Module 2. Muscle injury prevention

Unit 2.1 Prevention of the most frequent muscle injuries

2.1.1 Biomechanical characteristics of the hamstrings

Hamstring injuries of varying severity are very common in sports where there is a great deal of sprinting, and are especially prevalent in unexpected situations (sudden changes of direction or decision-making). This type of sprinting is unavoidable in sports like soccer, rugby (especially for the backs) or basketball, so it is no wonder that injuries to this muscle group become a worrisome health issue for our athletes, posing a real concern in many competitive environments at all levels.

Taking soccer as an example, if we do a brief analysis of epidemiological studies, we find muscle injuries in the back region of the thigh are among the most prevalent injuries, appearing frequently in many papers on the subject [See Hawkins and Fuller (1999); Hawkins, Hulse, Wilkinson, Hodson and Gibson (2001); Arnason, et al. (2004); Junge, Dvorak and Graf-Baumann (2004); Woods et al. (2004), Dupont et al. (2010), Ekstrand, Hagglund and Walden (2011 b), Stubbe et al. (2014)].

This forces us to assess the major mechanisms associated with this injury, thus allowing us to come up with the most suitable actions to prevent it.

Biomechanical Characteristics of the Hamstrings

In order to better understand the analysis of this injury mechanism, we will attempt to briefly summarize the biomechanical features of this muscle group.

Worth stating at the outset with this muscle group, it is in theory **biarticular**, meaning it passes through two joint centers: the hip and the knee, performing opposite functions at each center. This implies that in concentric contractions, this group behaves as a hip extensor, supporting the gluteus (this synergy is important for developing proper running technique), and knee flexor.

As far as the muscle's architecture is concerned, there are two elements to focus on: its architecture *per se*, and its architectural type, namely, the pennate type. Regarding its architecture, the muscles are characterized by long fibers (short head of biceps femoris

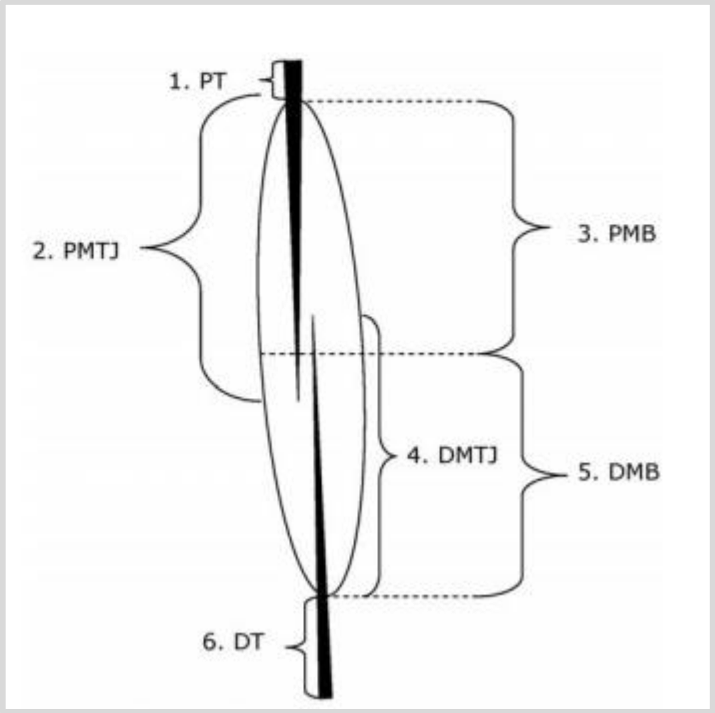
(BF), 85.3 +/- 5.0 mm [3.358 +/- 1.97 inches], long head of biceps femoris (BF) 139 +/- 3.5 mm [5.47 +/- .137 inches] and semitendinosus 158 +/- 2 mm [6.22 +/- .078 inches], with a combined average of 107 mm [4.21 inches] for the hamstrings). This represents a tendency towards showing a large number of sarcomeres in series and a moderately high ratio for muscle fiber/muscle length, making for muscles with a fast shortening speed and more excursion and influence on a joint. Therefore, in this muscle group, the sarcomeres in series (fiber length) will be crucial for functioning (Lieber, 2002).

