Module 3. Characterization of team sports with a focus on soccer. Analysis of physical demands

Unit 3.1 Analysis of acyclic sport

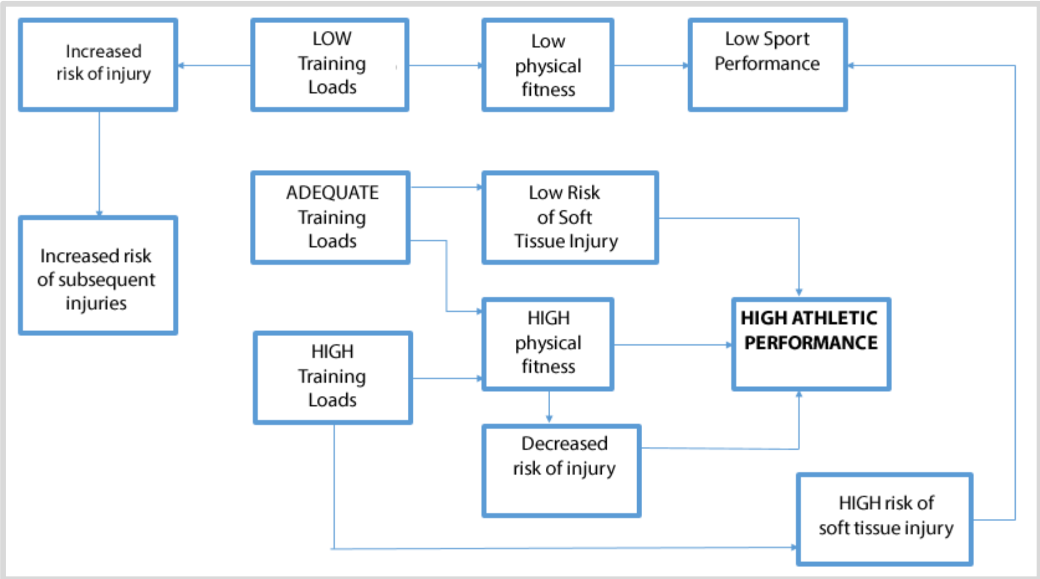
3.1.1 General characteristics of team sports

To understand and analyze the physiological responses of team athletes in their respective disciplines, we need to construct an accurate description of their distances, times, game modalities, etc. For this reason, we will show what the general qualities are for these types of activities in their acyclic condition. This will be done to arrive at more accurate conclusions about how these affect the performance of athletes on a general level and to facilitate an approach for each sport.

The primary reason for understanding this data is to make training programs and preparation of teams for competitions more efficient; perform in a manner that is sufficient to engage successfully in the competition, with the least energetic cost or risk of possible injury.

For many years, trainers and coaches of team sports have implemented training systems derived from track and field for the development of the physical qualities of their athletes without realizing the acyclic component that characterizes team sports. This practice, widely prevalent among high-level teams and coaches, may occasionally have resulted in two major problems: on the one hand, the development of athletes with strength profiles not suitable for optimal sports performance; and, on the other, perhaps more dangerous, to incur in overuse, by double-tapping the sources or deposits of energy available to cover the demands of the training. In relation to this, Malone (2017) it was asserted that those subjects with greater intermittent aerobic capacity have a lower risk of injury in elite soccer, although it would be unwise to transpose this association to the ability to exercise in a stable and continuous manner. This refers, as we said, to the specificity of the athlete's physical condition to the discipline he practices. Therefore, it is recommended to thoroughly monitor the training loads and perform an adequate periodization because the same absolute training load can be of greater or lesser risk according to the moment of the season in which the team finds itself. Moreover, in relation to the risk of injury, Gabbett (2016) Gabett asserts that the specific training load is vital in preventing injuries, and that the greater the intensity of training, the lower the risk of injury will be in team sports. Despite this, the risk of soft tissue injury is usually attributed to high intensity training and, therefore, it may be necessary to reduce the training load at certain times of the season. Gabett (2016) asserts that low training loads are associated with a higher risk of injury because they produce a decrease in the fitness of athletes. Once a player is injured, it becomes difficult for members of the medical teams and physical trainers to find the right moment to reintroduce the player into group training with his teammates due to the difficulty of defining the right training load to protect him from re-injury. This difficulty is since, if the player participates in training with loads for which he is not ready, he will have a high risk of injury, but if he remains at low loads he will not reach the appropriate physical levels to withstand the demands of competition.

Figure 1. Relationship between training loads, physical fitness, and injury risks



Source: Modified from Gabbett (2016).

Returning to the relationship between the specific physical conditions in each sport, according to Casas (2009), "maximum performance will be achieved by reaching a strength profile based on a training process that meets the specific characteristics of that sport." This is one of the criteria under which coaching staff must develop their training methodologies. Nor should we forget, as we said earlier, that the specificity of fitness is determined not only by the type of physical training that we indicate for the athlete but also by its absolute load. This includes, to a considerable degree, the load during competition.

By cyclic sports we mean those activities in which the same movement is repeated continuously from the beginning to the end of the activity. These include activities such as walking, running, swimming, pedaling, and rowing. In contrast, acyclic sports consist of integrating functions into an action which can be classified as simple or complex. Simple or pure acyclic sports are those in which a single motor pattern, action or combination of different unique actions is executed from the beginning until the end of the activity. These include pitches, jumps, weightlifting and gymnastics. On the other hand, we will focus on sports team in our study. Within compound or complex acyclic activities, we find team sports, boxing, wrestling, racket sports, etc., which we will describe in the next section.

General characteristics of acyclic sports

Following are the main qualities that characterize team sports as acyclic:

- Intermittent: this reflects the dynamics related to the constant stops and starts of the game. It is a quality subject to the rules of each sport that determines the times, forms, and distances of play.
- Situation: each action triggers several possible reactions and so on until the next pause in the game. In the case of individual sports like tennis, the response will be provoked in a single person (the opponent) or at most two, if we refer to the executor of the action. Therefore, a player may receive gestural information at the moment of

attack (as a deterrent) that makes him change his decision about the type of shot he will use and where he will aim. Using this example, we try to represent the infinite possibility of actions and reactions that can occur in each moment of play in a 1 on 1 sport. Now imagine what happens in team sports, in which the number of players and possibilities of action and reaction are greatly multiplied. It should be noted that not only the attacking team executes actions to provoke responses in the defending team, but that this also occurs in the opposite direction. Also, keep in mind that within each team there are several players running plays at the same time and generating reactions that are both collective and individual. Nor should we forget the presence and participation of the referees of the game, who make decisions to ensure both teams to adhere to the rules.

Team sports such as soccer are characterized by actions that present significant variations in intensity, duration, frequency, kinetics, and kinematics of muscular actions, with direct implications on cardiovascular, neuromuscular, and metabolic responses (Casas, 2009). Additionally, these sports are based on actions that have very specific movement patterns that require, for example, changes of direction at great speed or great accelerations and decelerations with high neuromuscular involvement. In soccer, for example, approximately 1350 different muscle actions were reported within a competition, including about 220 high intensity strokes with activity changes every 4-6 seconds (Mohr, 2003; Reilly, 1976).

3.1.2 Playing systems, playing models, characterization

The game model is the operationalization of play. Thus, game models determine how you are going to play and, therefore, give meaning to our training program. This is because the goal of preparation for competitions is to ensure that the team and each of its members are up to the challenges of the game in terms of its physical, cognitive, technical, tactical, and strategic aspects.

Therefore, we must ask ourselves: Is there a relationship between the style of play and the physical demands of competition? Of course. The style of play of each team will determine how they play and, therefore, will directly influence the distances traveled and the performance intensity that each player brings to competition as well as during training. In the latter case, physical and technical preparation is increasingly included within tactical-strategic tasks. The ideas of play brought to the game will determine the energy expenditure produced. Accordingly, some schools of thought, such as Tactical Periodization, propose making the game model the absolute center of training schedules at every level, area, and aspect. Therefore, we could say that depending on how much importance is given to the game model within the work methodology, it will come down to the relationship between it and the physical and physiological demands of training.

To reinforce this analysis, we must return to issues that relating to philosophy, e.g. the way that each coach thinks of conceives the game. Often, this will be included within a paradigm or school of thought and is based on a theory. The goal of a game model is to build, through training, a certain way of participating in the competitions based on certain principles that the coach will determine as the basis of the team's performance. During a competition or period, one must be able to adapt all areas and aspects that make up the process and the work program for a sport to this model. At the same time, within the same sport, and even within the same league, we find as many styles and manner of play as there are teams, including the possibility that a team will modify its game model from one game to another, at least from a strategic point of view. This game model concept is always aimed at achieving the desired sports performance and, therefore, the intended results. Therefore, it will be constantly analyzed primarily by the coaching staff of each team.

Naturally, Vázquez (2015) Vázquez highlights five key research fields in the pursuit of improved player and team performance. These are the following:

1) The design of protocols for the evaluation of physical performance.
2) The study of the injuries and processes that generate fatigue in the athlete.
3) The presentation of methodological proposals aimed at the analysis of the physical, technical, and tactical aspects of the game.
4) The detection of talents.
5) The study of the influence of different situational variables of the game on the performance and result obtained by the teams. (Vázquez, 2015).

These elements can help us understand what the logic of the game is and result in better performance. Considering the theme developed above where we explained the highly situational component of team sports, it is difficult to systematize or parameterize this analysis. For example, although we know how many meters a player runs during a match, at what average speed or with what energetic predominance they are executed, the number of passes per game (and how many of them are completed), the athlete's clinical history, and a sea of relevant data, we will not be able to parameterize their decision making, nor the reaction that this generates in other players (rivals and teammates) who are participating in the competition. Of course, this does not discourage us from continuing to investigate and work to continue improving both individual and collective athletic performance. Fortunately, it does makes clear that we will never be able to control the game completely.

