2.1 Types of Muscle Action

In order to understand how skeletal muscles function during human movement, we must study the possible movements in isolation in concentric, isometric and eccentric actions. These will be the result of the relationship between the stimulus and the response, and will be influenced by the relationship with the continuously changing environment, as is the case in team sports.

The authors have frequently referred to the term **contraction** to define the various aforementioned muscular actions (Komi, 2011). However, we call these muscular actions because contraction intrinsically describes a shortening, generated by the interaction between the actin and myosin molecules, which is characteristic of concentric action. This is not the case for isometric tension (where the length of the muscle group does not vary) or eccentric tension (which involves a lengthening of the muscle).

2.1.1 Isometric actions

Isometric contractions are characterized by the development of muscular tension without any variation in the joint range of motion, i.e. the muscle-tendinous unit maintains the same length during this tension. Using these types of actions in the training sessions has several advantages that we must take into account:

- During the rehabilitation processes, these allow for optimal control of the loads to be used, and can be precisely developed in the degrees of joint movement that are free from pain.
- On the other hand, this type of training allows for the use of bigger loads than those that are supported by means of concentric actions (Oranchuk, Storey, Nelson, and Cronin, 2019). Greater control of the exercise load, along with the possibility of developing greater tension, allows for exercising those joint angles and bodily positions that may be weak in a certain action. That is, if we are sure of the biomechanics to develop within each skill, it is possible to design pain-free exercises that strengthen the most typical positions within those skills.
- Regarding injured athletes, or those with symptoms of pain, isometric actions can have an analgesic effect, as a result of an alteration in the cortical channels of inhibition-excitation (Oranchuk, Storey, Nelson, and Cronin, 2019).

In this regard, we can highlight the different studies by an Australian research group (Rio et al., 2015), who compared isometric exercise with concentric exercise in volleyball players suffering from patellar

tendinopathy. They studied the effect upon finishing and 45 minutes after two types of exercise. For the isometric condition, a Biodex Pro was used and the athlete's knee was bent at 60º, carrying out 5 sets of 45 seconds at 70% of the CVM. For the isotonic condition, a knee extension machine was used and 4 series of 8 repetitions carried out, using a metronome to mark a total of 4 seconds in the eccentric phase, and 3 seconds in the concentric phase at 100% of the 8RM. In both cases, the recovery time between sets was 2 minutes. In order to observe the effect in both pre- and post-intervention sets, they performed a unilateral decline squat exercise.

In this study, the authors observed the effect on pain (using a VAS scale from 0 to 10), quadriceps strength in a maximum voluntary isometric contraction (CVMI), and cortical excitability and inhibition. This last parameter was studied through transcranial magnetic stimulation with unique pulses, which is a system that enables provocation of an electrical stimulus in the cerebral cortex, in order to assess the excitability of the motor cortex and the corticospinal tract. This allowed them to record possible changes in the motor outcome, which depends on a combination of changes in the excitatory and inhibitory neuronal tracts.

These results show a superior pain-reducing effect on isometric conditions, compared to isotonic. In addition, the first condition was sustained over time (45 minutes post-intervention). Isometric exercise also produced a decrease in cortical inhibition; a parameter that did not modify the isotonic condition of the exercise. The strength of the CVMI experienced a greater increase after the isometric condition compared to the isotonic; both immediately after the exercise and in the measurement taken after 45 minutes. These results led the authors to affirm that isometric actions can be used to decrease pain in subjects with patellar tendinopathy.

The work of van Ark et al. can also be found in this line of study (2016). They performed two types of interventions over the course of four weeks in basketball and volleyball players affected by patellar tendinopathy. In one of the groups, they designed an isometric exercise, while in the other the training was isotonic. The working protocols were the same as in the work of Rio et al. (2015), except that in the isometric group the intensity of the actions rose to 80% of the CVMI, while in the isotonic group the intensity decreased (80% of the 8RM). This intervention was carried out over the course of four weeks, in which a decrease in pain was recorded during the competition season (the period in which the study was carried out). In addition, there was a decrease in the VISA-P scale, without any significant differences between the interventions, which also demonstrated an increase in functionality.