Now, upon analyzing **fiber length/muscle length ratio** together along with another crucial mechanical parameter such as the **physiological cross-sectional area (PCSA)**, we find this muscle group divided as follows: the **semitendinosus** is a muscle with long fibers but with low PCSA (owing to a low pennation angle of 5°), thus its structure makes it favorable for shortening speed and muscular excursion, but with low strength levels; on the other hand, the **biceps femoris** is a relatively mixed muscle with both a moderate fiber length and PCSA, (owing to a larger pennation angle of 23°), which is to say that its capacity of producing force (according to its structure) is greater than that of its companion, the semitendinosus, and its biomechanical features put it in a situation of relative risk, given it is positioned so as to withstand the eccentric force produced in the final swing phase of running, unlike the semitendinosus, which can be activated quickly and produce a large amount of movement, but little force (Lieber, 2002).

The hamstring muscle group nevertheless has a function, based on their design, aimed at contraction speed, offsetting the force-generating function of the quadriceps (in accordance with their fiber length/ muscular length and PCSA characteristics). In any case, as we will see later, the architectural differences within the hamstring muscle group correlate with the epidemiological data, with the bicep femoris being the group most prone to injuries within this muscle group (Woods et al., 2004).

Finally, from an architectural point of view, they are complex muscles. To put it in simple terms, the hamstrings, and especially the biceps femoris, have tendons that line and traverse the majority of the muscle length. In other words, by plotting the muscles as pennate (similar to a bird's feathers), they show a large number of myotendinous and myofascial junctions, points where muscle fiber anchors and where contractile forces transition into movement. We also recognize that these areas have high rates of mechanical force transfer, and therefore have areas prone to rupturing, bearing in mind that the transition area from contractile tissue to connective tissue is the most injury-prone area. As an example of what has been discussed in this paragraph, we can see in Figure 1 a diagram of the architecture of the biceps femoris.

Figure 1: Diagram of Front View of Muscle-Tendon Complex of the Biceps' Long-Head

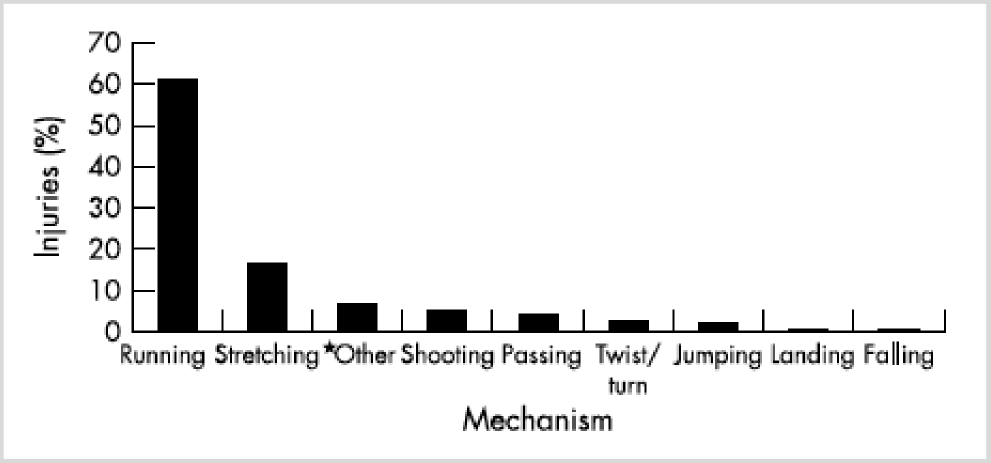


Source: Askling, et al., 2007, pg. 199,
Key: 1) Proximal tendon (PT). 2) Proximal Muscle-Tendon Junction (PMTJ). 3) Proximal Muscle-Belly (PMB). 4) Distal Muscle-Tendon Junction (DMTJ). 5) Distal Muscle-Belly (DMB) 6) Distal Tendon (DT).

