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CHOOSING VARIABLES ARE WE REPEATING INFORMATION OR PROVIDING ADDITIONAL INFORMATION?

INTEGRATION OF MEASUREMENTS. EFFICIENCY INDEX OF THE MODULE

3.1 Integration of internal and external load. Cardiovascular efficiency

When internal and external variables are integrated into a single numeric value, that is to say, when they are included in the same formula (for example ratios, indicators or variables of external load divided by indicators or variables of internal load or vice versa) they generate integrated indicators (Akubat, Barrett and Abt, 2014). This type of evaluation is based on relating the work performed and the energetic cost of the activity (Burgess, 2017). Integrating indicators from both dimensions (internal and external) provides information on several aspects, including: information on the physical fitness of the players or the team, assessing acute fatigue, or comparing efficiency between positions that players occupy on the playing field, from which interventions can then be tailored to the physical and physiological needs of each of the positions.

"Integrating external and internal load indicators allows us to evaluate different scenarios: physical fitness, fatigue, comparison between player profiles or demarcations"

Assessing the physical fitness of the team and/or players that form part of it allows us to identify if the team is improving without the need for complimentary tests, that is, training tasks that let us assess the physical performance of the team. This is extremely interesting, but the question that comes to our mind is about how to implement it.

The hypothesis about increased efficiency as the resistance levels of the subject increase was widely studied in laboratory conditions and in standardized field tests (for example the Yo-Yo Intermittent Recovery Test Level 1) where the most adapted subjects–with higher performances in this test in particular–cover a certain distance with a lower physiological impact (Bangsbo, Iaia and Kustrup, 2008; Boullosa et al., 2013). This point allowed for athletes to be assessed using submaximal tests; a lower cardiovascular impact (% maxHR) at 6 or 9 minutes of a submaximal test is related to an improved maximum performance, so athletes may not need to be subjected to maximal exertion tests, while at the same time

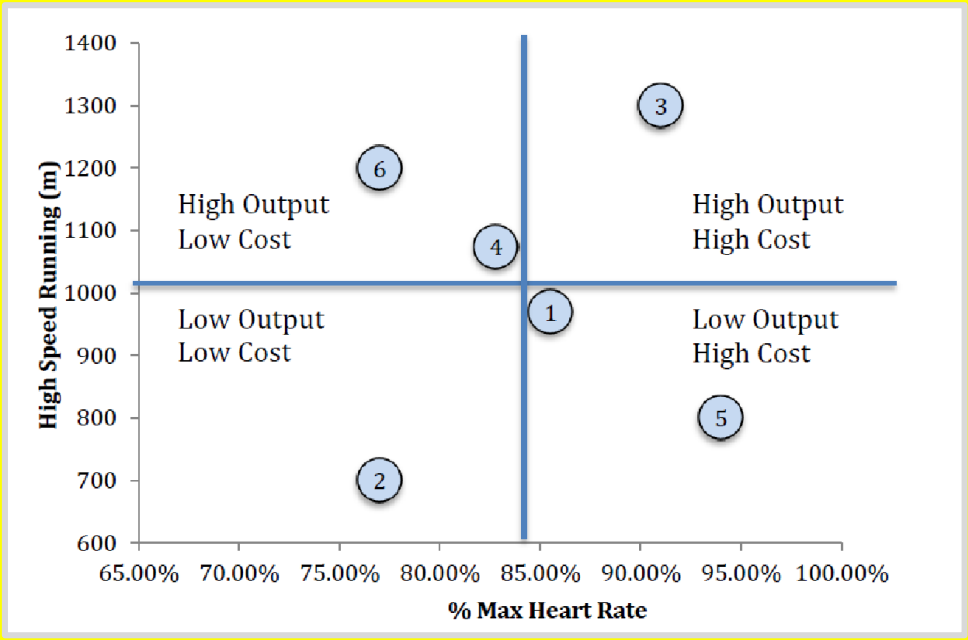
increasing the frequency of controls.1 With regards to this, it is important to identify the activity the player has undertaken during the tests because when using a test protocol where the athlete's velocity is marked by the athlete's sound emissions, it can be “the same” at different moments and we are conscious of the possible variability in the displacement velocity in this type of test.

When applying this to soccer training, mainly to small sided games, it provides the opportunity to follow-up on players using particular values of energetic efficiency, allowing us to foresee decreases or increases in the physical fitness of players and the team.

In order to determine the state of fitness of our athletes at a given moment, we could relate the activity performed (external load) to the impact generated on the athlete (internal load) (Figure 3.1).

[1] In order to clarify the example, we could mention the case of a player that goes from 160 bpm (corresponding to 80% of its maxHR) during test 1 to obtain a value of 165 bpm (82.5% of the maxHR) during test 2. This could be understood as a non-positive adaptation because with the same amount of work, the cardiovascular impact generated in the athlete is higher. However, another player goes from 160 bpm to 150 bpm, which is understood as an increase in cardiovascular efficiency.

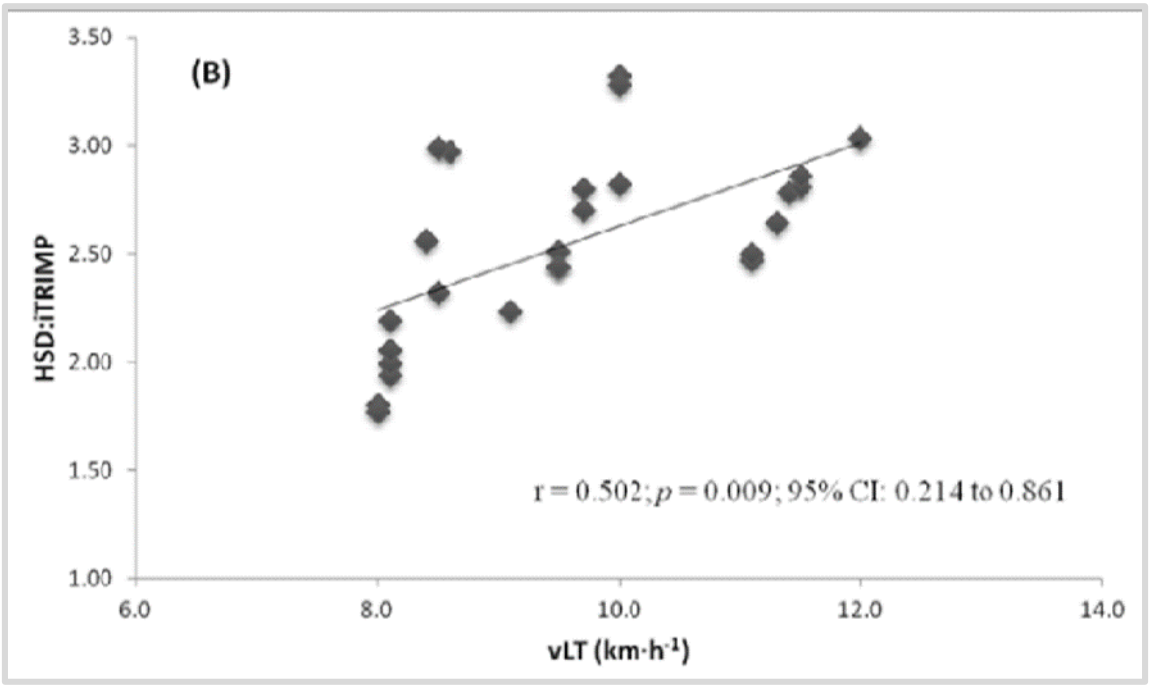
Figure 3.1. Internal load and external load values of six players during a training session



