight assigned to training load values on each day of training.

We must also consider that the calculations for acute load, chronic load and A:C load ratio, both in their traditional and exponential models, can be calculated for each of the load variables being studied. This means that both the internal load variables and the external load variables should be considered in the analysis. Naturally, this model should be applied to each athlete, as well as to the team average or the average of groups within the team, in order to simplify the information.

Next, we will describe the calculations for acute load, chronic load, and A:C load ratio for both the traditional model and the exponential model.

2.2.1 Acute load calculation

The acute load will represent the load that we just performed, which has impacted our current body, generating a negative state or a transient fatigue in our performance. Generally, it is the workload performed by an athlete in 1 week (7 days), although different durations can be used, as we will see later. Therefore, it will be calculated as the summation of the load from the previous 7 days or week, and represents the model's 'fatigue' aspect.

Table 1 Distance covered (m) by a player on different consecutive dates. This data will be used to calculate the traditional and exponential acute load values, the traditional and exponential chronic load values, and the traditional and exponential acute load ratio.

Date	Distance (m)	Date	Distance (m)
01/09/2017	11000	01/10/2017	9800
02/09/2017	13000	02/10/2017	9100
03/09/2017	9600	03/10/2017	8400
04/09/2017	9800	04/10/2017	7700
05/09/2017	0	05/10/2017	0
06/09/2017	8400	06/10/2017	6300
07/09/2017	7700	07/10/2017	5600
08/09/2017	7000	08/10/2017	4900
09/09/2017	0	09/10/2017	4200
10/09/2017	5600	10/10/2017	3500
11/09/2017	4900	11/10/2017	2800
12/09/2017	4200	12/10/2017	2100
13/09/2017	3500	13/10/2017	11000
14/09/2017	2800	14/10/2017	13000

15/09/2017	2100	15/10/2017	0
16/09/2017	1400	16/10/2017	9800
17/09/2017	700	17/10/2017	9100
18/09/2017	3000	18/10/2017	8400
19/09/2017	0	19/10/2017	7700
20/09/2017	0	20/10/2017	7000
21/09/2017	4800	21/10/2017	6300
22/09/2017	4700	22/10/2017	0
23/09/2017	3500	23/10/2017	4900
24/09/2017	4200	24/10/2017	4200
25/09/2017	4900	25/10/2017	3500
26/09/2017	5600	26/10/2017	2800
27/09/2017	6300	27/10/2017	2100
28/09/2017	0	28/10/2017	6000
29/09/2017	13000	29/10/2017	7000
30/09/2017	9600	30/10/2017	0

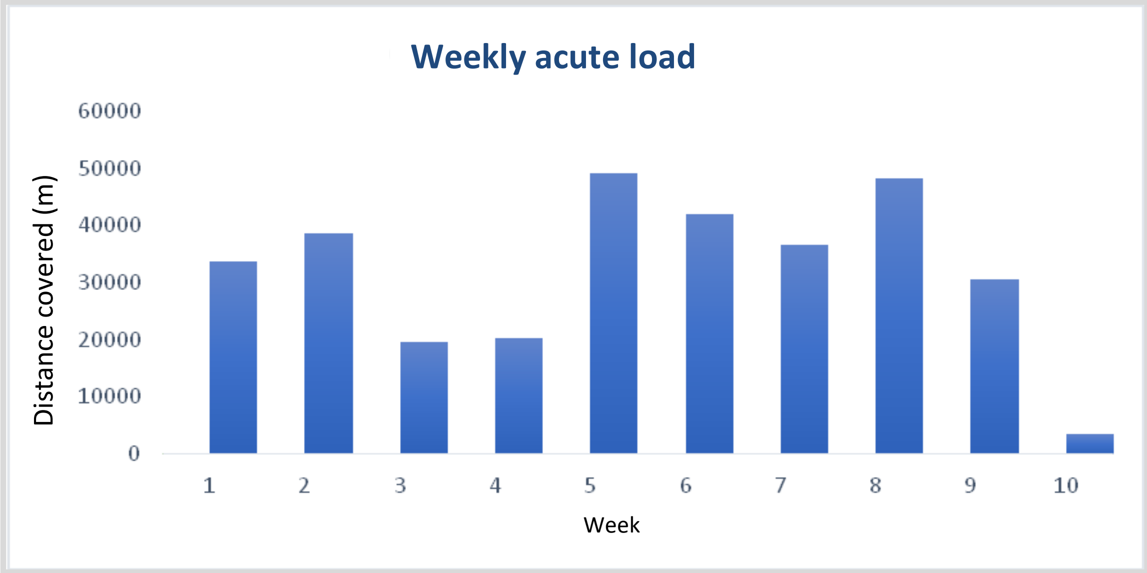
Source: Prepared by the author.

Traditional acute load calculation

The acute load calculation can be determined for complete weeks or for any date (only the activities from the 7 previous days are considered, providing that is the duration chosen for the acute load). Thus, for the example posed in table 1, during the first week training only takes place on 3 days (September 1, 2, and 3, 2017) and starts every Monday of the following week. On the other hand, we can express the acute load as the summation of the 7 days or as the average value of the 7 days (a value that, if multiplied by 7, will allow us to obtain the accumulated load). For example, the acute load on September 24, 2017, upon completion of that day's training session, expressed as the accumulated value, is 20,200 m. In other words, that is the distance covered by the athlete in the previous 7 days. Meanwhile, on September 20, 2017, upon completion of that day's load, the acute load is 10,000 m. We must keep in mind that these are calendar days, and thus a "0" is included for the days when no training load has been incurred. In the case that there are days with more than one session, the daily load will be represented as the summation of all those sessions. For example, the session on 10/29/2017 consisted of a morning session with a 4,000 m load and an afternoon session with 3,000, which means that that day's actual load reached 7,000 m.