2.1.2 Injury mechanism

Keeping the biomechanical and architectural features in mind, what could the main injury mechanisms be for this muscle group, especially in sports that rely on sprinting? Woods et al. (2004) published an interesting paper on the subject based on a study of injuries within this muscle group. The paper established that the injury mechanism is 91% involved in non-contact movements, and within this percentage, 57% of injuries arise in situations where sprinting or running at high speeds is involved. Similar data were found by Hawkins et al. (2001). (Figure 2)

Figure 2. Hamstrings Injury Mechanisms from Non-Contact Actions



Source: Woods, et al 2004

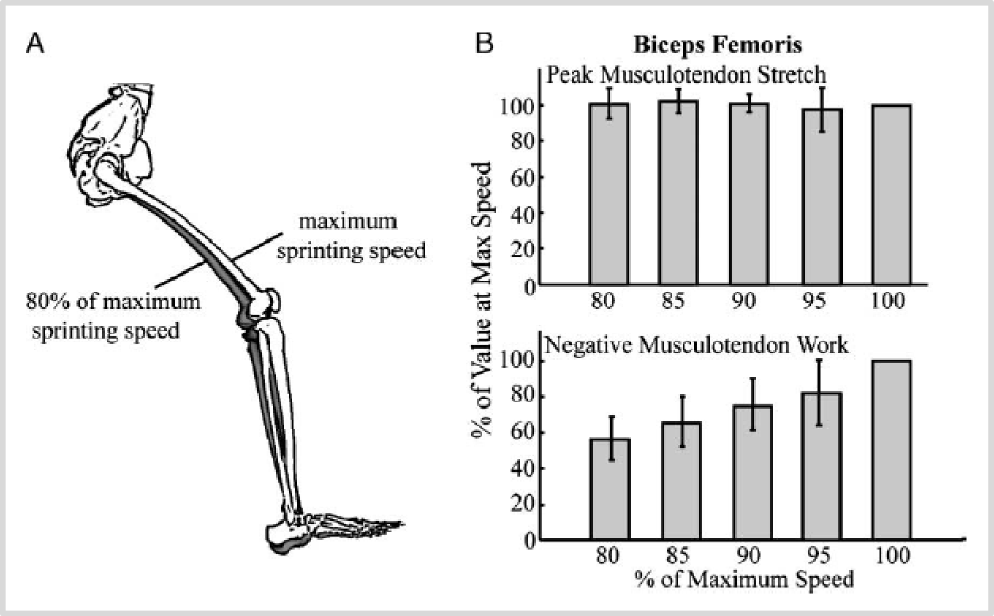
This aspect is related to the last part of the swing phase in running, in which the hamstrings should slow the high angular speed of the tibia in order to position it for the next step, extending the hip, which situates the hamstrings in an important eccentric action that will become concentric once the cycle of movement associated with running is complete (Thelen et al., 2006).

Within this muscle group, the biceps femoris is the most affected (Woods et al., 2004; Thelen, Chumanov, Sherry & Heiderscheit, 2006). Researchers Thelen, Chumanov, and Sherry (2006) have demonstrated through studies that the electromyographic activation of the semitendinosus, semimembranosus and biceps femoris muscles in this final swing phase was similar, but that the degree of stretching for the biceps femoris long head was significantly greater (9.5%) than that sustained by the semitendinosus (8.1%) and the semimembranosus (7.4%), which supplied a higher quantity of negative work for the biceps, interpreted as a specific injury risk factor for this muscle (Thelen et al., 2006).

Another important piece of information is the effect that running speed has on the mechanics of the hamstrings. On this subject, in laboratory settings the peak stretching of the hamstrings' myotendinous junction was assessed at different speed ranges (80%, 85%, 90%, 95%, and 100%), where it was observed that it remains unchanged across the speed ranges studied. Even so, the negative work done by the hamstring on the muscle-tendon unit increases considerably with velocity, as the inertial energy responsible for slowing down the hamstring increases (Thelen et al., 2006; Chumanov, Heiderscheit, & Thelen, 2011).

The hamstrings then have the function of absorbing and redistributing the kinetic energy of the swinging extremity before the foot's contact. Inasmuch as the kinetic energy increases proportionally to the squared speed, the negative work done by the hamstring muscles increases at a rate that exceeds the percentage of variation in speed (Figure 2) (Thelen et al., 2006).

Figure 2: Example of the Leg's Position in the Hamstring Injury Mechanism



Source: Thelen et al., 2006, pg., 139.
Figure 2. A. Showing the posture of the lower extremity at the moment of producing peak stretching in the hamstring's muscle-tendon junction. **B.** Variation of the peak stretching of the hamstring muscle-tendon unit (above) and of the muscular negative work (below) in connection with variation of running speed.