Note: Cross lines represent the average of the session analyzed. It is possible to observe how athlete number 5 displays poor levels of activity (workload) in a training session (in this case measured by the distance covered at high speed) which has had a high cardiovascular impact, measured by average heart rate. On the other hand, athlete 6 has a high workload with a reduced level of energy expenditure, which could be associated with an athlete with an increased level of fitness.
Source: Burgess (2017).

In other team sports–such as hurling–Malone, Doran, Akubat and Collins (2016) found that there is no significant relationship between the activity carried out during competition and the level of cardiovascular fitness. However, when integrating the external and internal load through a ratio, and relating these indexes with different performance variables associated with cardiovascular endurance (maximum oxygen consumption and 1st and 2nd ventilatory thresholds), significant relationships were then observed. These ratios were calculated by means of a quotient between the distance covered at high speed divided by the TRIMP (individual training impulse) and the distance covered at sprint divided by the TRIMP; players with a higher ratio have shown a higher cardiovascular performance level.

Figure 3.2. Relationship between the distance covered at high speed index HSD:iTRIMP (during *hurling* match) and the lactate threshold calculated by means of a specific test.



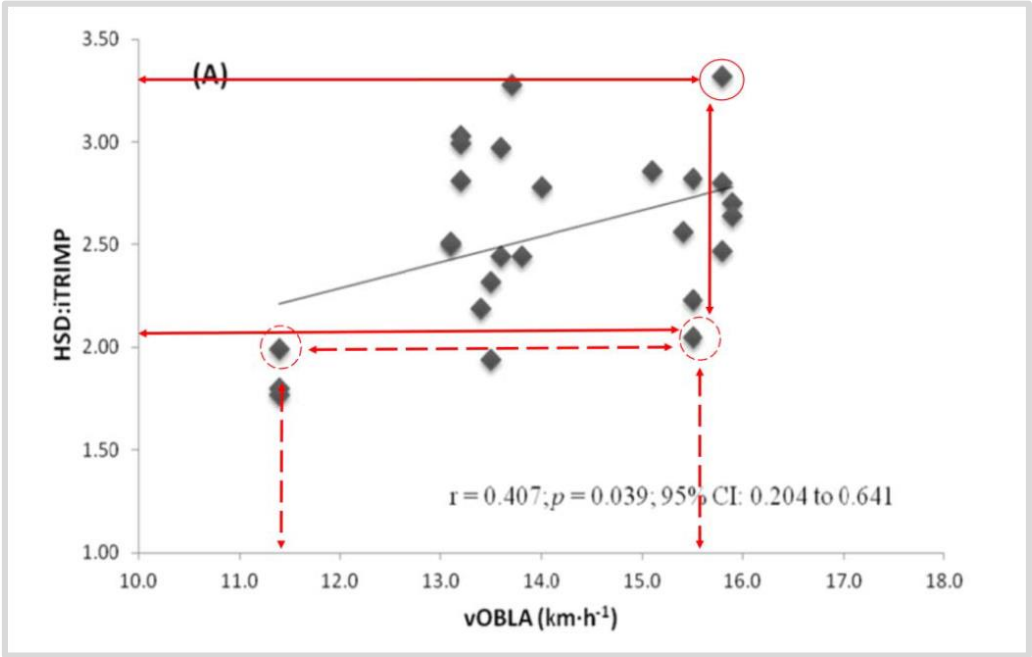
Source: Malone et al. (2016)

Figure 3.2. Relationship between velocity (km•h^{-1}) at a lactate concentration velocity of 4 mmol•L^{-1} ($_{v}$OBLA) and the efficiency index calculated with the ratio of distance covered at high velocity (>17.0 km•h^{-1}) and the cardiovascular impact (TRIMP) during the hurling simulation test.

However, this study presented by Malone et al. (2016) has received criticism as described in Weaving et al. (2017) that should be taken into consideration. The first of criticism refers to the use of a protocol that simulates the demands of a hurling competition, but that has a reduced variability of physical demand, so the distance covered (total, at high velocity and at sprint) is a variable that is only slightly modified, and that could be considered stable based on the low coefficient of variation (CV=1.9%). Weaving et al. (2017) maintain that the external load during the study by Malone et al. (2016) was effectively controlled within the study design, and as a consequence its use as an independent variable seems redundant.

Moreover, absolute velocity ranges were used and the GPS devices used showed a sampling frequency of 4 Hz (4 data points per second) with questionable validity and reliability when measuring high-speed displacements (Weaving et al., 2018).

Figure 3.3. Relationship between velocity (km·h^{-1}) at a lactate concentration velocity of 4 mmol·L^{-1} ($_{v}$OBLA) and the efficiency index calculated with the ratio of distance covered at high velocity (>17.0 km·h^{-1})



Source: Weaving et al. (2017), adapted from Malone et al. (2016).