Returning to the game model, it will ultimately be the one that will determine the physical-technical performance qualities of the players to select for an adult team well as those to be developed at the formative levels. The ideal case would be those institutions in which the game model of the first team determines a line of work at the formative levels. This creates, on the one hand, models for young players to follow as an element of learning within the institution and, on the other hand, allows the first division coach to find players more easily in the lower divisions to make up a professional squad.

3.1.3 Cognitive abilities in team sports

In regard to aspects that characterize complex acyclic or situational sports, we will refer to the concept of cognitive structure within sports training developed by Seirul.lo Vargas (2013): which is formed by "all the intra- and intersystemic processes that occur in the subject, which provide the possibility of optimizing their functionality to have all the information that emanates from any and all components of the various events that can appear in multiple environments and situations experienced during interactions in the game and in the trainings in order to extract what is necessary to process it in an way that puts it at their disposal in order to execute a possible motor action." With respect to these three possibilities of information processing, the author describes its functionalities as follows:

Cognitive Functionality 1: to extract all the information from oneself and from the specific environment both during the game and in training circulating through the systems that will allow him to identify the states and changes of any kind that are present at each moment of his active or passive intervention in events. These include: sensation, perception, representation, attention, and memorization (short and long term, sensory).

Cognitive Functionality 2: to treat, through processes of selection, differentiation, generalization, comparison, recognition, exclusion, inclusion, codification, and nomination, the information obtained by the aforementioned systems, through the following strategies:

- **Participation:** during the interactions of each motor and non-motor process experienced.
- **Socialization:** in interactions with other persons who take part in the exercise.
- **Verbalization:** in established communication both verbal and non-verbal.
- **Conceptualization:** involves knowing these experiences through the techniques used and the strategies achieved.

Cognitive Functionality 3: have the information to move to the plane of action within the game environment, transforming it into what is desired and expected. Some authors call them higher functions. These are: to argue, to testify, to judge, to learn, to make decisions, to communicate, to project, to create.

We must emphasize the constant interaction between these three cognitive functions. As one obtains the information, one is extracting and analyzing new information at the same time.

The objective for making clear how the cognitive structure of athletes works is to emphasize the constant variability of situations that are operating both in training and in competition for acyclic activities that are the product of decision making.

Unit 3.2 Analysis of physical demands in competition and training

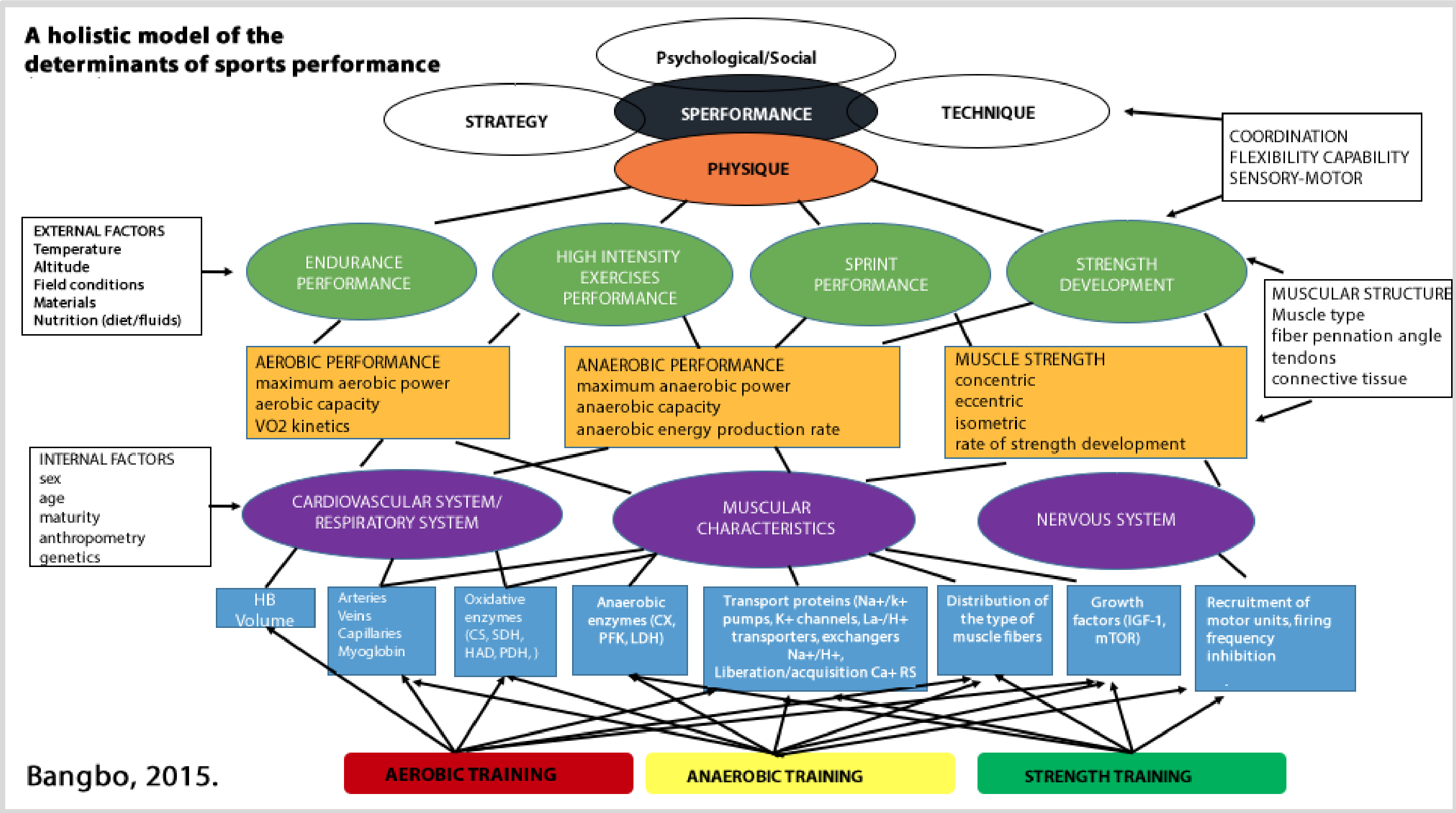
3.2.1 Factors determining physical performance

Performance in most sports is determined by the technical, tactical, psychological, and physiological characteristics of the athletes. In some disciplines, such as 100-meter races, marathons and rowing, the physical abilities of athletes strongly influence performance, while in others, such as ball sports, technical-tactical skills can compensate for some deficiencies in levels of physical fitness. However, in most sports, athletes need very good physical skills to meet the demands of competition and thus allow them to take advantage of their technical-tactical qualities.

Under optimum conditions, the demands of the sport are strongly related to the physical capacity of athletes, which can be divided into four categories: (1) endurance performance, (2) ability to exercise at high intensity for extended periods of time, (3) ability to sprint and (4) ability to develop high levels of strength through actions such as kicking a ball in soccer, or jumping and hitting in volleyball. In turn, not all categories are relevant in all sports. For example, the endurance component is not important for a 100-meter runner.

The capacity that determines the performance in each type of sport is based on the characteristics of the respiratory and cardiovascular system as well as the musculature in conjunction with the nervous system. The cardiovascular system is important for the transport of oxygen to the skeletal muscles while the muscular system plays an important role in the mechanical and metabolic behavior during exercise. Similarly, mitochondrial enzyme levels as well as capillary density exert a strong influence on aerobic performance. Sex, age, anthropometry, and maturation also determine respiratory, neural, muscular, and cardiovascular characteristics when dealing with children. Additionally, some environmental factors such as temperature, humidity, and altitude as well as nutritional intake before exercise can influence the performance of athletes (Bangsbo, 2015).

Figure 2. Holistic model of determinants of sports performance

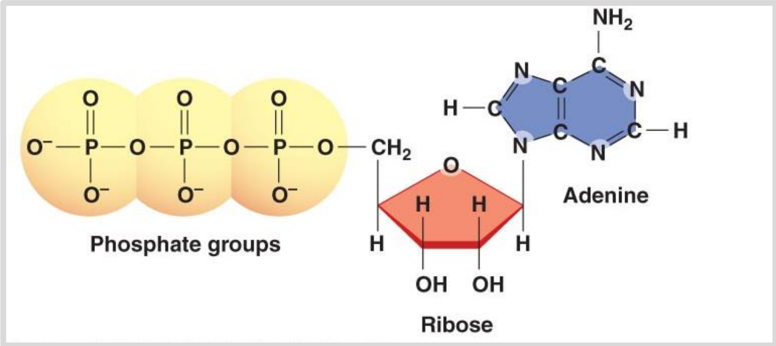


Source: Bangsbo, 2015.

3.2.2 Analysis of the physiological demands of team sports

When we perform muscle work, there is only one molecule that can handle the production of mechanical energy necessary for the interaction of contractile proteins: ATP or adenosine triphosphate. This molecule, composed of a nitrogenous base, a sugar of 5 carbons and a phosphate group, is present in very low concentrations in humans and therefore must be permanently resynthesized. Although this seems to be a contradiction, this ability to resynthesize ATP represents a biological advantage as the storage of large amounts of this metabolite in the organism would mean a high extra weight since ATP is a molecule of great size and weight (1 mol ATP = 503g), which in turn would increase energy demand. Thus, ATP is prepared to be degraded and resynthesized permanently thanks to the existence of energy reserves provided by human food sources. These reserves constitute a group of organic molecules that are stored in the body in different chemical forms from those which are ingested. These are: creatine, which is stored as phosphocreatine (PCr); glucose, which is stored as glycogen; lipids, which are stored as triglycerides and proteins, which do not have a storage deposit, although they may represent an energy reserve in certain emergency situations. These energy reserves play a fundamental role in the energy supply for ATP resynthesis as they are subject to degradation by various sets of enzymes, known as energy systems, whose role is the catalysis of these reserves to produce energy for ATP resynthesis.