The study by Rio et al. (2017), with a similar sample (twenty basketball and volleyball players) to the study of van Ark et al. (2016), examined the possible analgesic effect following isometric or isotonic exercise (over the course of four weeks), consisting of a unilateral decline squat exercise. They then compared the same aforementioned protocols (van Ark et al., 2016), as well as during the competition season. Both were effective in reducing pain, although the isometric exercise provided greater analgesia; which, according to the authors, leads to an increase in load-bearing capacity and performance.

Another study by the same research group (Rio, Purdam, Girdwood and Cook, 2017) carried out an intervention, consisting of isometric exercise in a bilateral squat, using a belt (similar to the Russian Belt). In this case, the intervention protocol was developed in order to observe a variation in pain and functionality, and was performed on a sample of 25 athletes with patellar tendinopathy. This intervention, carried out during the competition season, consisted of five 30-second repetitions done five days per week. Their results showed a reduction in patellar pain and enhanced functionality.

With regard to the connection established between the ability to generate isometric tension and a greater sporting performance (Wang et al., 2016), it is important to take into account the physiological characteristics of the muscle, as well as the effect that isometric training can have on the modification of the musculature, on the health and stiffness of the tendon, on the specific torque of each articular angle, and on the metabolic functions produced in these structures (Oranchuk, Storey, Nelson, and Cronin, 2019).

In this regard, Wang et al. (2016) found a correlation between isometric force in a Mid-Thigh Pull exercise, strength performance (squat 1RM), agility (T-test) and sprint (40m) among rugby players, which is why these authors support the use of this isometric test to monitor the level of performance in athletes of this particular sport. In a longitudinal design, Kubo, Kanehisa, Ito and Fukunaga (2001) studied the effect of isometric training on tendon elasticity in physically active young adults. For this purpose, they designed a 12-week intervention, with four weekly isometric training sessions, using unilateral knee extensions at 70% of the maximum voluntary contraction, performing 20 seconds per series and four series per session. They studied the vastus lateralis muscle through an ultrasound scan. This type of training enhanced muscle volume, maximum voluntary quadriceps contraction, muscle stiffness and speed of strength production, while decreasing electromechanical delay. This study is important because it indicates a possibility that isometric exercise can enhance stiffness, and has the ability to vary Young's modulus. In this perspective, this type of exercise could help us decide whether to introduce isometric training to enhance the explosive

strength of our players, but we have to remember that if we work in a static way, we will not involve the sport-specific neuromuscular and cognitive aspects, which can affect the true application of strength in the context of competition.

In addition, in relation to how isometric exercise can enhance sporting performance, it is important to keep in mind that, when referring to strength development, the changes related to muscle volume have to do with the articular angle in which a particular stimulus is applied.

Figure 1: Isometric actions during play, by applying struggle

Source: Romero Rodríguez, 2018, [own file], unpublished.

Isometric actions are not identified as determining factors in team sports, but it is important to keep in mind that there are many situations where the expression of struggle takes place. In this case, it is important to think about how to train within these sporting requirements, so that the isometric actions also become functional.