The example (Figure 3.3) illustrates two cases with the same efficiency indexes and a very different cardiovascular fitness level: two subjects with a low index of cardiovascular efficiency (HSD:iTRIMP close to 2) show very different performances in the resistance test–one of the athletes reached the concentration of 4 mmol•L^{-1} ($_{v}$OBLA) at 11.4 km•h^{-1} while the other athlete reached those values at 15.6 km•h^{-1}. Moreover, this athlete with a cardiovascular efficiency index of 2 and a velocity of 15.6 km•h^{-1} shows the same cardiovascular performance as another athlete with a cardiovascular index of 3.3 approximately. So, in spite of the significant relationship revealed, the practical application of such data should be limited when trainers want to predict the aerobic performance based on the cardiovascular efficiency indexes used.

It is important to point out that this proposal for assessing workload based on training tasks needs further investigation to determine the specific conditions that the training task should satisfy (for example, number of players, objective of the task, space dimensions, duration of each of the repetitions) and the variables

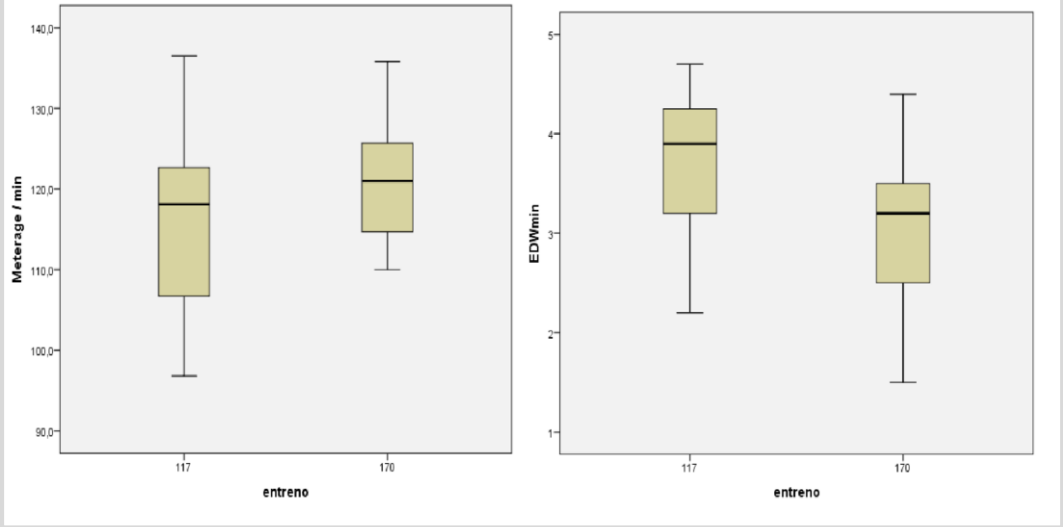
that should be correlated, keeping in mind these could be different based on the profile or role of the player during the competition.

As regards the longitudinal follow-up of our athletes, this load assessment could help us identify and foresee the future performance of our athletes. Let's review an example to illustrate this idea. We will compare the same task: a 11vs11 match on a 90 x 70 m field in two different training sessions (data not published), with nine weeks between sessions. In both sessions, the same task was repeated with the same repetitions and durations (3 sets x 13 min of work x 2 min of rest). Both sessions were held in the same conditions as far as possible with regards to these different variables: condition of the field of play, time of day, availability of balls, minimization, whenever possible, of time losses due to balls that leave the field or fouls committed (resuming play as soon as possible after each interruption). The results when comparing and interpreting both sessions were as follows: on the left side of Figure 3.4, we can see how the team had a higher pace of play ($m \cdot min^{-1}$) in one session (session # 170) compared to the one nine weeks prior (session # 117), although it was not significant. However, this workload implied a lower cardiovascular demand on players in session # 170 (right side of Figure 3.4). This could be interpreted as an efficiency increase in the body (run more and expend less energy). The results of this study suggest that, although it is not statistically significant, the level of activity (pace in $m \cdot min^{-1}$) was higher in session # 170 than in session # 117, while the second session (# 170) implied less effort for players. That is to say, it appears as though they adapted to the endurance training, increasing the athlete's efficiency in the game.

To assess the possible existence of chronic fatigue we can also use the efficiency indicator. Similar to what has been previously discussed, players may worsen their external load/internal load ratios due to the depletion of energy reserves, increased cardiovascular demand and/or reduced observable physical activity (such as a slower pace of play) or even less observable (such as the number of and intensity of accelerations and decelerations). However, we should not focus only on these types of combined variables (external vs. internal loads) as fatigue or overload states could be overlooked. In this sense, it is known for example that an athlete that is overloaded will have limited input from the cardiovascular system (Aubry et al., 2015) that can lead to a bias in data interpretation. In support of the hypothesis about sensitivity when determining the capability to detect states of fatigue, the work of Barbero-Álvarez, Boullosa, Nakamura, Andrín and Castagna (2012) with soccer referees and assistant referees found a significant decrease in the effindex ($m\ min^{-1}$/ % maxHR) as the matches progressed, while the distance covered did not decrease significantly. Based on these results, we

could understand that referees run the same, but with a higher cost, and, as a consequence, with a lower level of cardiovascular efficiency.