Figure 3. ATP molecule



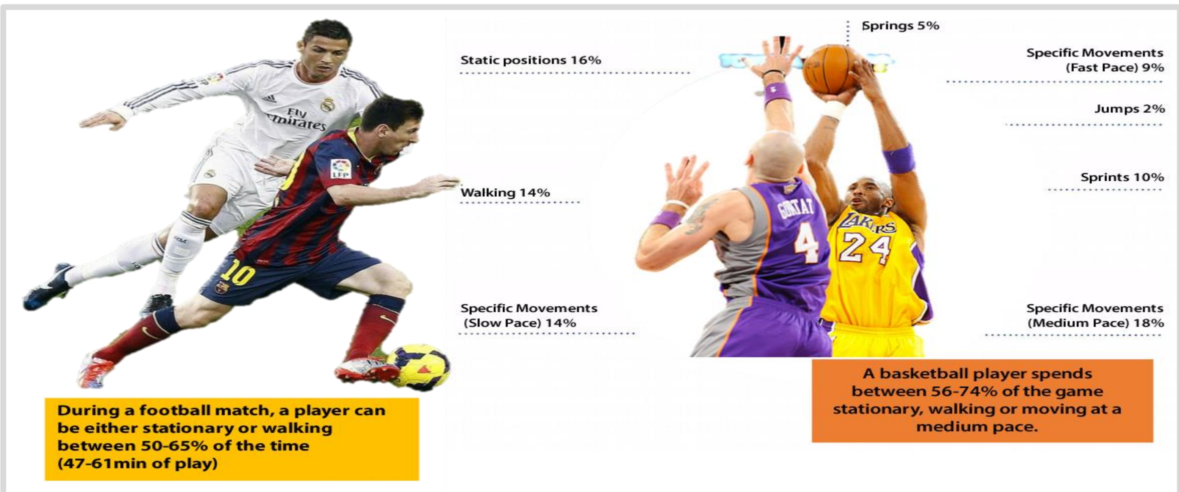
Source: Pearson, B., 2008.

Energy systems

To define them conceptually, we could say that there are three fundamental energy systems: the phosphatic system, in charge of degrading PCr; the glycolytic system, responsible for degrading glucose or glycogen; and the oxidative system, responsible for degrading glycogen, glucose, triglycerides, or proteins. Interestingly, these energy systems or groups of enzymes are characterized by degrading substrates at a certain rate, thus being able to resynthesize ATP at different rates. Although all act in tandem in what is known as an energetic continuum, some will predominate over others when performing sports activities at different intensities or durations, with intensity being the one that will predominantly determine the energy substrate to use.

When analyzing the strength profile of team sports, it has been noted that during the games, players spend most of the playing time walking or at low intensities, which indicates the predominance of the aerobic systems during the matches. For example, during a soccer match, a player may spend between 50-65% of the time either standing or walking (47- 61 min per match). Despite the clear aerobic dominance during the encounters, the definitions or actions with the greatest repercussion in these sports happen at high intensities, e.g. sprints, strikes, passes or headers. Therefore, understanding physiology during high intensity efforts becomes of great importance for training in team sports.

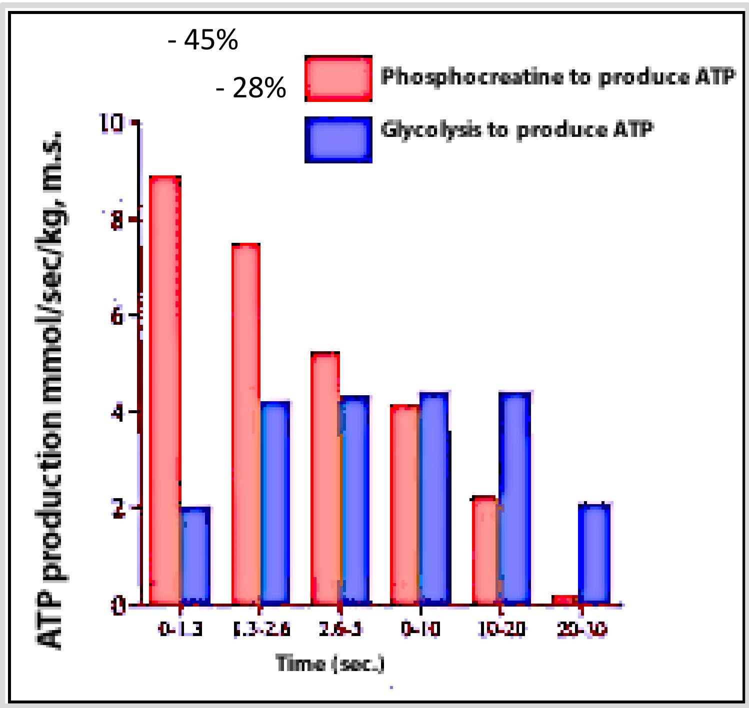
Figure 3. Strength profile during soccer and basketball competition



Source: Delextrat, 2011.

Among the energy systems that have the highest potency of ATP resynthesis are the phosphagen system and the glycolytic system. It is important to emphasize that the importance of having elevated rates of ATP resynthesis in this type of sport is due to the need to apply high levels of force in very short times (100-200 milliseconds), which will translate into high muscular contraction intensities. For this reason, it is important that these sports to train the physiological and locomotor systems to improve the rate of force production per unit of time or rate of force development (RFD). In this sense, since the maximum ATP resynthesis rate occurs between 0-1.3 sec, we can deduce that within that time the greatest effort intensities will occur during a match. However, a paradox arises here: if a player reaches his maximum speed of sprint in times near 5-7 sec, why are the rates of maximum resynthesis of ATP or energy production occur in considerably shorter times (0- 1.3 sec)? Naturally, this happens due to fact that the maximum energy level is not determined by high moving speed rates, but rather high acceleration rates, which are given precisely at the moment inertia stops, during the first second of muscle contraction. In the graph in the following figure, we see that from 1.3 sec, the rate of production of ATP per unit of time decays by 45% and then by 28% to 2.6 sec. Understanding the physiology of effort in these terms indicates the importance of training under the necessity of: (1) maintaining a high rate of ATP resynthesis per unit time, (2) delaying the generation of exercise-induced fatigue.

Figure 4. Interaction between phosphatic and glycolytic energy systems during the first 30 sec of maximum voluntary muscular contraction

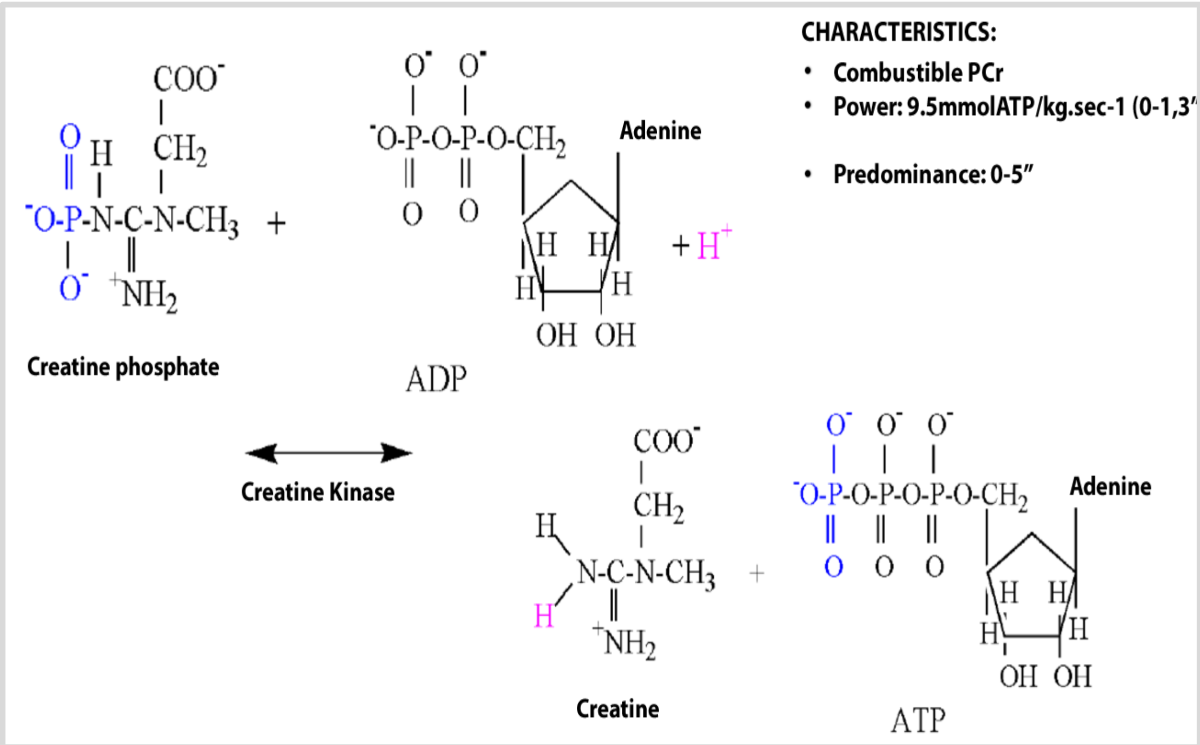


Source: Prepared by author

Importance of the phosphagen system in atp resynthesis and intracellular acidosis damping

Due to its biochemical characteristics, the enzymatic degradation system of PCr stands out for having two important properties: the first is its high ATP resynthesis potential as it can resynthesize up to 9.5 mmol ATP/kg dw.seg-1, a potency which is reached within the first second of muscle contraction; the second is its ability to dampen intracellular acidosis caused by the release of H+ that occurs due to ATP hydrolysis. The training of this energy system will allow a high rate of resynthesis to be maintained while delaying the onset of exercise-induced fatigue. The importance of maintaining a potent resynthesis system based on phosphagens is that each intermittent effort can be started with a higher intensity if a higher amount of PCr has been resynthesized than is degraded. To do this, we must know the kinetics of degradation and resynthesis of PCr and then consider the importance of maintaining high reserves of PCr in the body.