We can also calculate the acute load for the "calendar" weeks from Monday to Sunday using data in table 1, as shown in figure 2 below. As we can see, it is during week 5 when the highest acute load level is obtained, a calendar week from 09/25/2017 to 10/01/2017.

Figure 2. Weekly acute load obtained from the example described in Table 1



Source: Prepared by the author.

Exponential acute load calculation

As we have already noted, the exponential A:C load ratio tries to prioritize the load most recently performed and, for that, it uses an exponential model. The calculation is as follows:

$$\textbf{Exponential acute load} = \textbf{Load}_{today} \times \lambda_a + ((1 - \lambda_a) \times \textbf{Exponential load from yesterday})$$

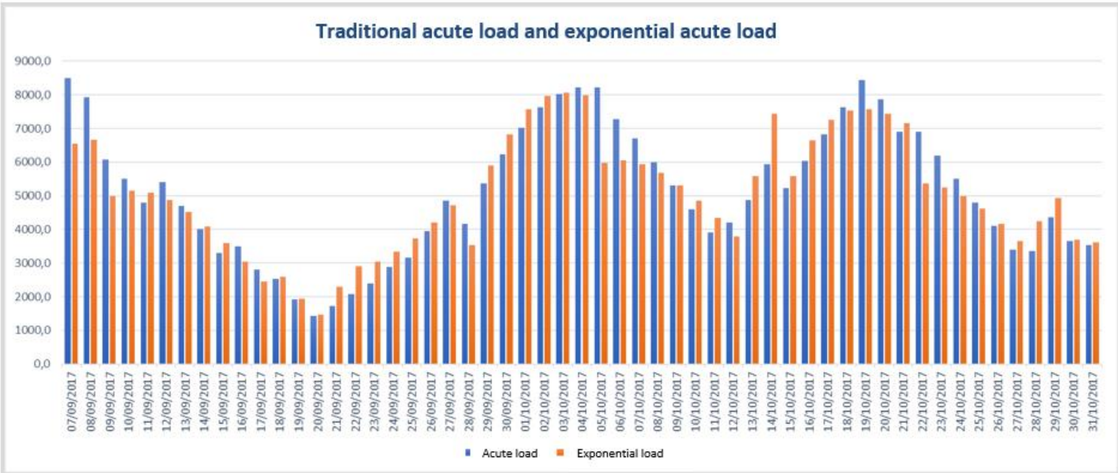
Where λ_a is a value between 0 and 1 that represents the grade of decay, with higher discount values than earlier observations of the model. λ_a is calculated as:

$$\lambda_a = 2/(N+1)$$

In acute loads, the N value will be 7 (if that is the number of days we used in the acute load completion model).

That day's load is multiplied by 0.25 (2/(7+1)) and added to the exponential acute load from the previous day multiplied by 0.75 (1-(2/(7+1)). For that, we need to calculate the previous acute loads. Figure 3, shown below, refers to the comparison between the traditional and exponential acute loads recorded in Table 1. To make this comparison, the traditional acute load has been expressed as the average of the previous 7 days. It is noticeable how on 10/14/2017 the exponential acute load (7440.8 m) is notably higher than the traditional acute load (5928.6 m). This is because a large part of the load during the 7 previous days was accumulated between 10/13/2017 and 10/14/2017, thus the exponential model shows a greater weight, which increases the value in comparison to the one obtained using the traditional model, where the location of the load within the 7 days does not make any difference.

Figure 3: Traditional acute load and exponential acute loadfor each day. Using data in table



Source: Prepared by the author.

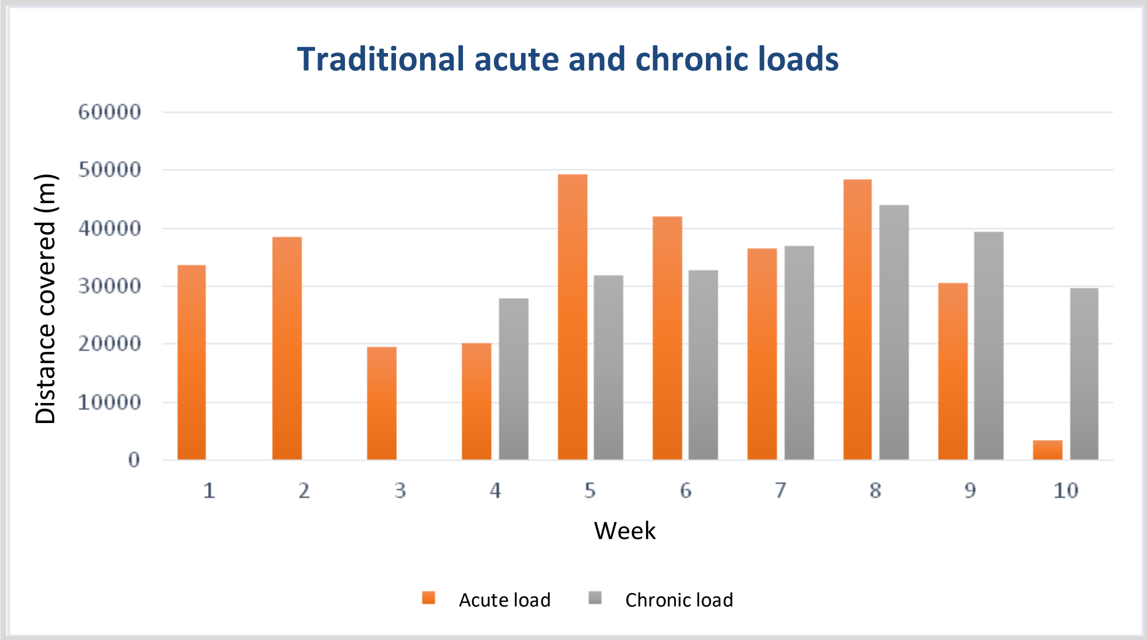
2.2.2 Chronic load calculation

Chronic load refers to the habitual load performed by the athlete. To calculate it, we generally use the value from 4 weeks (28 days) despite the fact that, as with the acute load value, other values can be used to calculate it. This information provides us with a clear indication of what an athlete has done prior to the current training session or match day. Therefore, it is commonly associated with the concept of fitness or the athlete's physical condition.