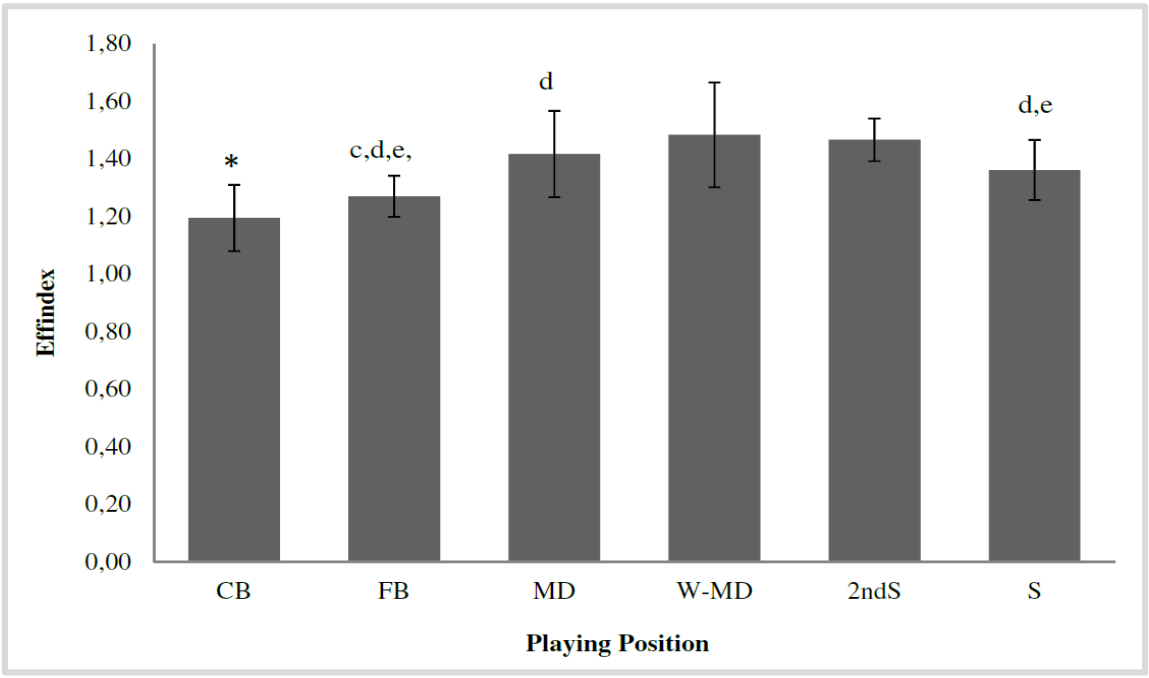
Figure 3.4. Average distances covered and Edwards indicator per minute



Note: both in three 13-minute repetitions of 11vs11 on a 90x70m field in two different sessions (117 and 170).
Source: Castellano & Casamichana (2016).

Finally, as regards the comparison between demarcations, the information obtained from the efficiency interpretation provides for an interesting line of application. For example, Suárez-Arrones et al. (2014) used the so-called effindex when they analyzed the first half of matches between professional players. The authors linked a displacement velocity variable (or pace) – such as meters covered per minute – with cardiovascular stress through the mean heart rate value by using the following formula: effindex = m•min-1 / %maxHR, and found differences between positions in the efficiency indicator. The authors found differences in the efficiency indicator depending on the demarcations. The interpretation of results in this type of research could be explained in two different ways: firstly, because players (demarcations) have different demands (what makes the player draw on different energetic systems). While on the other hand, these differences could indicate a more or less efficient use of the activated energetic systems when producing a movement. That is, the same distance is covered with a higher or lower energetic expenditure.

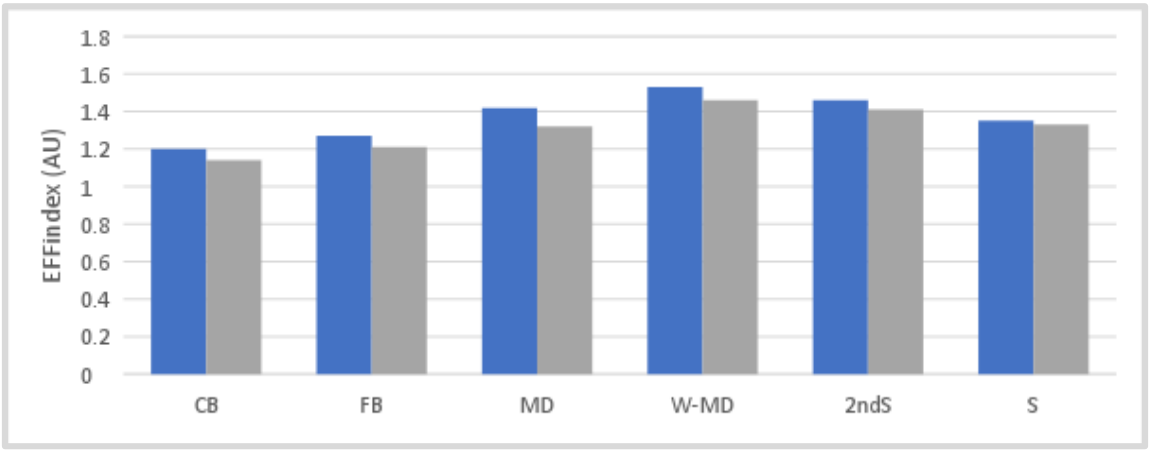
Figure 3.5. Indicator of cardiovascular efficiency in competitions based on the player's demarcation during the competition.



Source: Suarez-Arrones et al. (2014).

Moreover, if we calculate the cardiovascular efficiency indicator during the first and second halves of the match, it can be observed that the cardiovascular efficiency indicator is lower in every position during the second half, which could indicate to us that the athlete is in a state of fatigue. During the second half of the match – in this specific study – players covered less distance compared to the first half in all of the positions studied. The mean heart rate also declined during the second half, but to a lesser degree when compared to the activity (distance covered), which explains the decline in the cardiovascular efficiency indicator.

Figure 3.6. Indicator of cardiovascular efficiency in competitions based on the player's demarcation during the first and second half of the competition.



Source: Suarez-Arrones et al. (2014).

These results seem to indicate that as the activity progresses, for example during a match, the cardiovascular efficiency index decreases, which could indicate fatigue in the athlete. It is worth mentioning that deeper research is needed to this regard in order to improve these types of proposals when applying them to common contents in soccer training such as small sided games.

Recently, research has introduced new ideas related to this and that support the use of this type of efficiency index in the monitoring process and assessment of the training process (Delaney et al., 2018). Specifically, the cardiovascular efficiency indexes were obtained using the quotient between an external load variable and an internal load variable. However, in contrast to previous research, the internal load value is raised by a function based on the constant linear relationship between both variables.