It seems clear that the growing predicament concerning this injury is linked to two key points:

1) Our athletes' growing capacity to perform high-intensity efforts in competition and training, meaning the increasing capacity to spend longer times covering more distance at high-intensities and/or sprinting.

2) Underestimating the complexity of this muscle group. In other words, applying a simplistic and one-sided analysis for both anatomical and functional matters.

Furthermore, to conclude with this section's line of questioning, there is a relative consensus among the relevant literature that the main injury mechanism is located in high-speed eccentric movements of this muscle group in a position of maximum length (active stretching) in the final swing phase of the free leg while running, and especially in high-speed running.

This analysis is what permits us to explore the risk factors that encourage this condition and increase the risk for this muscle group, as well as what would be the best options for risk prevention.

2.1.3 Intrinsic risk factors for hamstring injuries

Age

In the majority of studies related to intrinsic risk factors, the athlete's age is analyzed. Muscle injuries, especially hamstring injuries, are no exception.

Accordingly, the majority of articles indicate that, as an athlete ages, the risk of sustaining injuries in the hamstrings increases (Arnason et al., 2004, Ekstrand, Hägglund & Walden, 2011 b). This trend suggests an increased risk for every year an athlete ages, starting from 23 years old, regardless if the athlete has had a previous injury in this muscle group or not.

Why age would significantly affect the risk of sustaining an injury is not entirely clear. It is hypothesized that the relationship between age and risk of injury could be explained by the reduction in the physiological cross-sectional area, and the reduction of type II fibers in this kind of muscle that has a preponderance of fast-twitch fibers.

Previous Injuries

There is a uniform and consistent consensus in the literature that the presence of a previous injury is an unequivocal risk factor in hamstring muscle injuries. Some authors, such as Oschard JW (2001) Arnarson et al. (2004), Hägglund, Waldén and Ekstrand (2013), suggest that it increases the risk of sustaining a hamstring injury by 1.5 to 3.5 times.

The explanation of how a previous hamstring injury increases the risk of a repeat injury can be found in the torque curve or angle that produces peak torque after an injury, namely, the post-injury modification of this biomechanical variable (Brockett, Morgan & Proske, 2004; Naclerio, Larumbe-Zabala, Monajati & Goss-Sampson, 2015).

On this topic, Brocket et al. (2004) report that subjects with previous hamstring injuries had peak torque angles that were more restricted than in the non-injured leg of the same subject, posing a risk of repeated injury. However, these authors insist that analyzing larger samples is warranted, in order to estimate the safe angular ranges within which the peak torque should fall, as well as the risk zones, and that such analysis should be granted more authority when working to identify at-risk subjects (Brockett et al., 2004).

Levels of Eccentric Force in the Hamstrings as Injury Risk Factors

Garret (1990) proposes that during sprinting movements, the deceleration of the leg and foot during the final swing phase requires a significant eccentric activation in the hamstrings to compensate the moment of forward force, and that this force, which directly influences the hamstrings (considering the biarticular features of this muscle group), is the element that can cause injuries in the myotendinous junction.

Keeping this in mind, in recent years some have suggested that the hamstrings' eccentric force levels are an important factor for predicting injury risk, making the increase in eccentric force an important point to keep in mind when organizing prevention programs for this muscle group (Naclerio Ayllón, 2010).

Imbalances of Forces in the Hamstrings and the Quadriceps

Based on what has been discussed in the previous paragraphs, analysis of levels of eccentric force should be an important element to keep in mind when considering which of our athletes are at risk of sustaining injuries in this muscle group.

Accordingly, the force ratio between the antagonist thigh muscle has been studied for some years, with the aim of finding the appropriate ratio that will yield a reduction in the injury risk factor for this muscle group (Naclerio Ayllón, 2010).