Traditional chronic load calculation

Traditional chronic load is commonly expressed as a 4-week or 28-day average value. According to the example in table 1, figure 4 shows the traditional chronic load calculation for each week. This load was calculated as the average of the current week with the three previous weeks. Meaning, the chronic load in week 8 (44,025 m) was obtained as the acute load value for week 5 (49,200 m), 6 (42,000 m), 7 (36,600 m) and 8 (48,300 m).

Figure 4: Acute load and chronic load calculated using the traditional model for each week using data in table 1



Source: Prepared by the author.

Exponential chronic load calculation

To calculate the exponential chronic load, we need to consider the temporality of training loads. As we have already noted, the exponential A:C load ratio attempts to prioritize the load most recently used. The calculation is as follows:

The formula used to calculate it:

$$\text{Exponential chronic load} = \text{Load}_{today} \times \lambda_a + ((1-\lambda_a) \times \text{Exponential load from yesterday})$$

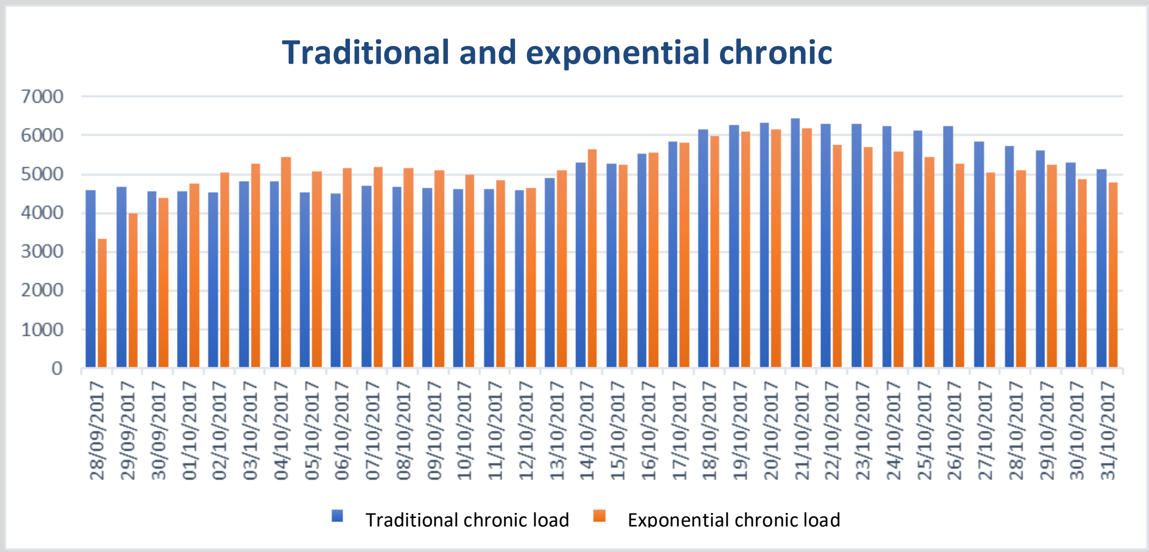
Where λ_a is a value between 0 and 1 that represents the grade of decay, with higher discount values than earlier observations of the model. λ_a is calculated as:

$$\lambda_a = 2/(N+1)$$

In chronic loads, the N value will be 28 (if that is the number of days we used in the acute load completion model).

That day's load is multiplied by 2/29 (2/(28+1)) and added to the exponential chronic load value from the previous day multiplied by 1-(2/29). For that, we need to calculate the previous exponential chronic loads. Figure 5 below refers to the comparison between the traditional and exponential chronic load data recorded in Table 1.

Figure 5: Traditional and exponential chronic load data shown in Table 1



Source: Prepared by the author.

To make this comparison, the traditional chronic load has been expressed as an average of the previous 28 days. It is noticeable how on 10/26/2017 the traditional chronic load (6239 m) is notably higher than the exponential chronic load (5259 m). This is because a large part of the load during the previous 28 days was mostly accumulated at times far from the date studied, which lowers the exponential model value, while in the traditional model the location of the load within the 28 days does not make any difference.

2.2.3 Acute:chronic load ratio calculation

As we can infer, there are now a multitude of possible configurations when it comes to defining the A:C load ratio. On one hand, the ratio can be calculated for each of the load variables or any of their components (volume and intensity) and thus far, it is most common to use internal load measurements (mainly the session-rating of perceived exertion obtained by multiplying the rating of perceived exertion by the duration of the session in minutes) and external load measurements obtained through GPS technology (total distances covered or at high speed and measurements associated with accelerations/decelerations). Additionally, the time window when defining acute load and chronic load is also variable. Usually, 7 days (one week) has been used as the time window for acute load, and 28 days (4 weeks) for defining chronic load.