Efficiency index = external load variable / internal load variable x

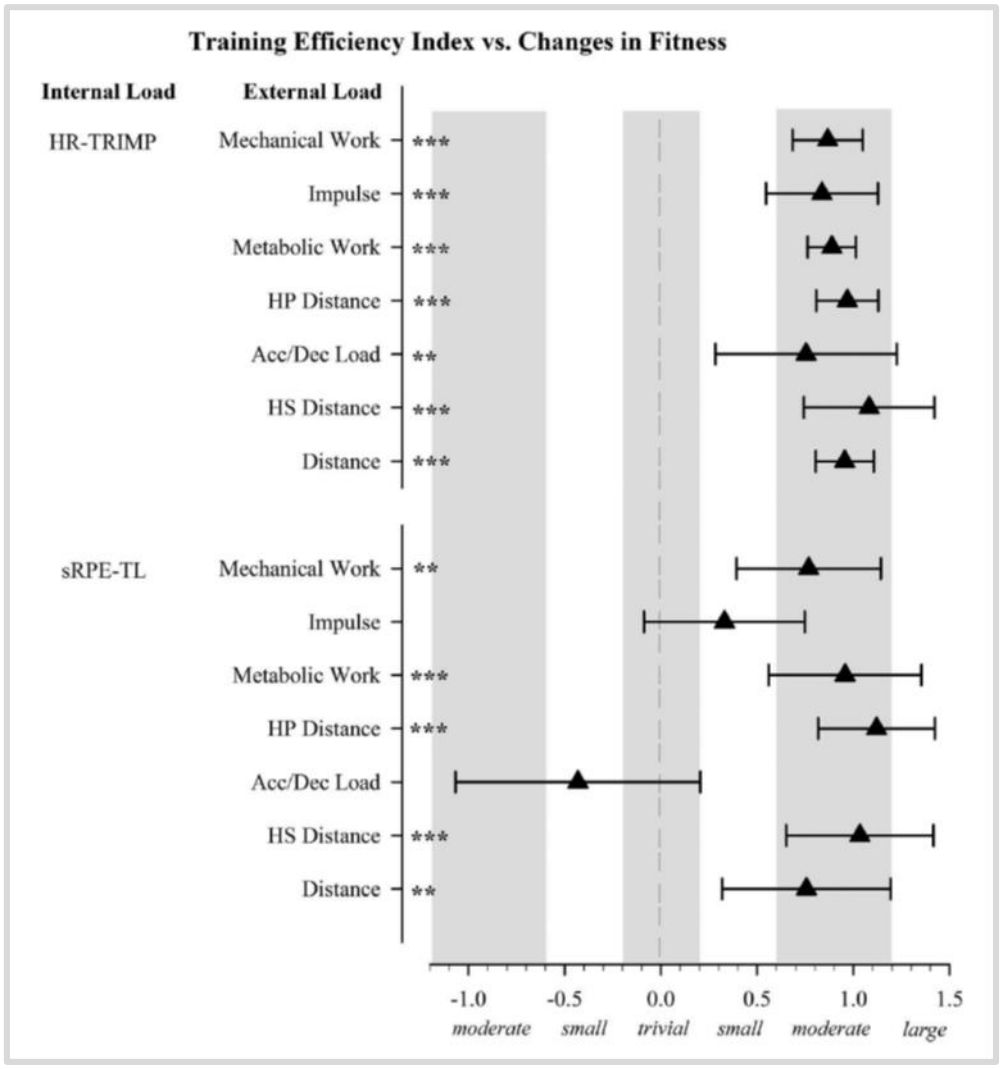
For example, the cardiovascular efficiency indicator can be calculated relating the total distance covered with the cardiovascular impact generated in the athlete (iTRIMP index), raising this last variable by the value of the constant linear relationship between both measurements (external load and internal load variables) using this formula:

Efficiency index = distance covered / iTRIMP 0.87

So, the numeric value to which the internal load variable is raised depends on the constant linear relationship between the external load variable and the internal load variable used to calculate the efficiency index (Delaney et al., 2018).2 Furthermore, the authors indicate that when establishing this efficiency index, it is vital that the relationship between the external load variable and the internal load variable utilized in the model have a high correlation. This will allow for the interpretation of higher-than-expected deviations, showing us if the player is getting better or worse. Thus, greater activity without a simultaneous increase in the internal load would reflect a positive training result. On the other hand, an increase in the internal load without a simultaneous increase in the athlete's external load would represent a negative effect of training.

[2] The authors studied the relationship between the different efficiency indexes used and the change that took place in a continuous test of 1.2 km round trip after 7 weeks of training.

Figure 3.7. Relationship between different training efficiency indexes.