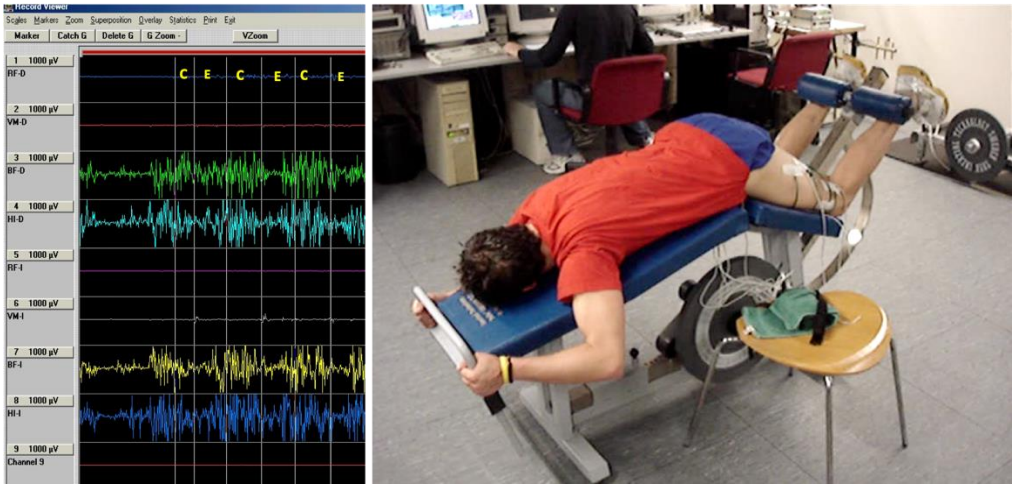
When this stimulus is applied to a stretched muscle, the hypertrophic effects of training are greater than when it is applied to a contracted muscle. We must keep in mind that, according to the position and the articular angle during isometric contraction, the muscle will work in an elongated position that is either superior or inferior to its resting position (Alegre, Ferri-Morales, Rodriguez-Casares, Agudo, 2014). The work of Oranchuk et al. (2019) explains that the stimuli of isometric force on elongated muscles have a greater effect on the ability to perform dynamic actions, such as concentric contractions, eccentric contractions or even jumps with counter-

movements; when compared to the work of muscles in more contracted positions, in terms of their resting length.

2.1.2 Concentric actions

From a scientific point of view, concentric action is the most studied mechanism of the different muscle actions, and the studies by Hugh Huxley are especially centered on this type of action (Huxley and Hanson, 1954). In fact, it is understood that the muscle fiber, in its resting length, will be able to establish a greater number of cross-bridge formations by causing a greater development of strength, according to the cross-bridge theory. Despite this, it is important to note that the ability to generate tension will depend not only on the contractile component, but also on the elastic and neuronal properties of the neuromuscular system.

Figure 2: Muscle activation in concentric action, measured by electromyography



Source: Romero Rodríguez, 2018 [own file], unpublished.

It is important to note that concentric actions are not carried out in isolation, except in cases where such a decision could be justified. On the other hand, it is important to carry out studies and training based on the joint movement of eccentric and concentric action, when we refer to dynamic actions. In addition, we must consider studying the individual behavior of the different muscles that we want to record, by means of electromyography. This recording, together with video analysis, can help separate the electrical activity of the muscle into its concentric and eccentric phases, as shown on the left side of Figure 2.

Taking into account that concentric action is best understood from a physiological point of view, it is important to understand in this topic that there are few longitudinal studies conducted solely with concentric-based interventions, since the beneficial effects of eccentric actions have been established (Romero-Rodriguez, Gual and Tesch, 2011, in readaptation; Askling, Karlsson and Thorstensson, 2003, in prevention; Tous-Fajardo, Gonzalo-Skok, Arjol-Serrano and Tesch, 2016, in performance). This leads the interventions to focus on exercises that involve the entire stretch-shortening cycle (SSC).

In the following topic, we will discuss papers that study eccentric action in isolation, since this has been identified as a good way to prevent muscle and tendon injuries, as well as to treat highly prevalent injuries in the sport as chronic tendinopathies. In contrast, isolated concentric actions are considered a negative means of treating chronic patellar tendinopathies (Jonsson and Alfredson, 2005).

Figure 3: Concentric actions for acceleration, both in competition and in isolation

Source: Romero Rodríguez, 2018, [own file], unpublished.