Therefore, the A:C load ratio can be set for different time durations for acute load, chronic load, and each variable (for external or internal load). In this sense, Carey, D. L, Blanch, P., Ong, K. L., Crossley, K. M., Crow, J. & Morris, M. E. (2017) studied, in Australian rules football players, which acute and chronic load variable and duration were best related to likelihood of injury; and used acute load on days 2 to 9, and chronic load on days 14, 18, 21, 24, 28, 32, and 35, which produced 56 different A:C load combinations. Also, 6 different dependent variables were chosen for the calculation, which produced a total of 336 A:C load ratios under study. Based on the results obtained from this study, it seems that these models should be adapted to the context, including sports certainly, but also the competition structure and calendar (Carey et al., 2017), and perhaps even the method of playing and/or training and the athletes themselves.

Table 2: Load variables

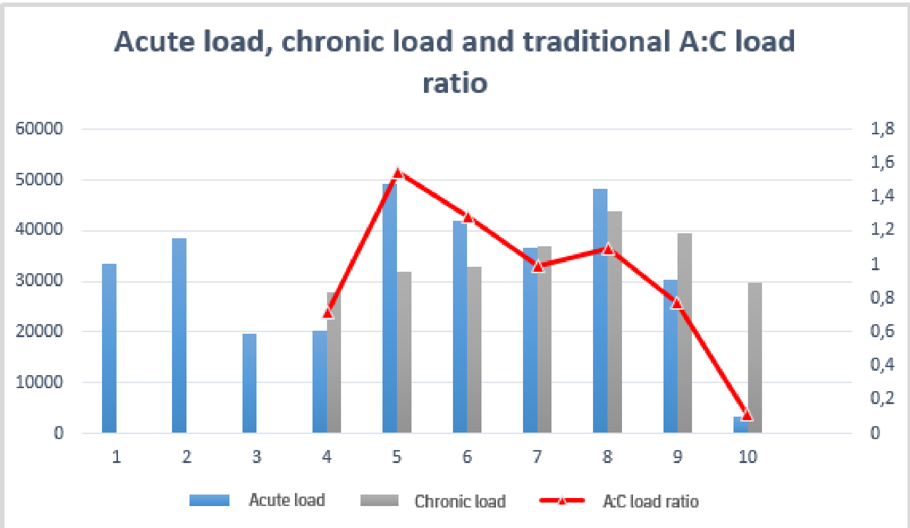
Variable	Definition
Distance (m)	Distance above 3km/h
Session-RPE (arbitrary units)	Athlete rating of perceived exertion x sesión duration
Player load (arbitrary units)	Custom metric measuring the magnitude of rate of change of aceleration[17]
Distance-load (m^2 min^{-1})	Distance x mean speed
HSR (m)	Distance above 24 km/h
MSR (m)	Distance between 18 and 24 km/h
HSR, high speed running; MSR, moderate speed running	

Source: Carey, 2017, p. 3.

Traditional acute:chronic load ratio calculation

The traditional A:C load ratio is calculated by dividing the acute workload (fatigue) by the chronic workload (physical condition). For example, in week 8, we can observe an acute load of 48,300 m, which is divided by a chronic workload of 44,025 m, resulting in an A:C load ratio of 1.10 (48,300/44,025 = 1.10).

Figure 6: Acute load, chronic load and acute:chronic load ratio calculated using the traditional model for each week using data in Table 1



Source: Prepared by the author.

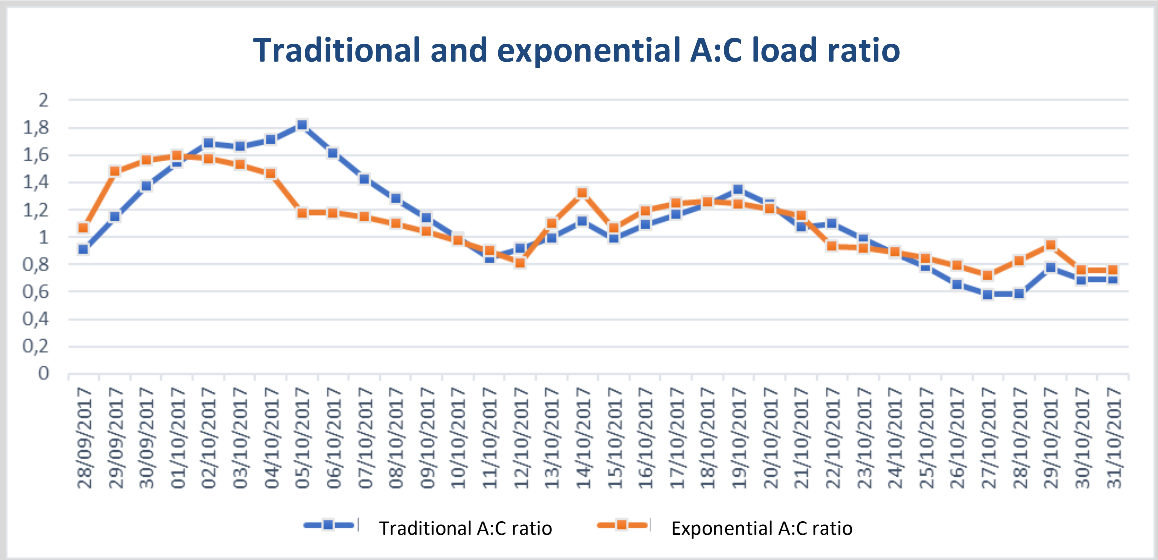
This A:C load ratio allows users to consider the training load the athlete has already performed (during the most recent week of training) in relation to the training load for which he has been prepared (over the past four weeks).

Generally, in team sports like soccer, which has regular competitions (each weekend), the acute workload is the training load performed by an athlete in 1 week, and the chronic workload is the average acute workload over 4 weeks (as already explained). This being said, it is important to keep in mind that these periods can be modified according to the schedule associated with that particular sport.