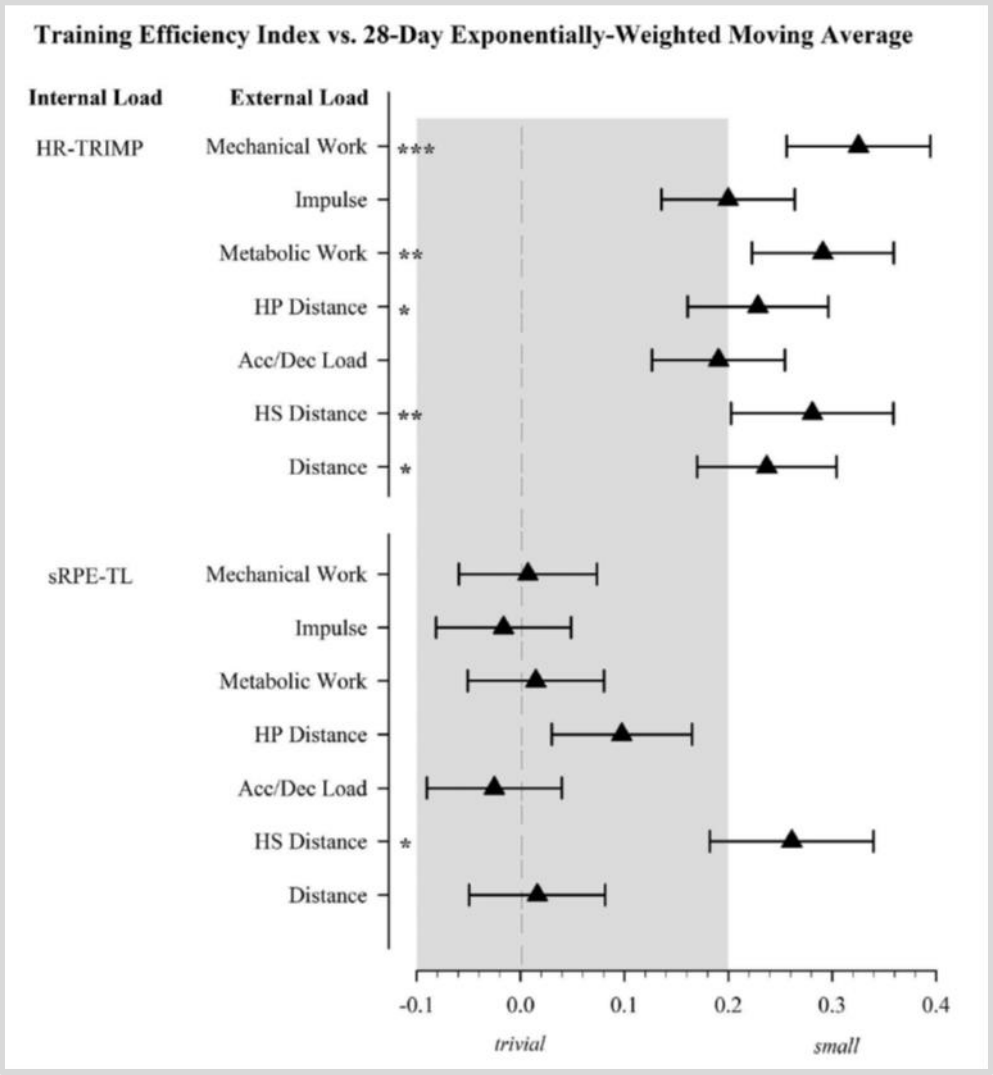


Note: * This indicates that the probabilities of seeing effect are more than 75%

In the previous figure, it can be seen how there is a stronger relationship with the changes produced in the 1.2km resistance test when the efficiency indexes are measured using heart rate (TRIMP index) in comparison to the rate of perceived exertion (RPE). As for the external load variables studied, it should be noted that a greater correlation exists with training adaptations when efficiency indexes are calculated utilizing variables that integrate velocity and accelerations, such as metabolic power (represented as metabolic work in Figure 3.8) or distance covered at high metabolic power (represented as HPdistance in Figure 3.8).

Moreover, the authors studied the relationship between these efficiency indexes and the chronic load. For said purpose they used the exponential calculation that weighted the training sessions that were closer in time more heavily.

Figure 3.8. Relationship between the different Training Efficiency Indexes (TEi) calculated using different combinations of external and internal load variables, and the chronic load of the last 28 days calculated based on the exponential model in 27 professional rugby players.

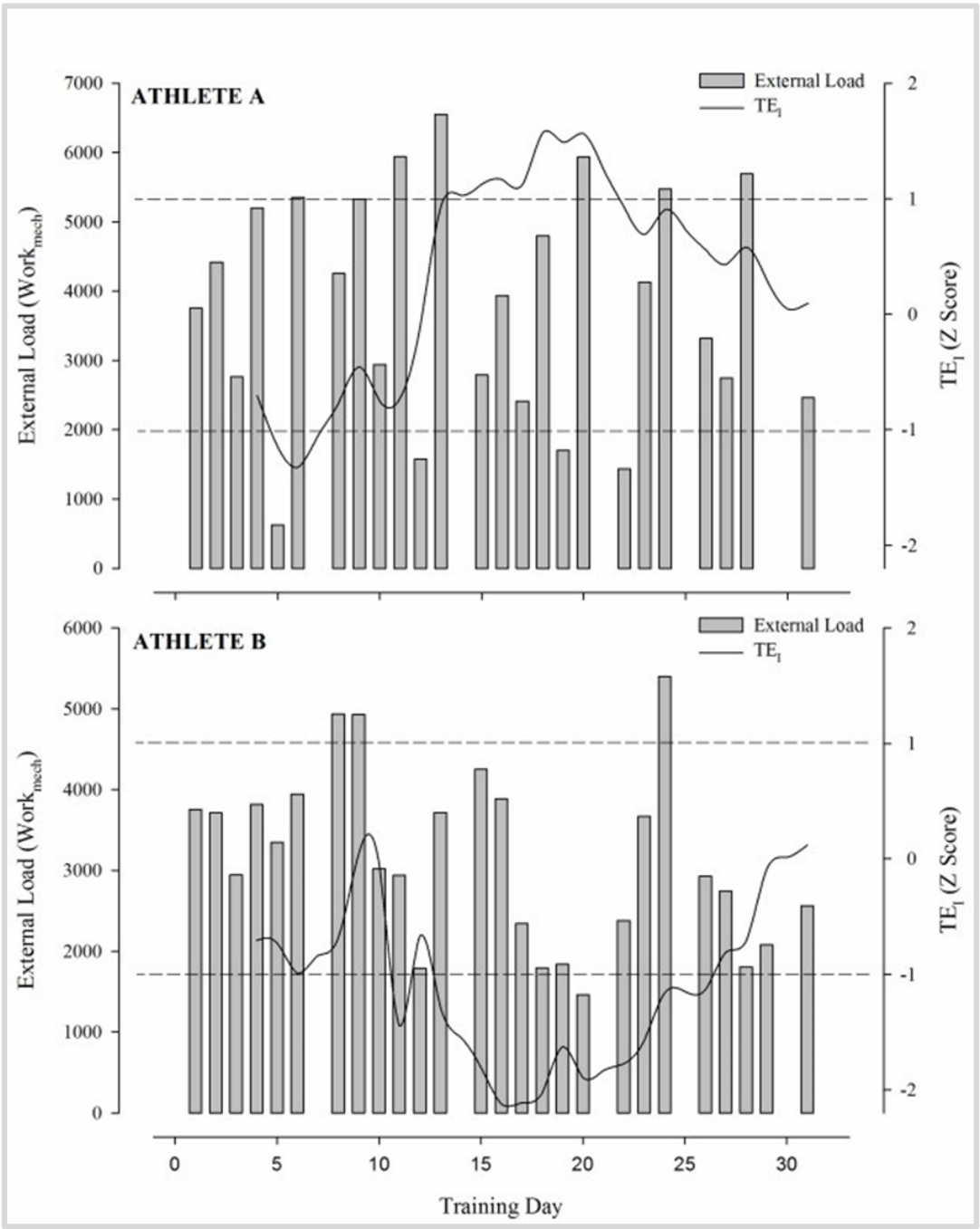


Note: * This indicates that the probabilities of seeing effect are more than 75%

The authors once again found a higher correlation with the chronic load values accumulated over the last 28 days when efficiency indexes are calculated using

heart rate (TRIMP index), compared to Rate of Perceived Exertion (RPE). As for the external load variables studied, it should be noted that a greater correlation exists with chronic load when efficiency indexes are calculated utilizing mechanical work variables that integrate velocity and acceleration variables such as metabolic power (represented as metabolic work in Figure 3.8) or distance covered at high metabolic power (represented as HS distance in Figure 3.8).