It has been understood for years that the type of concentric exercise involves a greater metabolic output, compared to eccentric actions. Tesch, Dudley, Duvoisin, Hather and Garris (1990) compared concentric and eccentric actions of the extensor muscles in the knee, and observed that the decline in strength was much greater when performed concentrically. In addition, the electromyographic signal of the rectus femoris and the vastus lateralis quadriceps was superior in concentric actions; a parameter that clearly denotes a greater metabolic output. On the other hand, the eccentric action, with the need to develop a certain tension, does not trigger the same electromyographic signal as concentric action. This may be due to the greater elastic component, which generates tension in the eccentric modality of muscle action (Horstman et al., 2001; Westing, Seger and

Thorstensson, 1990; Komi and Bosco, 1978). Pasquet, Carpentier, Duchateau and Hainaut (2000) explain that concentric exercise causes a greater alteration of the excitation-contraction process, which also indicates a greater output of energy substrata.

In this regard, there is less ability to generate tension, greater fatigue and greater lactate production in concentric actions, compared to eccentric actions (Horstmann et al., 2001; Kraemer and Castracane, 2015). In line with the above, Linnamo, Bottas and Komi (2000) compared both types of activity in the brachial biceps, observing that fatigue also depended on the condition of the muscle tension generated. This difference in the characteristics of activation, according to the type of muscular action, has been supported for years by numerous studies (Babault, Pousson, Ballay and Van Hoecke, 2001; Rutherford, Purcell and Newham, 2001), which affirm that concentric actions entail a greater metabolic output.

In order to understand the differences that exist between concentric and eccentric exercise, it is important to reference the work of Roger Enoka (Enoka, 1996), which was mentioned in the previous module. This paper explains that, while the recruitment of motor units does not differentiate between the two actions in their maximum expression, they do show different behavior in submaximal intensities. Specifically, this work studies the parameters of order of recruitment, pulse frequency and threshold of recruitment of motor units. It can be observed that concentric actions involve a greater frequency of impulses, and this leads to a thought process with a different neural order between the two types of actions. That is, this neural order is unique, in accordance with the type of muscular tension generated. According to these facts, concentric action means a greater recruitment of motor units to exercise with a load similar to that of eccentric action. As was previously mentioned, this may be due to a better performance of the eccentric action in generating tension (Kraemer and Castracane, 2015).

In terms of muscular strength, concentric training produces less hypertrophy than that which is generated eccentrically (Colliander and Tesch, 1990; Hortobágyi et al., 1996), as well as less strength gain. Although we discuss this topic throughout the course on post-injury readaptation of athletes, it is necessary to link this to the lower hypertrophy caused by concentric training, due to the fact that this type of exercise generates less strength than when performed eccentrically (Colliander and Tesch, 1990; Hortobágyi et al., 1996). The combined effect of gravity with the elastic properties of the musculoskeletal system tissues causes an athlete to execute an eccentric muscular action with a greater load than what he/she can execute through a concentric action (Kraemer and Castracane, 2015).

Despite the limitations presented by concentric exercise, compared to eccentric exercise in terms of generating strength, hypertrophy and

metabolic savings, it is important to note that human actions (and sports skills in particular) are developed through the SSC. That is, although it does not seem convenient to carry out training that isolates the concentric component, it is important to carry out training exercises through the execution of concentric and eccentric actions, alternating with isometric actions when necessary. In this regard, they alternate over time and are practiced simultaneously, if we are referring to different muscles that intervene in an exercise**.** In addition, the work of Higbie, Cureton, Warren and Prior (1996) explains the specificity of the adaptations. The authors affirm that eccentric exercise is more effective than concentric in increasing force in eccentric actions, just as concentric exercise is more effective than eccentric in increasing concentric force. Therefore, muscular hypertrophy and neural adaptations increase force generation from outside in both conditions.