Figure 5. Resynthesis of ATP and damping of H+ from phosphocreatine

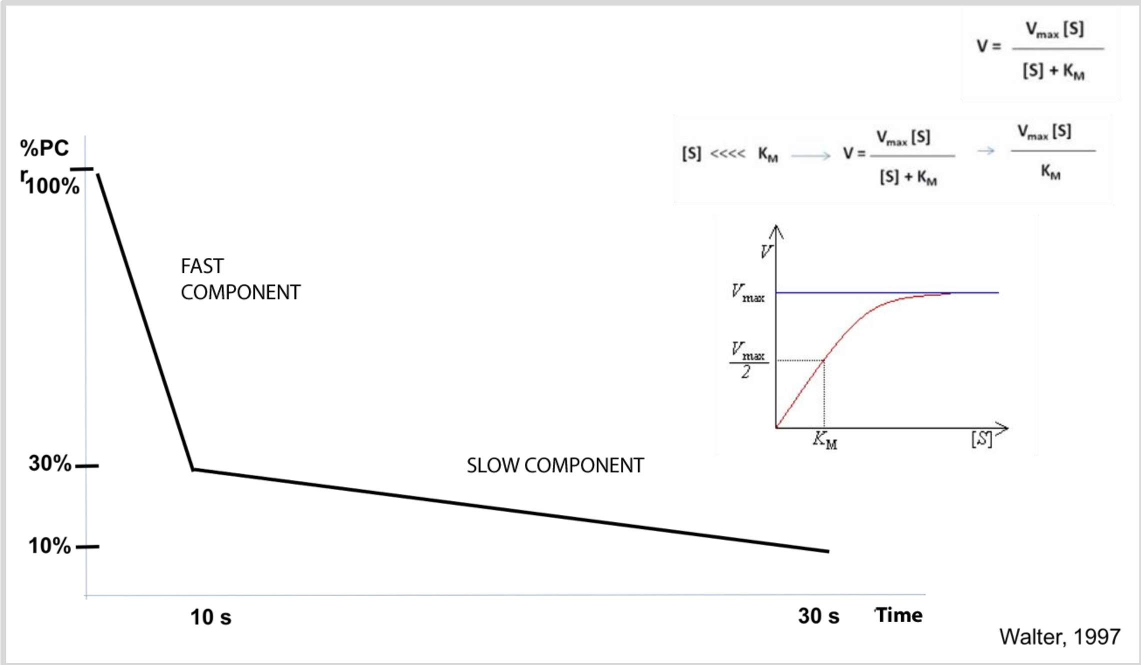


Source: Adapted to https://goo.gl/Mn6Fnz

Kinetic degradation of PCr

The degradation kinetics of PCr has been observed to occur in biphasic form with a fast phase of approximately 10 sec duration where 70% of PCr is degraded and a slow phase of 20 sec where the remaining 30% is degraded. The characteristics of this PCr catalysis rate are determined by the Michaelis Menten constant of its unique enzyme, creatine kinase (CK), which determines that CK will increase its activity proportionally to the availability of the substrate (PCr). This means that the higher the availability of PCr, the high the activity rate of CK, whereas when the substrate depletes, the rate of CK activity also decreases. Therefore, it is very important to train our players to be able to resynthesize large amounts of PCr during a match. This resynthesis occurs essentially during pauses for recovery.

Figure 6. Phosphocreatine degradation kinetics

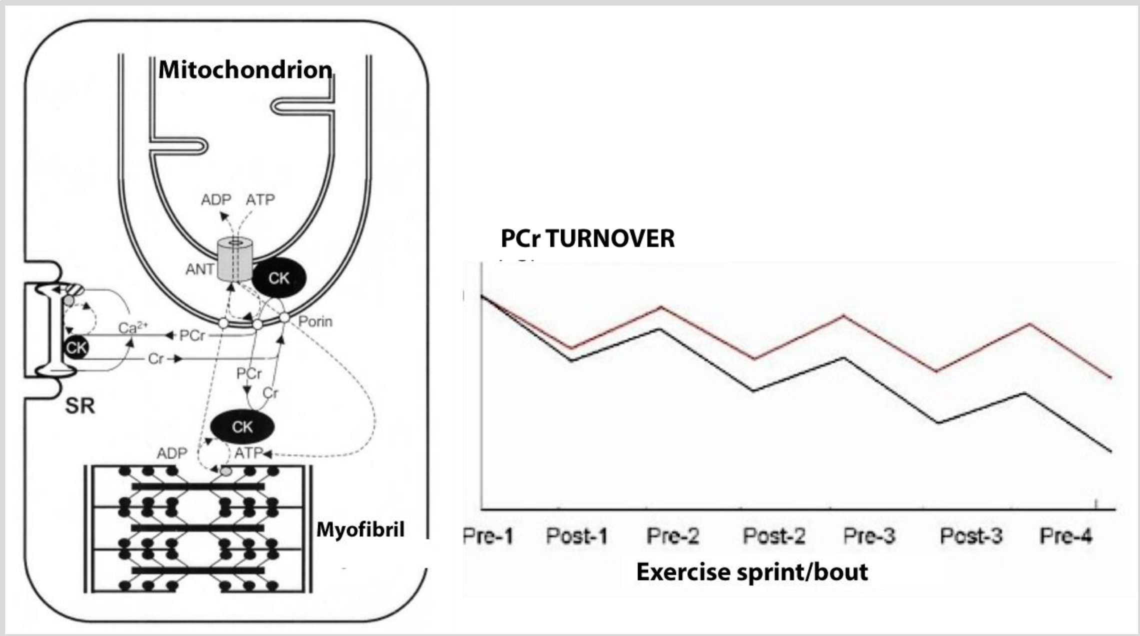


Source: Walter, 1997.

How to improve the ATP resynthesis rate from PCr during pauses between intermittent exertions?

It has been known for a long time that PCr resynthesis occurs thanks to the energy input from the degradation of a mitochondrial ATP molecule through a mechanism dependent on aerobic metabolism. Therefore, higher PCr resynthesis rates will be obtained in those subjects with better aerobic capacities, determined by a higher mitochondrial density, especially in Type II fast fibers where PCr is depleted. Thus, mitochondrial density could be a limiting factor for the rate of ATP resynthesis by anaerobic pathways as in the case of the phosphagen system. In the following figure, we observe on the left the mitochondrial resynthesis loop of PCr. On the right is a graphical representation of the strength profile of two athletes in relation to turnover of PCr along four repeated sprints. As one can see, the athlete of the red line, having greater resynthesis power between sets, can maintain a higher strength profile, allowing us to observe a clear advantage in relation to his adversary. In short, if we want to achieve high demands of muscular contraction we must degrade a lot of Phosphocreatine but also have the capacity to resynthesize it at a high rate during recovery efforts, a goal that can be achieved with high mitochondrial biogenesis in fast fibers. In turn, these facts suggest the importance of supplementation with creatine during certain times of the season in athletes who practice intermittent type sports.

Figure 7. Mechanism of mitochondrial resynthesis of phosphocreatine

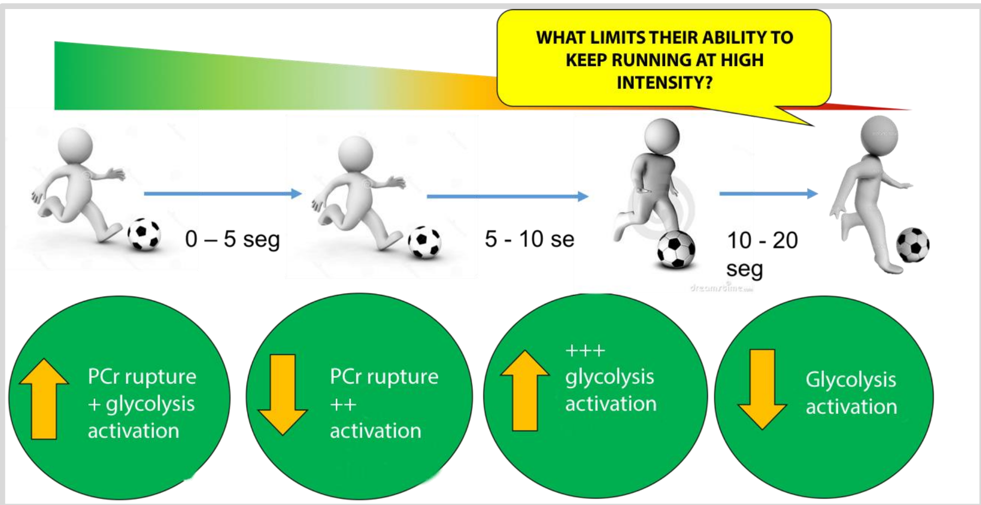


Source: Elaborated by author.

What determines the fall in ATP resynthesis potential after the first few seconds of muscle contraction?