Figure 3.9. External training load (bars) and efficiency index (line) of two athletes during the first month of the preseason

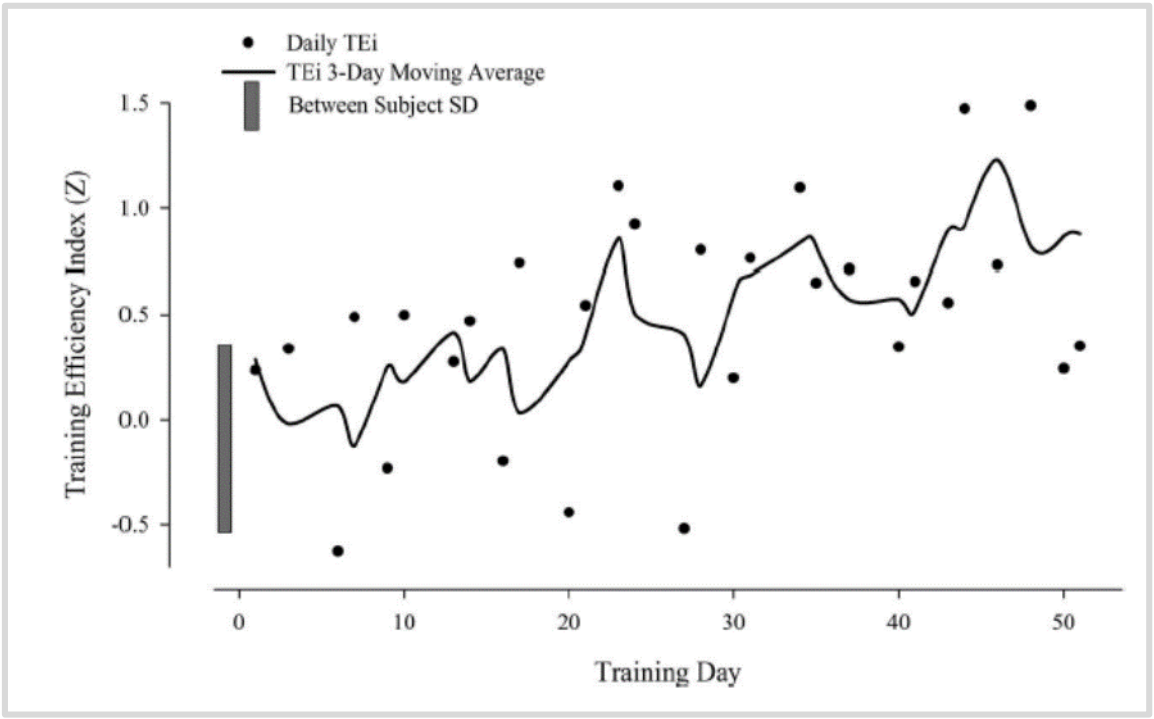


Note: In order to represent the efficiency index we've used the Z Scores.
Source: Retrieved from http://sportperfex.com/2018/02/20/how-you-should-be-using-gps-in-team-sports-part-2-do-less-the-training-efficiency-index/

We should be cautious and rigorous when interpreting these results. In Figure 3.9, we've recorded the external load and efficiency indicators during a month of training, where, at first sight, we can see how athlete A seems to correctly adapt, as his efficiency index increases, while athlete B seems to have a negative adaptation based on the decrease shown in the efficiency indicator. In Figure 3.8, we can observe certain relationships between the chronic load and the efficiency index, which could be a very interesting alternative to assess an athlete's level of physical condition.

However, as can be seen in Figure 3.10, the efficiency index varies greatly between different training days (Delaney et al., 2018). These fluctuations in the efficiency index should be studied in greater depth since a link to the athlete's state of acute fatigue was not found after studying its relationship to athletes' well-being, fatigue, and/or pain (Delaney et al., 2018). These authors indicate that this variability could be explained by the number of variables affected by heart rate, such as hydration, the ingestion of caffeine, or changes in environmental conditions, among others. Thus it seems that the analysis should not focus on short-term responses, but on chronic or long-term adaptations and therefore analyze efficiency index trends over time.

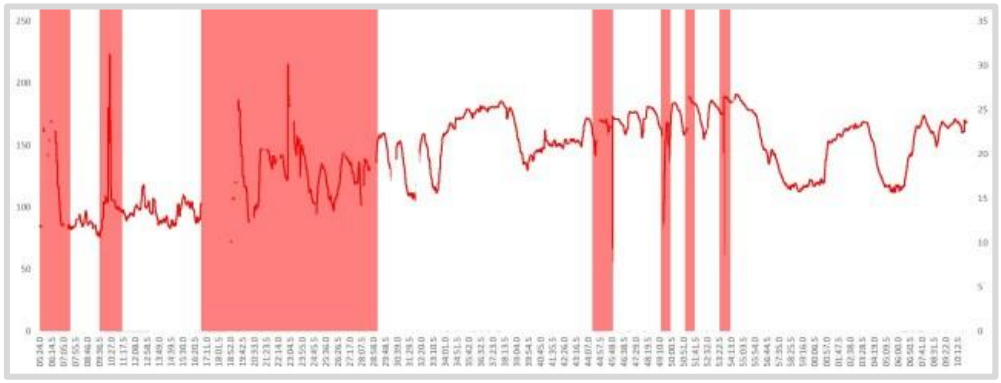
Figure 3.10. Example of the changes in the training efficiency index (TEi) calculated using mechanical work/iTRIMP 0.87 during a training period of 7 weeks in 38 professional rugby players.



Notes: The efficiency index in training is expressed in Z Score and it represents the team average. The black line represents the acute load of 3 days of training.
Source: Delaney et al. (2018).