2.1.3 Eccentric Actions

Eccentric actions are discussed at length in this course, given the important role that this type of exercise plays in enhancing performance, prevention and readaptation of injuries. This is expressed in the literature, but it is also necessary to keep in mind that, in the vast majority of cases, we will be interested in working on the entire stretch-shortening cycle (SSC); a concept we will discuss in the following topic.

Unlike concentric and isometric actions, during eccentric action, the muscle generates tension while experiencing an increase in length. That is, the external resistance exceeds that which is imposed by the articular moment, causing the agonists in this action to stretch instead of shorten (Nishikawa, 2016). According to Douglas, Pearson, Ross and McGuigan (2017), this produces an absorption of mechanical energy, which can be dissipated in the form of heat or accumulated for use in the concentric action that immediately follows. Eccentric actions play a key role in controlling and producing the movement, assisting with energy efficiency in particular.

Figure 4: Eccentric exercise in deceleration actions, both in competition and in isolation

Source: Romero Rodríguez, 2018 [own file], unpublished.

The actions of deceleration in competition are strongly linked to the capacity for eccentric exercise, which the muscles involved in braking can develop. This type of exercise has to be optimized through strength training, where actions should be sought in relation to the perspective of kinematic and dynamic sports skills, as we can see in the strength training course.

Taking energy into account, as was mentioned in the previous topic, concentric actions entail a greater output than eccentric ones (Babault et al., 2001; Rutherford et al., 2001). In this regard, according to muscle metabolism, it is worth noting that the mechanical tension produced by force during stretching causes a state of muscle ischemia, which will lead to potential adaptations in skeletal muscle. Eccentric actions produce an increase in the acidity of the environment, enhanced by high muscular tension that can be produced in the passive tissues. This leads to both deterioration of fibers and the activation of the sympathetic nervous system, which will facilitate the processes of hypertrophy (Hedayatpour and Falla, 2015).

We previously introduced the role of eccentric actions in controlling movement. As we pointed out in the course related to readaptation to post-injury competition, eccentric actions play an important role in neuromuscular control; a necessary requirement for progress in training and the readaptation process towards greater variability and complexity in exercise, through the development of neuromuscular coordination.

We have previously mentioned the work of Roger Enoka (1996) to explain the different recruitment behaviors, and how the tension that exists

between eccentric and concentric actions is produced, although this fact was called into question by subsequent research (Duchateau and Enoka, 2016). Nevertheless, it is necessary to continually emphasize the importance of this fact, because it may lead us to ask questions that the literature does not yet appear to be asking. In other words, if we start with the premise that the production of strength is different between the two types of action, we might consider whether an athlete could carry out one type of action or another with ease or difficulty. If we think about skills development, would it be possible for a soccer player to be able to accelerate more and not have as much ability to brake quickly and change direction, while another player might possess the exact opposite skills? On the other hand, if this is true, could it be that this reality is partly determined by the type of neuromotor recruitment that occurs differently in concentric and eccentric actions? It is evident that the ability to accelerate is related to the production of strength in concentric actions, while the ability to decelerate essentially depends on strength that is generated eccentrically. In the context of sports performance, players are often known as being accelerators and decelerators. We have previously mentioned that eccentric actions present a lower discharge frequency in motor recruitment, as opposed to concentric tension, although this is not related to any inhibition mechanism that depends on the amount of tension produced by the muscle (Duchateau and Enoka, 2016).

In this last review by Duchateau and Enoka (2016), the authors conclude that there is a difference that normally exists between the activation of motor units when a concentric or eccentric action is performed, irrespective of the exercise to be performed. This phenomenon will depend on the musculature involved, the needs of the exercise from a biomechanical perspective, and the adaptations that are dependent on age and training. The CNS triggers a specific activation strategy in the strength-generating actions that are accompanied by muscle elongation. Various localized mechanisms are involved at both the supraspinal and spinal levels, in order to generate this specific modulation of the eccentric actions. Certain aspects of this topic are still unknown. With regard to sports skills, it is important to note that the loads imposed during competition time demand an instant response from the musculature. If we keep in mind that stretching reflexes have a significant delay in the muscle response that is necessary to stabilize in the event of a disturbance, eccentric tension, produced by the elastic structures of the skeletal muscular tissue, will have a key role in the required stabilization. These are recurring situations in team sports (Nishikawa, 2016).