Exponential acute:chronic load ratio calculation

The exponential A:C load ratio is calculated in the same way as the traditional one; that is, by dividing the acute load by the chronic load. However, the calculations for acute and chronic loads differ when using the exponential format, and because of that, the exponential ratio presents different values.

Figure 7: Traditional and exponential acute:chronic load ratio using data from Table 1



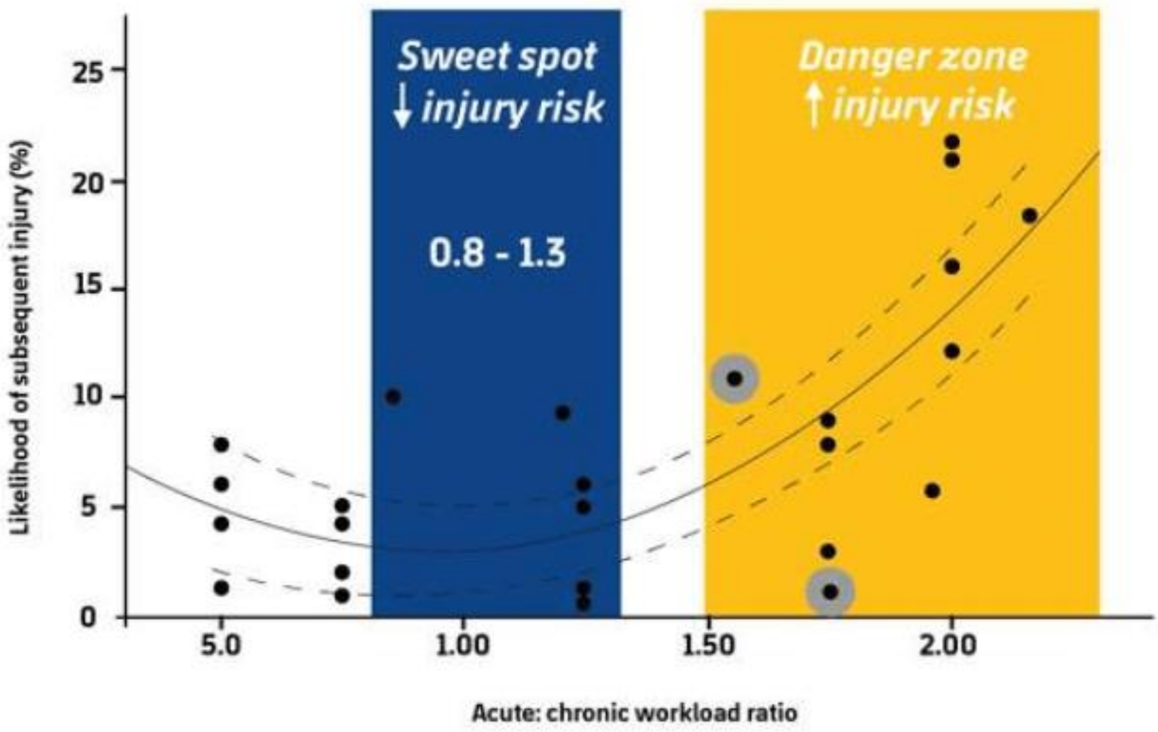
Source: Prepared by the author.

To calculate the exponential chronic load, we need to consider the temporality of training loads. As we already noted, the exponential A:C load ratio attempts to prioritize the load performed most recently and, for that, it uses an exponential model.

Acute:chronic load ratio interpretation

With regard to the significance of the values we will obtain by calculating the ratio, we now will list some ideas. If the acute training load is low, meaning that the athlete experiences minimal fatigue, and the chronic training load is high, meaning the subject is in adequate physical condition, then the athlete will be suitably prepared, with an A:C ratio value close to or less than 1 (Gabbett, 2016). On the other hand, when the acute load is high, due to a sudden increase of training loads, and the chronic load is low, this means that the athlete has insufficiently trained to develop his level of fitness, the subject will be fatigued, with a A:C workload ratio value above the unit value. In figure 8, we can see the representation of the A:C load relationship. The green shaded area (*"Sweet Spot"*) indicates a low injury risk, while the red shaded area (*"Danger Zone"*) symbolizes the values at which injury risk is high. In order to minimize injury risk, sports professionals must try to maintain the A:C workload ratio within the range of 0.8-1.3, approximately (Blanch & Gabbett, 2016).

Figure 8: Guide for interpreting and applying acute:chronic workload data



Source: Adapted from Gabbett, (2016).