The fall in the [PCr], together with the accumulation of ADP, AMP, Pi and catecholamines, strongly activate glycolysis, after the first few seconds of muscle contraction. This allosteric activation of glycolysis by PCr degradation prevents the maintenance of high effort rates for large periods of time, which implies a physiological need for the athlete to recover if he wants to repeat intense efforts again. The power of ATP resynthesis will deteriorate as more powerful energy systems lose their predominance due to a series of ionic and enzymatic phenomena that finally result in an inhibition of the electrical discharge of the spinal motor neurons on the muscular fibers. Thus, the loss of potential during high intensity efforts is due to intrinsic limitations of anaerobic metabolism. This inevitably leads us to the concept of Anaerobic Speed Reserve.

Figure 8. Limiting Factors of Metabolic Potency in Short, High-Intensity Efforts

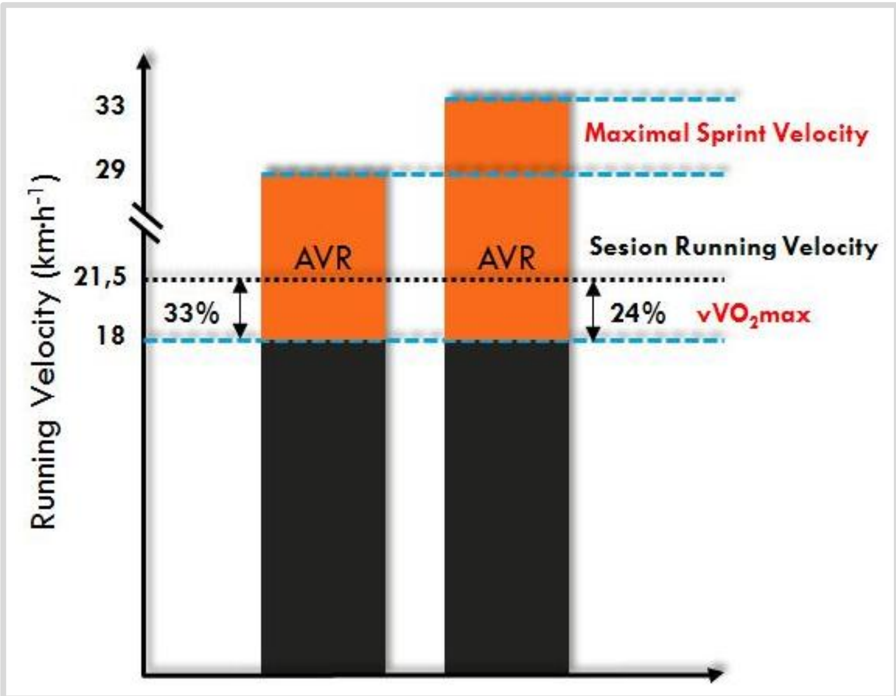


Source: Elaborated by author.

Anaerobic speed reserve: what is it and what is it for?

Proposed by Bundle and Billat in the 2000s, the concept of Anaerobic Speed Reserve (ASR) represents a "reserve" of race velocity once an individual has reached their velocity associated with maximal oxygen uptake or vVO2max (i.e., the difference between the maximum sprint speed and the vVO2max). Thus, subjects with similar vVO2max values may have different sprint velocities, which determines their ASR. Furthermore, the amount of energy derived from the anaerobic metabolism that will be available for a series of high intensity exercises will also be different. As we said earlier, greater intensity of muscle contraction produces greater falls in ATP resynthesis power. Therefore, an increase in the dependence of the anaerobic metabolism results in a decrease in the power production during successive muscular contractions, which Is evidenced by alterations in neuromuscular activity. The physiological adaptations associated with an increase in ATP resynthesis mechanisms by aerobic pathways may be associated with an increased ability to resist fatigue during repeated sprint exercises.

Figure 9. Anaerobic velocity reserve of two athletes with the same vVO2max

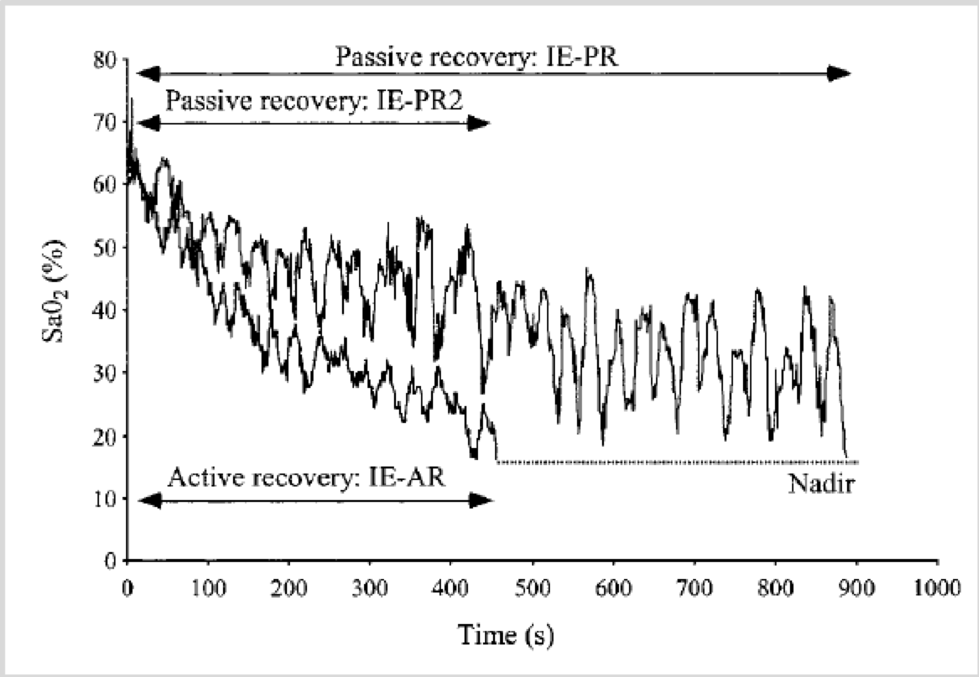


Source: Recovery from https://goo.gl/vY6T5i

Recovery and resynthesis of PCr

The type of recovery will inevitably affect the PCr resynthesis rate, and this variable can be controlled in team sports training and to a much lesser extent during matches or competitions. According to this, it has been observed that the passive recovery between efforts allows a greater recovery and resynthesis of energetic substrates. The mechanisms involved in this phenomenon could have to do with a restriction in the reoxygenation of hemoglobin and therefore the resynthesis of PCr during the active recovery pauses. Thus, the bioavailability of oxygen mediates its effects on the performance of sprints increasing the rate of resynthesis of PCr during the pauses of the exercise.

Figure 10. Hemoglobin reoxygenation rates in passive or active pauses

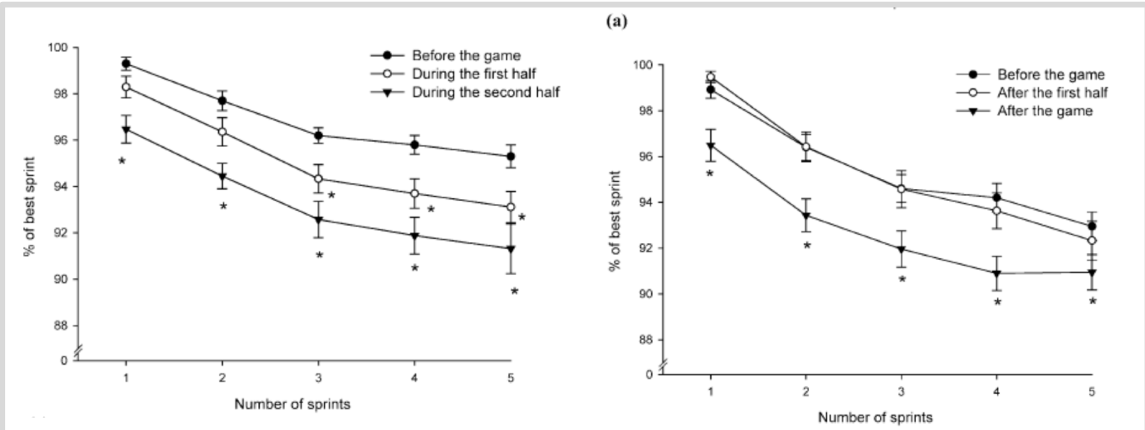


Source: Elaborated by author.

How does fatigue develop in acyclic sports?

In a famous study developed by Krustrup et al. (2006), they tried to observe how fatigue developed in team sports. Through a series of neuromuscular measurements, they could observe that fatigue during this type of effort occurs in the short term, after high intensity intra-game efforts (left figure) and in the long-term, towards the end of the game (right figure)

Figure 11. Temporal development of short- and long-term fatigue in soccer, measured by performance of sprints at different points in the competition

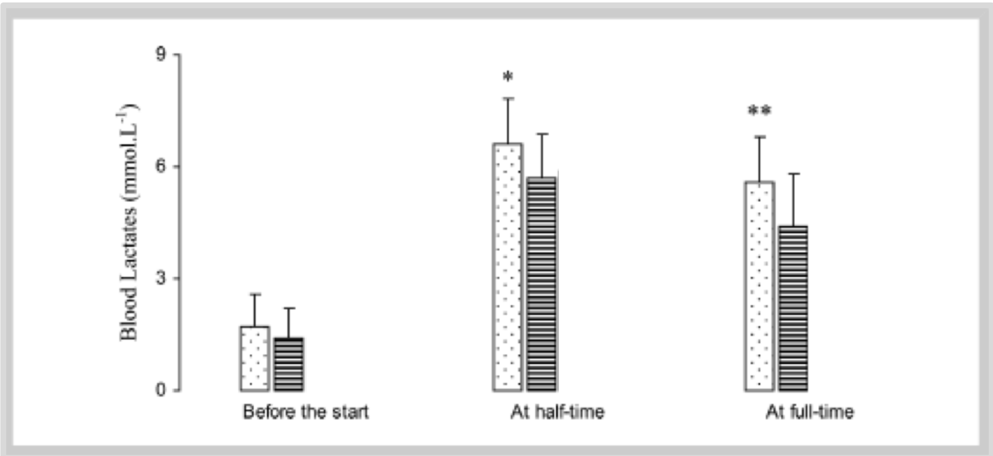


Source: Elaborated by author.