In relation to the neural adaptations caused by eccentric exercise, different studies have already shown that an increase in the ability to produce strength, acquired through training, occurs at the spinal and supraspinal levels. These adaptations will depend on the type of predominant muscle

contraction in the exercise performed and the level of intensity. This should not surprise us, since we know that the central nervous system employs a different strategy for muscle control during eccentric contractions, compared to concentric or isometric contractions, as was previously mentioned (Enoka, 1996; Enoka and Duchateau, 2016). This is reflected, among other things, by the selective recruitment of fast-twitch fiber motor units and the different activation levels. In addition, a high level of cortical activity has been shown in the preparation and execution of movement during eccentric activities, especially by the concurrent modulation of afferent input during muscle stretching, which leads to reduced participation of the stretching reflex. In addition, cortical activation is greater when it comes to providing feedback on the eccentric exercise performed.

These differences in neural involvement have also been expressed at the motor unit level, which present a decrease in the action potential threshold necessary to produce the activation, as well as an increase in the frequency of stimulation impulses. Therefore, after eccentric training, there is a greater recruitment of motor units at the same relative strength (Hedayatpour and Falla, 2015). We can also observe the work of Fang, Siemionow, Sahgal, Xiong and Yue (2004), who proposed that eccentric movements require a significantly longer preactivation time, and a significantly greater magnitude of cortical activity for the execution of such movement. Both phenomena infer greater activity of the central nervous system, possibly due to a greater risk of injury with this type of action, along with a greater degree of difficulty in performing movement and a single motor unit activation pattern, when performing eccentric muscle actions at the maximum level.

The effects produced through training will depend on the degree of mechanical tension, the hormonal response and the rupture that the stimulus generates at the cellular level. It is important to keep in mind that actions that require a high intensity eccentric activation will trigger a strong presence in the musculature. We can connect the aforementioned action to microscopic muscle tissue injuries, generated by the high mechanical tension that this type of activity can produce, especially in athletes who are trained to support certain load levels (Hedayatpour and Falla, 2015). In this sense, the main three responsible parameters for micro injuries are high intensity workout, eccentric tensions and performing unusual exercises. These events, which signify greater adaptations than in concentric and isometric exercise, also produce temporary loss of strength, pain and muscle inflammation (Tous, 2010). In addition, muscle injuries often occur in uncontrolled eccentric actions (landing or change of direction), in which the contracted muscle is stretched beyond its ability and an injury occurs.

Here, we have an important factor to take into account: the speed of the action, which influences the athlete's ability to adjust or control movement. Thus, muscle injuries in eccentric actions often occur at high speeds of execution of the movement, and with a significant factor of uncertainty. Based on this, it has been proven that in athletes without experience in this type of training, once the first eccentric training session has been carried out and a reasonable recovery period has passed, they can carry out a second training session with considerably less muscle damage than after the first session. Therefore, it can be inferred that the threshold of muscle injury increases, followed by a protective effect (Tous, 2010).

As a result, it is necessary to introduce the components of variability, intensity and uncertainty in training, especially in team sports, in which there is a need to develop eccentric actions where there is a risk of injury by means of a significant temporal constraint. In this regard, the inertial devices, which are mentioned extensively in the courses on training and readaptation, are especially relevant because of the eccentric overload that this implies, and variability of exercise that they can provide.