2.3 Traditional A:C load ratio vs. exponential A:C load ratio

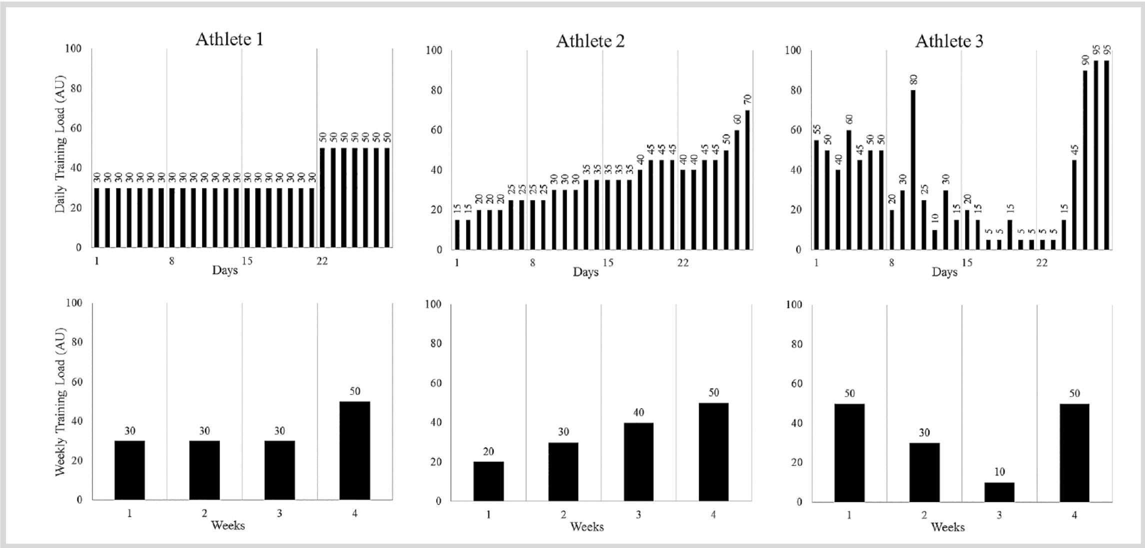
As detailed, there have been two models used and studied in scientific literature in recent years: the traditional A:C load ratio and the exponential A:C load ratio. The exponential model attempts to overcome some of the limitations of the traditional model, because the traditional calculation method does not differentiate in terms of when the training load was accumulated.

The traditional model uses the absolute (total) workload performed in 1 week (acute workload) in relation to the 4-week chronic workload (meaning, the 4-week acute workload average). This model suggests that each workload in an acute and chronic period presents the same value. This means that the traditional calculation method does not differentiate in terms of when the training load was accumulated, but rather gives the same weight to the session completed the previous day as a session completed 4 weeks prior. Therefore, the traditional model considers the relationship between load and injury to be linear and, therefore, any workload in a given time period is considered to be the same. This model does not consider a decline in physical condition nor does it recognize variations in how loads accumulate. One possible solution to overcoming these limitations of the traditional model is to use the exponential model.

The exponential model is more emphatic on the latest workload performed by the athlete, assigning decreasing weight to each previous workload value. This means that the latest loads are prioritized or assigned a higher value. This model was designed specifically to account for the decaying nature of the training effect and the non-linear nature of the relationship between injuries and workload.

In the example provided by Menaspà (2016), we have an example that involves three athletes. In the upper part of Figure 9, we can see how the three athletes accumulated loads at different times. While athlete 1 accumulated a fairly stable load, athlete 2 has done so progressively and athlete 3, with high variability. In the lower part, we can see the average load obtained per week. However, both the acute and chronic loads they performed are the same (acute load = 50 AU; chronic load = 35 AU), and as such they will obtain the same A:C load ratio (1.43 AU) when using the traditional model. In conclusion, based on this risk factor, all of them would have the same likelihood of injury.

Figure 9: Daily workload for the 3 athletes studied

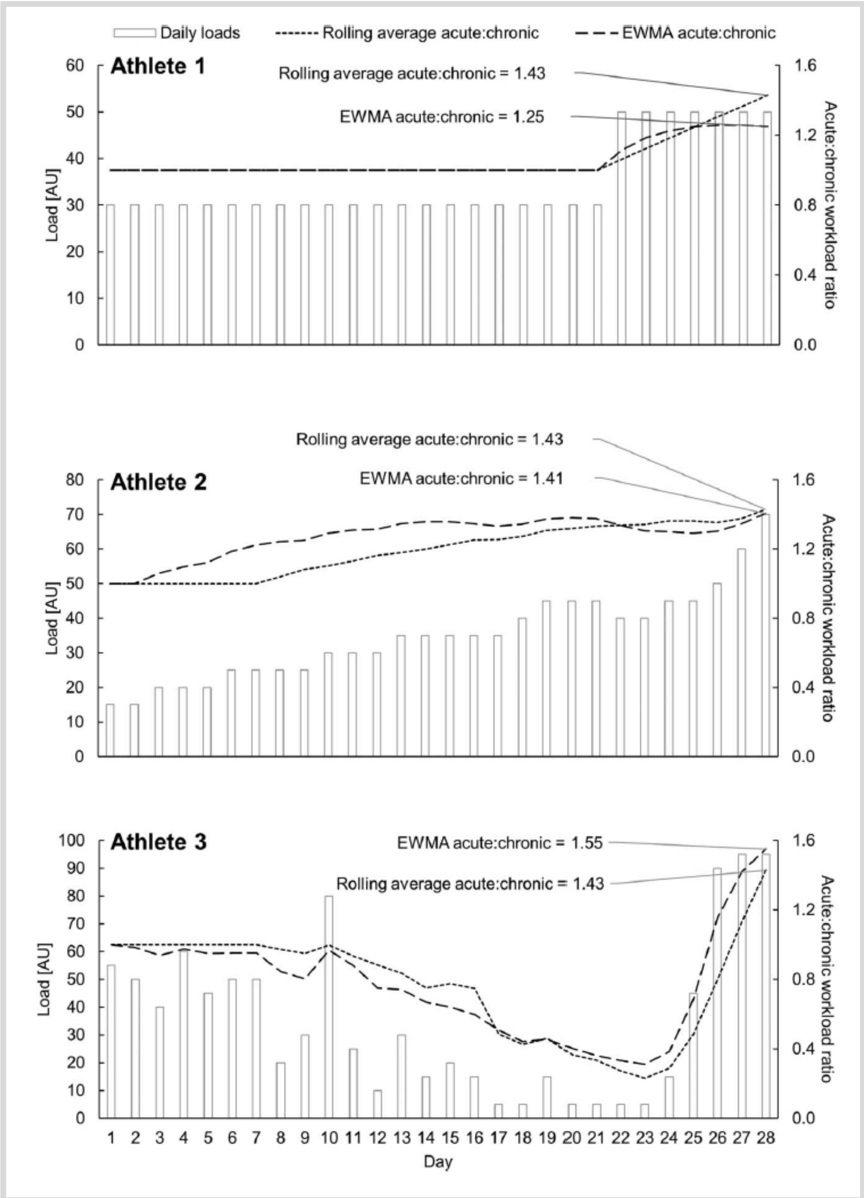


Source: Menaspà, 2016, p. 1.