In relation to acute intra-exercise fatigue, it has been historically determined that this is due to the accumulation of the waste product of predominantly anaerobic metabolism during high-intensity efforts, which consists mostly of lactic acid accumulation. Some theoretical work of the last decade asserted, however, that lactic acid cannot be formed due to physiological pH in humans given its acid dissociation constant (pKa). Thus, the species formed would be lactate and not lactic acid which could not release H+ and cause acidity or fatigue given its conjugate base condition. Other recent theories (Lindinger, 2008) coincide with lactate and non-lactic acid formation in the body, although they suggest that these metabolites as well as others may exacerbate ionic changes (K+, Cl-), modulate ion channel conductance (Na+/K+, Katp, ClC-1) or to influence ionic sensitivity processes such as sarcolemma excitability, contributing in another sense to the occurrence of acute fatigue during exercise by generating physicochemical changes in water content.

Regardless of its contribution in fatigue mechanisms, the production of lactate in an organism is fundamental for the redox potential maintenance and the corresponding glycolytic potency of ATP resynthesis. In addition, lactate serves as a fuel and can be oxidized in other tissues for purposes of energy production in the form of ATP or glycogen via hepatic neoglucogenesis. Thus, lactate production is indispensable for the maintenance of high muscle contraction intensities. Studies with basketball players (Abdelkrim, 2010) have observed that elite athletes (white bars) have higher lactate values after the first half as well as at the end of the game when compared to lower level athletes (striped bars).

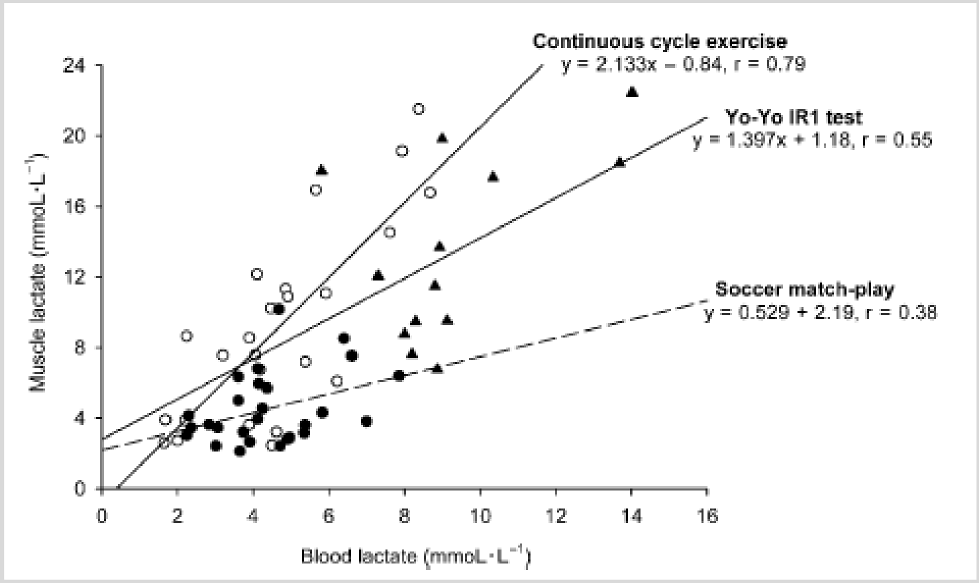
Figure 12. Average lactatemia values in amateur and elite basketball players during different moments of the game



Source: Elaborate by author.

Independent of this, it appears that blood lactate assessments do not reliably represent what happens within the muscle fiber when it comes to intermittent type efforts, limiting the determination of blood lactate repeatedly over time during these type of efforts (Krustrup, 2006). Unlike what happens during continuous type efforts, the difference between lactate production and removal during intermittent efforts seems to affect the coefficient of variation between lactate samples obtained under these conditions. This means that during intermittent exercise, blood lactate levels may be high despite relatively low muscle levels. It may also be the case that the closer together the blood samples are taken, the greater the differences between these two concentrations.

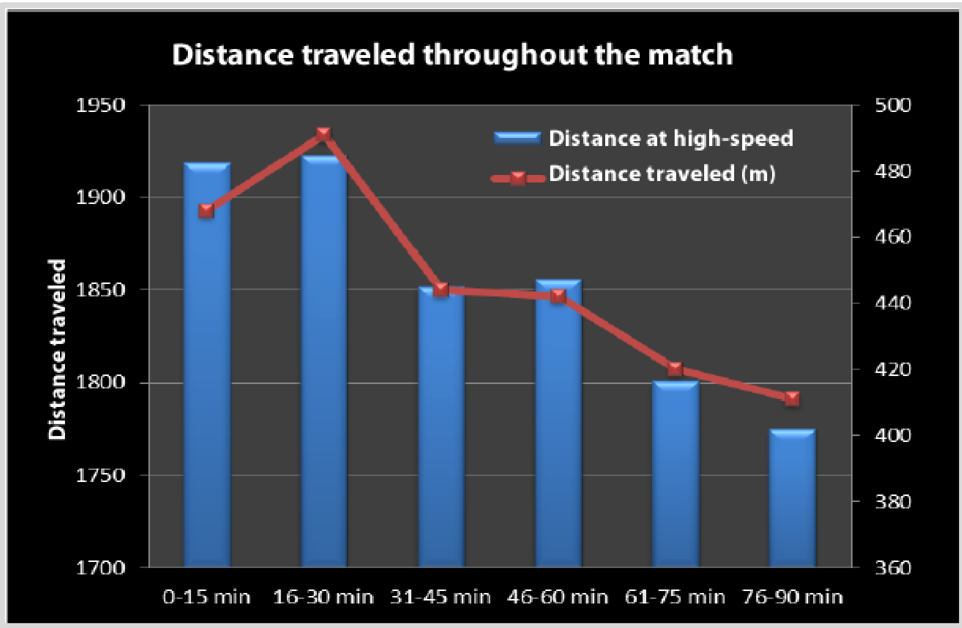
Figure 13. Correlation between blood lactate and muscle values in different types of effort. The black dots represent lactate values during a soccer match, the white points during a continuous cycling test, and the triangles during a Yo-Yo test with intermittent recovery



Source: Elaborate by author.

Finally, long-term fatigue during this type of effort is determined by three main factors: muscle glycogen depletion, hyperthermia, and dehydration, the first being the most common if one is playing in temperate environments. This long-term fatigue can be observed in relation to the total distance traveled towards the end of the match as well as the distance traveled at high speed. Strategies to prevent this type of fatigue recommend that one maintains a high aerobic fitness in players as well as eating a high carbohydrate diet and preventing dehydration and hyperthermia by consuming pre-exercise fluids and developing strategies to combat the heat.

Figure 14. Total distance covered at high intensity throughout the match. Taken from David Casamichana, 2014; adapted from Carling, 2010



Source: Adapted from https://goo.gl/CnCKEu.

3.2.3 Description of the physiological demands of soccer and other team sports

General effort profile in team sports

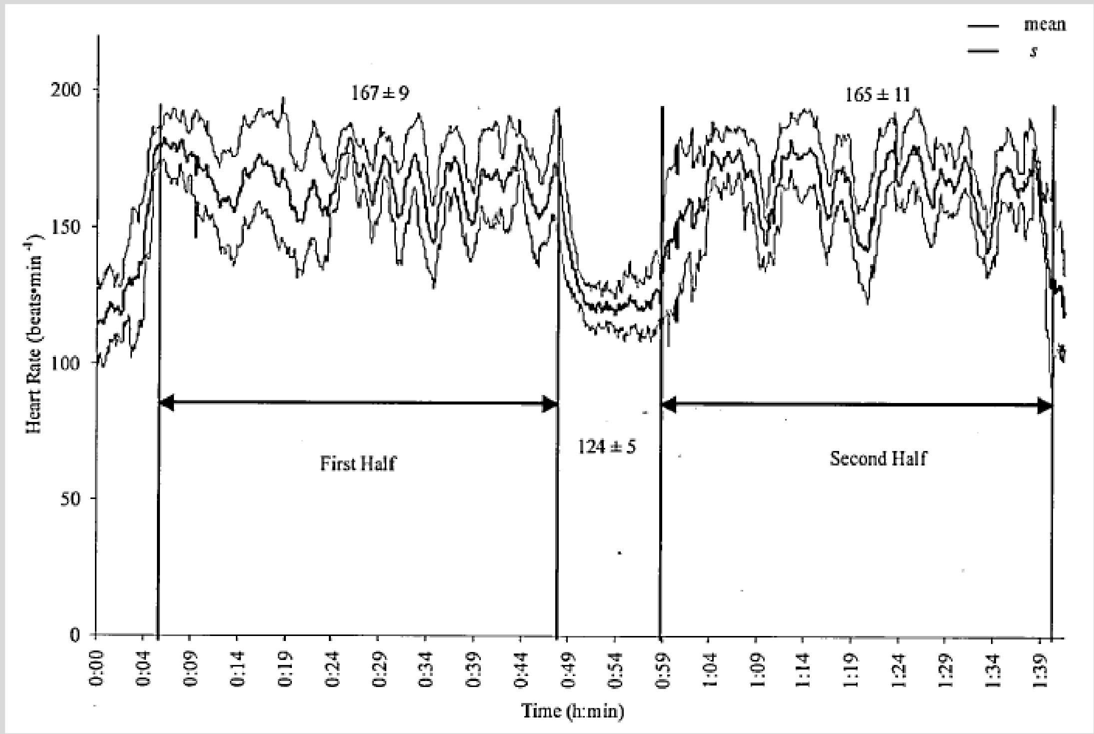
Basketball and rugby

The autonomic nervous system's responses can provide us with very useful information about the organism's functional adaptations to physical exercise (Aubert, Seps and Beckers, 2003). However, the HR (heart rate) response pattern to changes in intensity during a continuous exercise and an intermittent exercise is notably different, which can lead to differential adaptations in the autonomic nervous system between athletes that practice one type of sport or the other (Ostojic et al., 2010).