2.1.4 Stretch-Shortening Cycle (SSC)

As we approach the topics of movement and sports training, it becomes difficult to analyze these from such an isolated perspective, such as types of muscle actions. In motor tasks, as was previously explained, we will find countless concentric, eccentric and neuromuscular isometric actions, such as coactivation and reciprocal inhibition. These will take place simultaneously in different zones of the body, and will be organized in order to achieve a high level of skill in each motor action. In the development of basic and sport-specific motor skills (this classification is discussed in the course on strength training), the study of the SSC takes on special meaning. This is worth highlighting, as we have referred to the differences between concentric and eccentric actions (Enoka, 1996; Enoka and Duchateau, 2016), and the SSC occurs in practically all sporting actions. Within this SSC, there is a transition between eccentric and concentric actions and, if we observe the existing differences in the neural order to organize both actions, this can be interpreted as a critical moment in the success of a sporting action.

Figure 5: SSC during competition

Source: Romero Rodríguez, 2018 [own file], unpublished.

In sports actions, continuous decelerations are triggered, followed by acceleration movements. These maximum intensity actions are representative of the stretch-shortening cycle, where eccentric and concentric actions are sequenced. In Figure 5, we can see the player in red approaching the possessor of the ball, for which he/she has to regulate his/her deceleration; where the quadriceps are significantly involved, along with other muscles. As a result of the possessor's action, the player in red has to move quickly from a braking action to an acceleration, and the quadriceps are therefore predominantly concentric. It is important to highlight the eccentric - concentric transition, in order to enhance these skills.

The difficulty in completing a SSC is especially important, according to the explanation of Enoka and Duchateau (2016). Supported by different authors, the researchers explain that small stretches are produced in the deceleration stage of an action, caused by the rapid oscillations in length suffered by muscles that decelerate (Bawa and Jones, 1999). Furthermore, we must keep in mind that this deceleration is accompanied by a very high demand for stabilization, which leads to minimal variations in the articular position that occur in the eccentric - concentric transition, and possibly triggering very rapid recruitment and derecruitment of motor units.

These actions involve certain postural changes that will trigger a change in the force vectors, which also leads to the recruitment of motor units that are different from the muscle itself (ter haar Romeny et al., 1982); especially biarticular muscles (Nardone and Schieppati, 1988). Similarly, there will be another consistent adaptation in the modification of the role that synergetic muscles can have (Nardone, Romanò and Schieppati, 1989). In relation to this, we must keep in mind that the continuous variations in length of the musculotendinous unit, often produced at high speed, will trigger continuous stretching reflexes during the SSC.

For a SSC to occur, an external force must first trigger active stretching of the muscle (typical behavior of an eccentric action). This force is provided by the ground, for example, in a sprint or jump; that is, in the actions in a closed kinetic chain. The eccentric action is automatically followed by a concentric action. The performance achieved in this concentric phase will evidently be greater than that which can be achieved by isolated concentric action, and this is the key reason behind carrying out a SSC. The characteristics that a SSC must have in order to be effective are as follows:

1- Good *preactivation timing* prior to the eccentric phase.
2- A short, fast, eccentric phase.
3- An immediate transition between the stretching phase (eccentric) and the shortening phase (concentric).

These conditions usually occur correctly in "normal" SSC situations, such as running, walking, or jumping under controlled conditions (Komi, 2003). This does not reflect the reality of the sport, but the sporting actions lead to situations where emergencies in the surroundings cause the SSC and specifically, the eccentric - concentric transition, to take place in situations with high instability and speed. In high-speed sprints, usually with a large number of perceptual stimuli and continuous decision making in team sports, injuries are caused by this high intensity and by the interaction with other skills, such as deceleration, acceleration, change of direction and spin actions. To provide a well-known example of harmful mechanisms produced, according to the literature, the hamstring muscles are usually injured at the end of the oscillation phase in the eccentric - concentric transition, when they work eccentrically by slowing down the limb and thus controlling the knee extension (which participates in the support of the foot in oscillation). These muscles must quickly change their role to facilitate hip extension and to function concentrically. It is at this moment that they are most vulnerable to injury because of the high burden they are faced with (Woods et al., 2004).