Regarding figure 9, the upper part shows the daily training load for each of the three athletes studied, while the lower part shows the acute load for each of them. The acute load for week 4 (50 AU) and the chronic load at that point (4-week average, 35 AU) are identical for all three, all three athletes obtaining an A:C load ratio of 1.43.

The exponential A:C load ratio was proposed in an attempt to overcome this limitation, where the loads performed by the athlete far apart in time present a lower score in comparison to those performed closer in time. Williams, S., West, S., Cross, M. J., Stokes, K. (2016) present the calculation for this ratio based on the three examples above, where we can see how athlete 1 exhibits the lowest A:C load ratio and athlete 3, the highest.

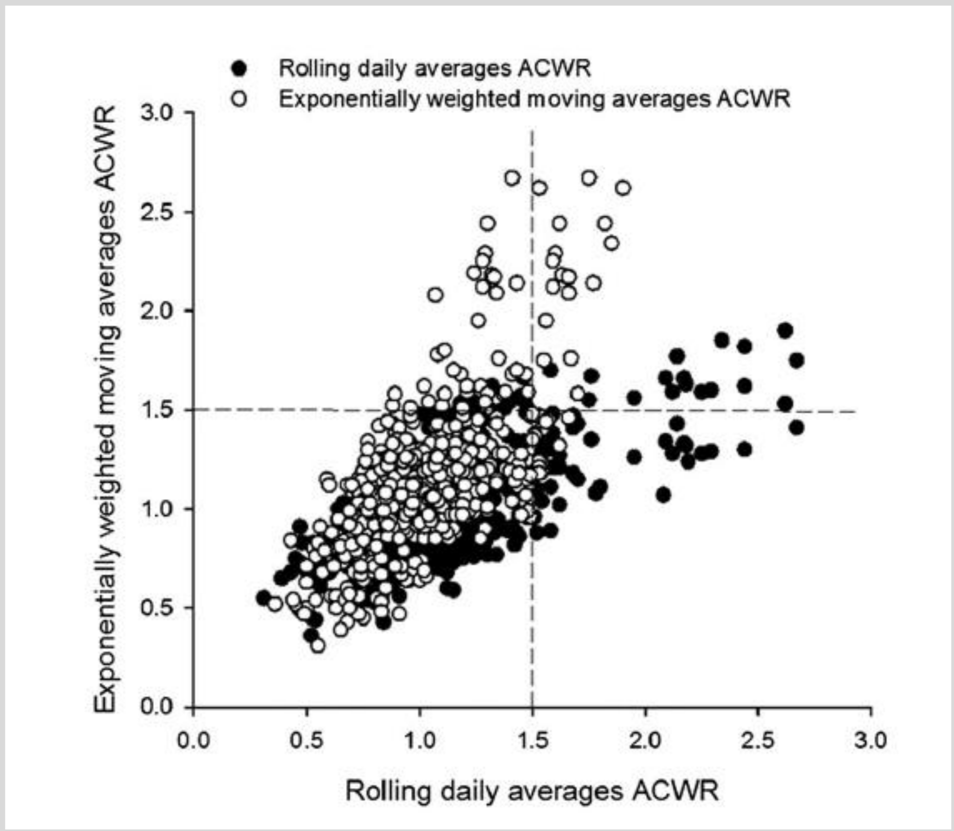
Figure 10: Traditional and exponential acute:chronic load ratio calculation for the three previously presented examples



Source: Williams et al., 2016, p. 210.

Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2017) compared both models to find out which method exhibits greater sensitivity to injury incidence. Additionally, it graphically displays the calculation for both models.