Thus, it would be helpful to understand whether heart rate can be a useful parameter for assessing strength profile in intermittent sports. On this topic, Ben Abdelkrim, Castagna, El Fazaa and El Ati (2010) have observed that the HR response was greater in a group of basketball players at an international level when compared with players at the national level. The higher level of a group of athletes may be associated with greater cardiovascular stress and thus, a greater HR response. These authors concluded that HR represents a highly useful index for assessing global physiological stress during a match, even though this variable can be easily influenced by other factors like anxiety, stress (Tumilty, 1993), nutritional status, and temperature (Gilman, 1996).

When strength profiles are assessed among homogeneous groups, the results can be contradictory. For example, in rugby, Coutts, Reaburn and Abt (2003) observed that there were no significant differences in average HR nor in time passed at moderate and high intensity between the first and second half of a semi-professional match. However, Helgerud, Engen, Wisloff and Hoff (2001) observed that in soccer there were more time spent in zones of higher HR in the first half when compared with the second half, and that this response was even more accentuated after an 8-week period of high intensity training at intervals.

Figure 15. Average heart rate during a semi-professional rugby match



Source: Coutts et al., 2003.

During play, basketball players maintain a high average heart rate (HR), ranging from 165 to 180 beats/minute (bpm), while sometimes reaching a maximum theoretical HR (220 ppm-age). Values of 150 ppm are observed during pauses (stopped ball). According to McInnes, et al. (1995), average HR during play time was 168 ± 9 ppm (89% HRmax.). During 75% of this time, 85% of HRmax was exceeded, while 50% of the time was performed at HR greater than 90% of HRmax. 15% of the time remains at a HR close to the maximum, i.e., above 95% of its HRmax. The previously mentioned values correspond to working time or the moments in which the ball is in play. On the other hand, minimum values were found during free throws and dead times in which the HR descends to 70-75% and 60% of the HRmax., respectively.

The heart rate has an intermittent behavior due to the short playing times with equally short breaks which are prevalent in this discipline.

In relation to this, Barrios (2002), in a study carried out after observing 10 games of the ACB and Copa del Rey in 2000 and 2001, counted an average of 76.1 actions versus 72 pauses. With the objective of designing the training schedule and its loads, this is a fact to consider. The average time was 30.7 seconds during play and 33.4 seconds during breaks. This establishes that the ratio of work to pause in basketball is 1:1. This is relevant for the handling of intermittency in the design of the trainings, especially those that focus on resistance. 45.5% of the actions in the game lasted between 1 and 20 seconds, and 28% between 21 and 40 seconds. According to Barrios (2002), approximately 57% of pauses are due to personal fouls.

In terms of aerobic power, it is lower than in other predominantly aerobic sports. On the other hand, within the same sport, we found that the highest levels of VO2 occur in the point guard or guards with 65.5 ml/kg.min against 57.84 ml/kg.min in the small forwards (McInnes et al., 1995). McInnes (1995) found an average lactate level of 6.8 ± 2.8 mmol/L within which values of up to 13.2 mmol/L were found. Independent of these average values, we must clarify that the contribution of the glycolytic pathway, which is where lactate comes from, varies considerably depending on the moment of the game as well as between games. This is mostly in competitions such as the NBA, where one can play up to 3 or 4 games per week.

With changes in the rules came changes in physical capabilities. E.g. shortening the time of possession (from 30 to 24 seconds) increased running volume due to the constant change of ball possessions. Moreno (1987) determined that the distances traveled in competition are 6104 m for point guards, 5632 m for small forwards and 5552 m for centers. These data are complemented by the velocities and intensities of the distances run, arriving at the conclusion that the greatest number of actions, regardless of the position on the team, are carried out at speeds between 1 and 3 m/s.

Soccer

"Soccer, as a large-field sport, involves intermittent high-intensity efforts, meaning repeated actions involving work/pause that are distributed acyclically throughout the game, with both aerobic and anaerobic energy systems being used jointly (Bangsbo, Mohr and Krustrup, 2006). In this sense, a rate of between 1000-1400 short duration actions that change every 3-5 seconds have been reported during a football match that involve a wide variety of actions with and without the ball e.g. running at different speeds, feints, tackles, and all other actions (Iaia, Rampinini, and Bangsbo, 2009; Mohr, Krustrup, and Bangsbo, 2003), all of which occur unpredictably depending on the circumstances of the game (Drust, Atkinson, and Reilly, 2007)." (Casamichana, 2014)

"Soccer players have a great ability to make intense efforts repeatedly (Bangsbo, Iaia, and Krustrup, 2008). Players are also required to develop important velocity, muscular strength, power, agility, and maximal aerobic power while at the same time demanding a great number of technical and tactical-decisional skills (Rampinini, Imperrizzeri, Castagna, Coutts, and Wisløff, 2009). The maximum oxygen consumption (VO2max) of elite players approaches values between 55-70 mL/kg*min-1, with individual values above 70 mL/kg*min-1 (Davis, Brewer, and Atkin, 1992; Reilly, Bangsbo and Franks, 2000; Wisløff, Helgerud and Hoff, 1998), placing the anaerobic threshold in elite players between 80-85% of the VO2max and 80-90% HRmax (Helgerud, Engen, Wisløff and Hoff, 2001; Stølen, Chamari, Castagna and Wisløff, 2005). In terms of intensity of play, many studies have evaluated heart rate (HR) as an indicator of intensity in players of different levels, age, and sex (Helgerud et al., 2001; Stroyer, Hansen and Klausen, 2004). Ali and Farrally (1991) determined median HR values near 172 ppm in Scottish semi-professional players. Bansgbo (1994a), on the other hand, described HR avg. values for Danish players of 160 ppm and for elite Danish players of 170 ppm. Likewise, in Swedish professional players, Brewer and Davis (1994) recorded values of HR avg. near 175 ppm. Mohr, Krustrup, Nybo, Nielsen, and Bangsbo (2004), observed HR avg. of 160 ppm in regional level players during friendly matches. Based on these data, HR values during the game could be around 160-

170 ppm (fluctuations between 160 and 190 ppm occur) so it is reasonable to think that the aerobic system is used as a priority (90 % of energy consumed) during matches. Bansgbo (1994b) found FC avg. and FC max of 85% and 98% of maximum values (Bangbo et al., 2006; Krustrup, Mohr, Ellingsgaard and Bangsbo, 2005), which indicates the high physiological load borne by players during competition." (Casamichana, 2014)

"On the other hand, VO2max can be estimated using the relationship between HR and VO2max during a treadmill test (Espósito, Impellizzeri, Margonato, Vanni, Pizzini, & Veicsteinas, 2004). If this relationship is assumed, the average exercise intensity during play of 85% of HR max would correspond to an average oxygen consumption (VO2 avg.) close to 75% VO2max during the match (Astrand, Rodahl, Dahl and Strømme, 2003). This would be equivalent to an average of VO2 of 45.0, 48.8 and 52.5 mL/kg*min-1 for a player with VO2max values of 60, 65 and 70 mL/kg/min-1 respectively and probably reflects the energy expenditure in modern soccer. For a 75-kg player, these data correspond to 1519, 1645 and 1772 kcal spent during the game (1L oxygen/min corresponds to 5 kcal), assuming the mentioned values of 60, 65 and 70 mL/kg.min-1 of VO2max (Stølen et al., 2005), with the main sources of energy being muscle glycogen, blood glucose mobilized from hepatic glycogen, and fatty acids (Bangsbo, 1994b). It has recently been observed that after a soccer game, some biochemical markers such as creatine kinase, urea, uric acid, myoglobin, or C-reactive protein may be altered (Andersson, Raastad, Nilsson, Paulsen, Garthe and Kadi, 2008; Ascensão, Rebelo, Oliviera, Marques, Pereira, & Magalhães, 2008), reflecting the effect of the metabolic and mechanical stresses on the activation of the purine cycle and amino acid degradation (Brancaccio, Maffulli and Limongelli, 2007) Despite all this, HR measurements during a match are likely to lead to an overestimation of VO2 due to factors such as dehydration, hyperthermia or mental stress that could elevate HR without affecting this parameter (Bangsbo et al., 2006). Taking these factors into account, it is suggested that VO2 avg.during play may be around 70% of VO2max (Bangsbo et al., 2006). This estimation of VO2 during competition is supported by measurements of core temperature during play (indirect indicator of energy production), which are close to 39-40°C and suggest that the load during the game is around 70% VO2max (Edwards and Clark, 2006; Mohr et al., 2004). In an effort to expand the knowledge of VO2max in soccer players, several researchers have concluded that players with higher VO2max values travel more total distance, perform more activity at high intensity, perform more sprints, participate in a greater number of decisive actions during the game and have a better recovery between high-intensity efforts (Bangsbo and Mizuno, 1988; Chamari, Hachana, Kaouech, Jeddi, Moussa-Chamari and Wisløff, 2005; Hoff, 2005) in addition to having a greater mobilization and lipid utilization during the game, which allows for reserving muscle glycogen for intense and decisive actions, Reilly and Thomas, 1979) and to accumulate less lactate (LA)."(Casamichana, 2014) Through a bibliographical review, Gorostiaga (1993) concludes that high level players should have VO2max values close to or above 65 ml/kg/min. This would allow them to maintain an average pace of intense play and a greater recuperation.