When using the efficiency index we should be aware of a series of limitations. For example, if the external load variable integrated in the efficiency index is derived from a GPS signal, the static activities of fight or body opposition with adversaries that are energetically demanding but do not provoke displacement will be underestimated. Fighting, colliding and shooting, among others, are activities that will not be taken into account by GPS technology, and since they are high intensity, they alter the relationship between external and internal load, thus invalidating the efficiency index in the evaluation of the athlete's level of fitness. Moreover, we should ensure that the data integrated is complete as any problem that arises during the recollection (for example: interruptions in the activity record by the GPS if there are difficulty accessing the satellites, the pulsometer drops during training) will render the efficiency indicators as useless (Figure 3.11).

Figure 3.11. HR recording during a training session where the red stripes represent the part of the session where the pulsometry signal has been interrupted.



Note: The GPS recorded the velocity signal throughout the entire period of training, while heart rate monitoring was recorded for 60% of this time, thus jeopardizing the results.
Source: Retrieved from http://sportperfex.com/2018/02/20/how-you-should-be-using-gps-in-team-sports-part-2-do-less-the-training-efficiency-index/.

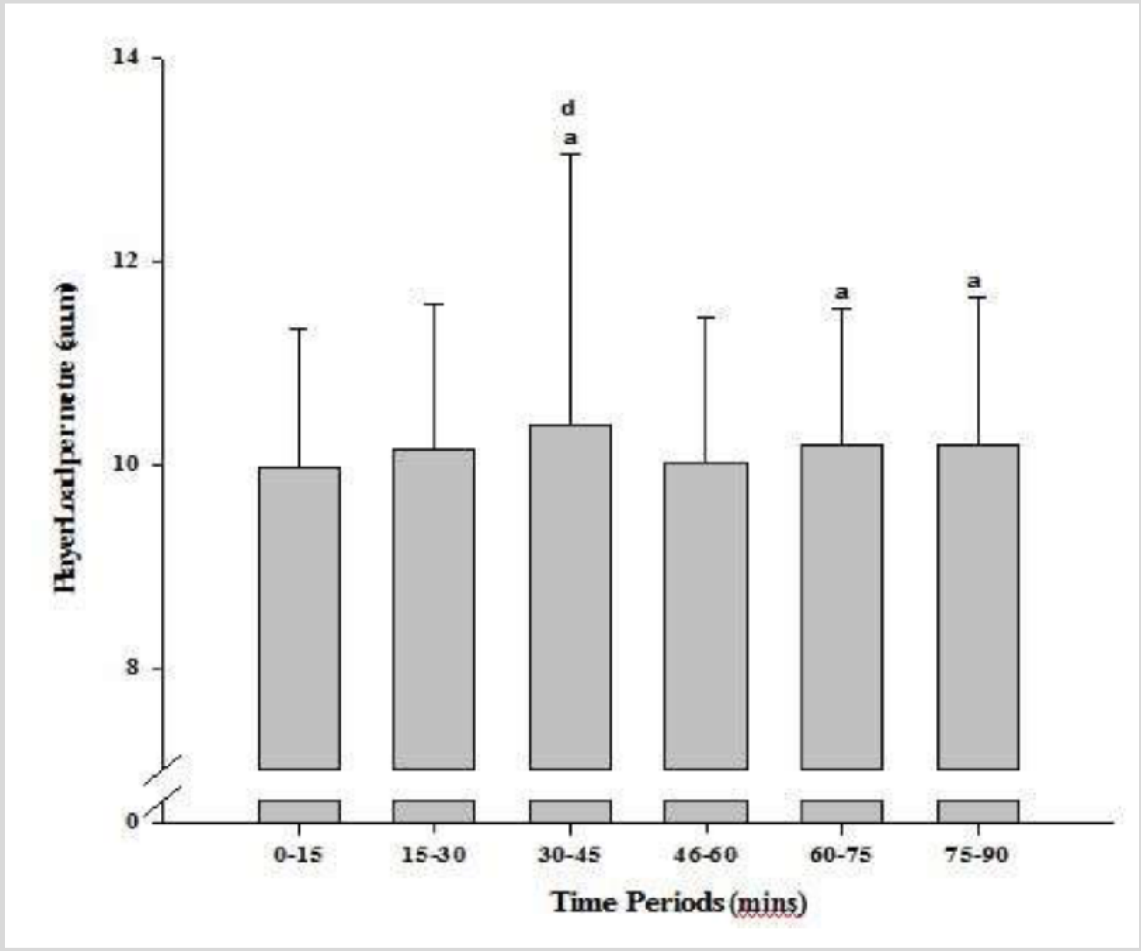
The example (Figure 3.11) refers to recording errors, in this case caused by the pulsometry signal, which could lead to the analyses derived from this signal having said error. For example, the TRIMP index of cardiovascular impact, and therefore the efficiency indexes that use indicators based on the heart rate signal as internal load variables. Accordingly, the use of the scale of the rate of perceived exertion could be an alternative that allows for increased consistency in records, although the validity of the efficiency indexes calculated with this variable is lower compared to the indexes calculated with variables based on heart rate, as is represented in Figures 3.7 and 3.8.

3.2 Indicators of Mechanical Efficiency. Mechanical Efficiency

Integrating information on external load indicators can also provide us with information that helps us in decision-making. In this respect, the first estimates were obtained by dividing the load indicator obtained through accelerometry (player load) by the total distance covered. As the match progresses, the distance covered decreases and so does the load indicator obtained from accelerometry, the player load (Barret et al., 2016). However, the ratio increases as the match progresses. In spite of the fact that both measurements have a high correlation, this relationship can be affected by fatigue. The increase in the mechanical efficiency ratio is justified by the authors on the basis of a reduction in stride length, which leads to a greater number of steps, and therefore a greater number of "recorded" impacts through accelerometry (Barret et al., 2016).

Analysis using mechanical efficiency indicators provides new ways of assessing our athletes with everyday practices or simple field tests. For example, we could make athletes run before training under standardized conditions to assess the alterations in their mechanical efficiency index, or even assess this at the end of the session to determine the possible effect generated by the activity undertaken during training.

Figure 3.12. Mechanical efficiency indicator obtained using the load indicator obtained from accelerometry and distance covered at different moments of the match



Note: The letter **a** indicates a significant increase in the 0-15 minute period, while the letter **d** indicates a significant increase in the 46-60 minute period.
Source: Barret et al. (2016).

In spite of positional differences in the ratio found in hockey (Polglaze, Dawson, Hiscock & Peeling, 2015) little research has been conducted in this field. However, this undoubtedly needs to be studied in depth in the coming years.

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