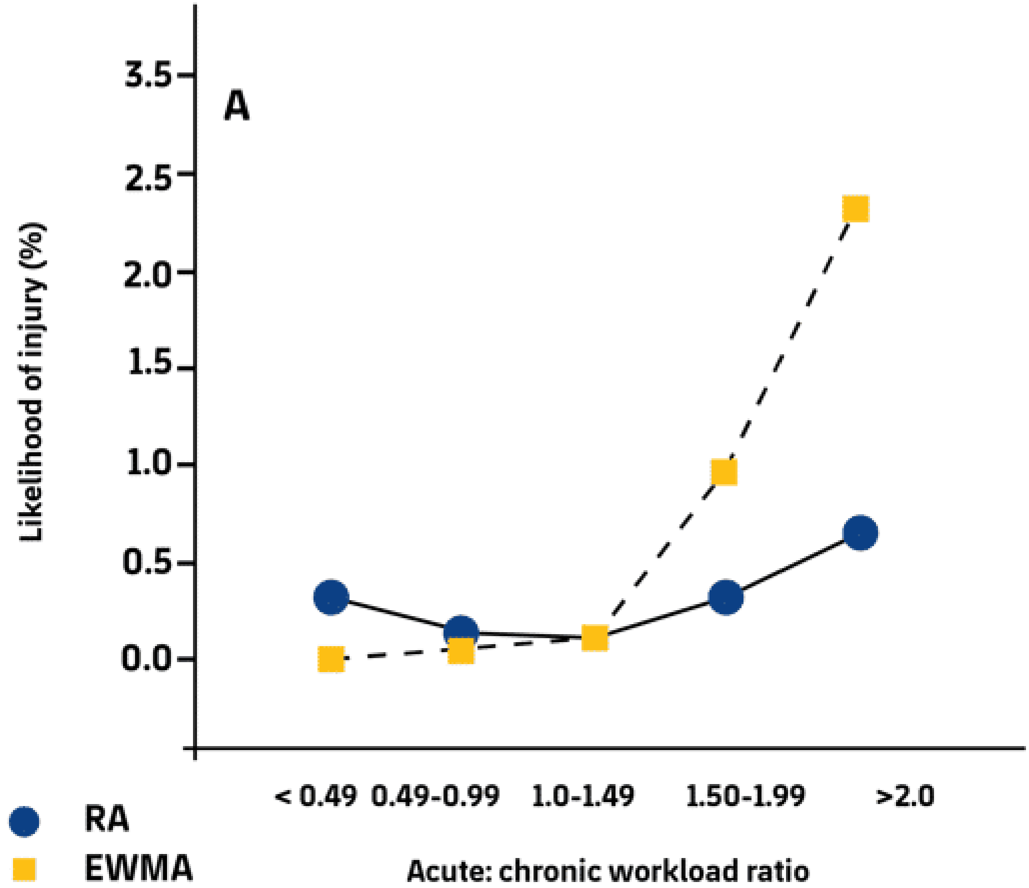
Figure 11: Acute: chronic load ratio relationship obtained through the traditional method (rolling) and through the exponential method



Source: Murray et al., 2017, p. 3.

Murray et al. discovered how the exponential method is significantly more sensitive compared to the traditional method (rolling), regardless of the moment of the season (pre-season or competitive season) or the dependent variable used (total distance, distance at moderate speed, distance at high speed or player load).

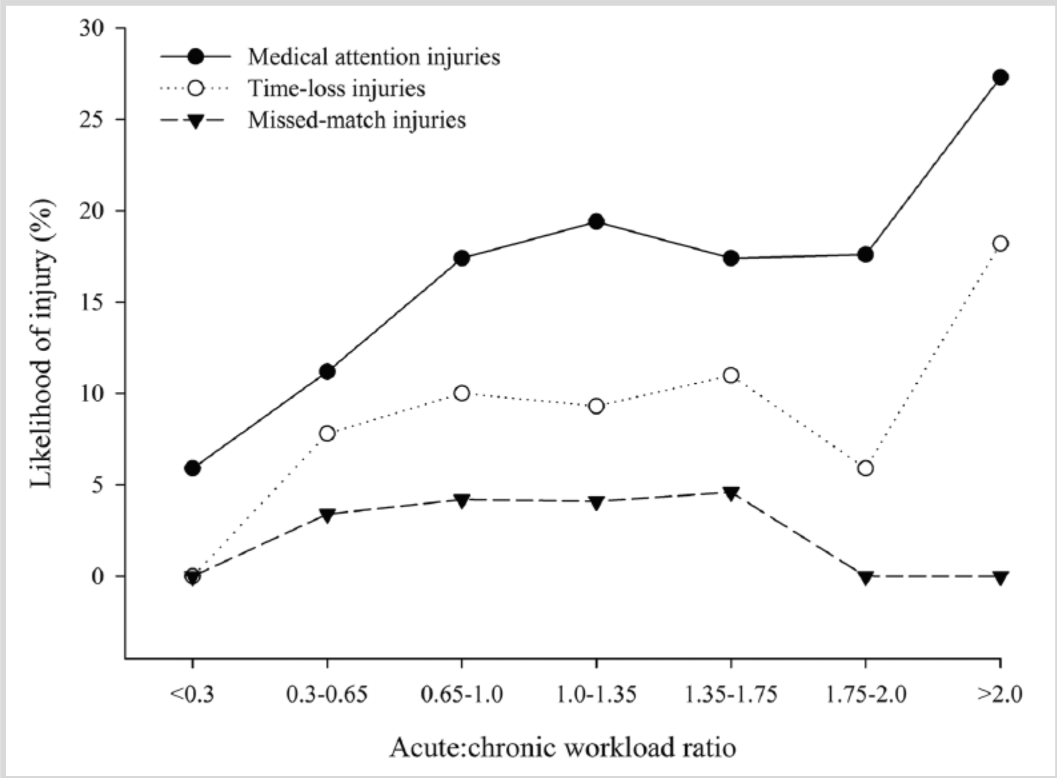
Figure 12. Injury likelihood at different acute:chronic load ratio magnitudes obtained through the traditional method (RA) and through the exponential method (EWMA), calculated based on the total distance covered during the competitive season.



Source: Murray et al., 2017, p. 4.

Additionally, in this sense, it is worth mentioning that injury definitions have not been considered. As we can see in the next figure, the risk of receiving medical attention is always higher than the risk of taking leave or missing a match due to an injury. In figure 13, we can see how when the A:C load ratio is above 2, there is a greater probability that medical attention or leave will be required, without increasing the probability of missing a match. Based on these results, modifying the injury concept when reviewing these type of relationships can also modify the conclusions and practical applications derived from the workload. Thus, we must be cautious when comparing findings from different studies, and be consistent when using the injury concept (Hulin, 2017). Additionally, each context is different, with different competition schedules, different action plans for sore or injured athletes, or different abilities among medical staff to help athletes recover. Therefore, each context may require a different configuration.

Figure 13: Relationship between the acute:chronic load ratio and the risk of receiving medical attention, being on injury leave and missing matches due to injury in professional rugby players



Source: Hulin et al., 2017, p. 931.

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