"Although it is true that aerobic metabolism is predominant during play (Bangsbo, 1994), the key actions for success in this sport are sprints, jumps, duels, shots, disputes, etc. which are dependent on anaerobic metabolism (Stølen et al., 2005), which highlights the importance of anaerobic lactic and alactic energy systems in achieving success in this discipline. An elite player performs 150-250 brief, intense actions during the match (Mohr et al., 2003). Therefore, some authors have argued that there is a high rate of phosphocreatine degradation (25-30% below the rest values) during different parts of the game (Krussup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006). Obviously, phosphocreatine (PCr) levels are critical for resynthesizing adenosine triphosphate (ATP). However, restoration of PCr deposits are largely dependent on aerobic metabolism (Hoff and Helgerud, 2004). Glaister (2005) performed a review of the ability to repeat sprints, typical of a multitude of intermittent sports (badminton, basketball, soccer, etc.) in which small periods of maximum or submaximal intensity are repeated with relatively short periods of low-moderate intensity. He concluded that the ability to maintain multiple sprints depends on many factors, but the availability of PCr and the intracellular accumulation of inorganic phosphorus (Pi) are likely to be the most important determinants of physiological responses, fatigue mechanisms and the influence of aerobic conditioning. In addition, the fact that both PCr resynthesis and Pi elimination (via ADP phosphorylation) depend on aerobic processes suggest that more resistance-trained athletes may have a better ability to maintain intensity in this type of effort. To determine the participation of anaerobic metabolism, concentrations of blood before, during, and after the matches have been studied. The average concentrations of La during the game have been described between 2-10 mmol/L with individual values above 12 mmol/L (Bangsbo, Nørregaard and Thorsø, 1991; Krustrup et al., 2006) , which suggests that the anaerobic energy system is summoned highly during different intense periods of the game (Mohr, Krustrup and Bangsbo, 2005). Despite these data, it is important to bear in mind that assessments are strongly influenced by the player's activities in the 5 min prior to sample collection (Stølen et al., 2005). (Casamichana, 2014)

Lactic parameters in soccer

According to Bangsbo et al. (in 1991), the problem with lactic acid measurements in team sports is that the values found in blood correspond to the effort made in the last 5 minutes prior to sampling. Therefore, it is not possible to determine the energy product of the whole match. Faced with this, Grosgeorge (in 1990) split the 90-minute match to be able to take the samples, and thus, the results are relatively stable. Castellano (in 1996) found the following values in amateur players. At the end of the first half, an average lactate volume of 7.3 mmol/L. Prior to the beginning of the second half, the levels decreased to an average of 4.40 mmol/L. At the end of the second half, blood lactic acid values were 4.8 mmol/L and 10 minutes late were at 2.2 mmol/L.

Yagûes (2002) poses a rather clear concept regarding the contributions of lactic anaerobic metabolism. On the one hand, the dependence of the use of this system with regards to the position of the players in the field. High levels in the wing players, followed by midfielders, with the central defenders using this system the least. Although at certain times the blood lactate concentration can rise in active muscles, the constant stops and recovery phases of medium and low intensity that occur during the game allow for a rapid elimination and reuse of this and avoid a progressive accumulation to limiting values.

Finally, by way of conclusion, average values of 3.8 mmol/L have been observed. There seems to be a coincidence in a lower lactate concentration in blood during the second half. This presents a certain logic, considering that in the second half, the total distances covered decrease along with the number of high intensity actions.

Energy substrates

After performing muscle biopsies in six first division Swedish players before, during, and after a match, significant decreases in muscle glycogen reserves were found, including in the first half. At the end of the game, the players showed a very important emptying of reserves, since they had used between 60% and 90% of their initial reserves. On the other hand, it was demonstrated that greater distances were traversed by the players who had higher levels of muscle glycogen prior to the beginning of the game. Additionally, they performed race times at 75% higher maximum speeds.

The energy substrates used during the game are distributed as follows:

- 70% from carbohydrates.
- 20% from fats.
- 10% from proteins.

The highest percentage of carbohydrates comes from muscle glycogen and only a small part from hepatic glycogen (Bangsbo, 1994). It is also observed that the concentration of free fatty acids increases during the match, especially in the second half. As for the recovery of muscle glycogen reserves, it has been found that when soccer players eat a diet that contains the adequate proportion of carbohydrates (between 40 and 50%) within 24 hours of finishing the game, they are still 30-40% lower than the values found before the start of the match (Bangsbo, 1994).

Muscle glycogen stores are still not fully recovered 48 hours after the end of the match (Jacobs, 1982). Phosphocreatine fluctuations were measuring using magnetic resonance imaging during three periods of intermittent two-minute exercise, which included maximal, low intensity and recovery contractions, like soccer activities. PCr levels dropped to 50% of the maximum but were almost completely restored at the end of the two-minute periods of intermittent exercise (Bangsbo, 1994).

This suggests that the contribution of the anaerobic alactic system is very important and that ATP and PCr are likely to be continually resynthesized during periods of low intensity to be used extensively in high intensity phases (Yagûes, 2002).

Total distance traveled

At present, most specialized literature agrees that the distances traveled are around 9 to 12 km, varying by 2 to 3 km for the same player per game. The average is around 10 km.

Differences depend on the position on the field occupied by the players. Midfielders run between 1/2 and 1 km more per game than defenders and forwards (Gorostiaga, 1993). A midfielder has a more important global activity with longer runs. Attackers and defenders are characterized as alternating between relative rest and numerous explosive actions of short sprints (Pirnay, 1993).

The data expressed above refer to total numbers, without addressing difference in the modalities under which athletes cover these distances. But we cannot fail to emphasize the importance of the irregular and intermittent way in which they move, with great changes in speeds and direction.

Gorostiaga (1993) determined the percentages of the intensities under which these distances are traveled.

- 55% to 60% walking or standing, between 40 and 54 minutes.
- 35% to 40% moderate speed (less than 15 km/h) from 31 to 35 minutes.
- 3% to 6% submaximal speed (between 15 and 25 km/h) from 3 to 5 minutes.
- 0.4% to 2% maximum speed (+ 25 km/h) from 22 to 170 seconds.

On the other hand, maximum intensity efforts are made for different distances traveled:

- 50% for distances of less than 12 meters.
- 20% for distances of between 12 and 20 meters.
- 15% for distances between 20 and 30 meters.
- 15% for distances between 20 and 30 meters.

The number of accelerations per game, starting from standing or running is approximately 130 (Smodlaka, 1978). On the other hand, the number of rhythm changes during a match is usually close to 1000 (Bangsbo, 1994).

Effective playing time

This concept refers to the time during which the game is active and when it stops. The average effective time is about 48 min. This is equivalent to 54% of the statutory time. If we divide it in first and second halves, the effective playing time is 57% and 51% respectively. It should be highlighted that the first 15 minutes of the game is where the greatest effective time is found, which gradually decreases until the end of the match (Castelo, 1994).

Around 50% of soccer moments, including both play and pause, are between 0 and 15 seconds (Hernández 1996). Colli and his collaborators obtained data that they never published, where 51% of the actions last less than 20 seconds. Pauses ranging from 1 to 20 seconds account for 75% (44 times per game) of the total.

Conclusions

We can draw the following conclusions regarding the mechanical demands of soccer:

- The distances traveled range from 9 to 12 km, with a variation of between 2 and 3 km. The average is around 10 km.
- The average effective playing time is approximately 48 minutes and 39 seconds. This is equal to 54% of total match time.

- The player is standing still or walking for between 40 and 54 minutes. Between 31 and 35 minutes of running at at least 15 km/h. Between 3 and 5 minutes is at a speed between 15 and 25 km/h. Running only at speeds above 25 km/h occurs between 22 and 170 seconds.
- 51% of the actions last for less than 20 seconds. While only 9, (5%) last more than 60 seconds.
- The majority of pauses last between 1 and 20 seconds and represent 75% of the total (about 44 times per game).
- The game density (or working protocol) ranges from 1:1.3 to 1:1.8. In other words, the pauses are slightly longer than the working time.
- Per game, there are around 130 accelerations and about 1000 changes of pace.

From a physiological perspective, the conclusions are as follows:

- The heart rate fluctuates close to 170 bpm on average during a match. For 2/3 of the playing time, the players work above 85% of the maximum HR.
- The average oxygen consumption for the game is 3.5 liters per minute. This is equivalent to 76% of the maximum VO2. Different percentages of VO2 are presented depending on the position occupied: 69% for defenders, 66% for mid-fielders and 43.3% for forwards. Total estimated energy expenditure is 1530 Kcal in 90 minutes.
- Lactate values are found to be between 3 and 8 mMol/l and the individual variations can be from 2 to 12 mMol/l. There is a lower concentration in the second half and the total distance traveled and the number of high intensity actions also decrease in this period.
- Although the lactate concentration at times is high in active muscles, the constant recovery phases and the medium and low intensity periods allow for rapid elimination and reuse of lactate in blood, which prevents accumulation to debilitating values.
- Muscle glycogen plays a key role in the match because it is used predominantly and can be depleted quickly.
- It is possible to define soccer as a mixed sport in which, despite the long duration of the effort in which the aerobic system constantly supplies energy, there are many explosive actions that require energetic contribution from the anaerobic pathways.
- The participation of the anaerobic alactic metabolism during the game is very important quantitatively because it is one of the main elements responsible for the decisive actions in a game (reflected in the explosive force of the lower limbs and the speeds of very short runs).

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