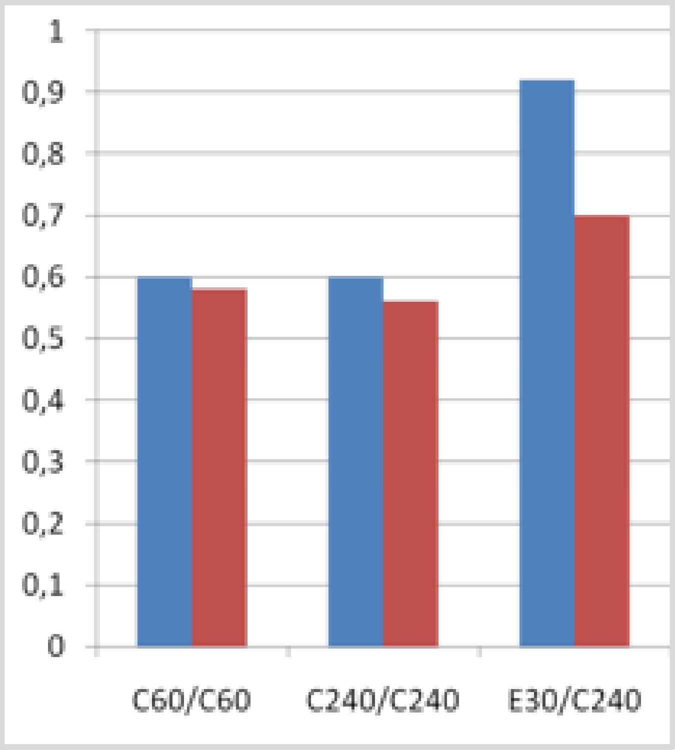
This ratio was closely analyzed across different studies, focusing on the expression of concentric force, generally considering a ratio of around 0.60 H/Q (in other words, hamstring force over quadriceps force) in an isokinetic dynamometer for an angular velocity of 60°/second. This ratio of 0.60 was considered the baseline below which the hamstring will be at risk of sustaining injuries (Orchard, Marsden, Lord & Garlick, 1997; Brockett et al., 2004)

The main critique of this ratio, especially since the first appearance of the paper published by Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen (1998) (which presented a new way of evaluating the ratio, considering the eccentric relationship of hamstrings between 30°/seconds and 60°/seconds, taking into account that the force-velocity curve for eccentric movements remains relatively constant, unlike the drastic fall in force at higher speeds in concentric movements, with 240°/seconds concentric in the quadriceps) is that it does not take into account the physiological and functional reality of manifestations of strength in these muscle groups in real game situations. Therefore, the method for drawing connections between the force levels of these antagonistic muscle groups, as considered by Aagaard et al. (1998), is closer to the reality these muscles undergo in sprint movements. This is called a functional ratio.

Based on these facts, the research groups of Croisier, J.L., Forthomme, B., Namurois, M.H., & Vanderthomme, M. (2002) and Croisier, J.L., Ganteaume, S., Binet, J., Genty, M., & Ferret J. M. (2008) presented two important papers related to this functional ratio that will be summarized below.

In the first paper by these authors, published in 2002, 26 male athletes (14 soccer players, 7 track and field athletes and 5 martial artists) were evaluated, each having a background of hamstring injuries and chronic pain in this muscle group. The conventional and functional ratios were evaluated in an isokinetic dynamometer, and a significant reduction was found in the functional eccentric ratio of flexors at 30°/s and the concentric functional ratio of extensors at 240°/s in the leg with the previous femoral injury, when compared with the leg that had not been injured. This fact did not correspond with the conventional torque observed under normal standards. The significance of this paper was to correlate this ratio with the discovery of a functional deficit that could be underestimated by the conventional ratio.

Figure 3: Different Ratios Comparing the Hamstring and Quadriceps Torque in Injured and Non-Injured Legs



Source: Crossier et al., 2002, pg. 201
Key: Blue: Contralateral Hamstring. Red: Injured Hamstring.
C60/C60= Concentric 60°/Concentric 60°; C240/C240= Concentric 240°/Concentric 240°; E30/C240= Eccentric 30°/ Concentric 240°.

The second, more recent paper by these authors (Croisier, Ganteaume, Binet, Genty & Ferret, 2008), considered a broad analysis of the ratio of force imbalances between quadriceps and hamstrings, tested with isokinetic dynamometers, and the injury risk factors of this muscle group in a follow-up after the evaluation.

This paper turned out to be incredibly important, especially because of the sample obtained from 687 soccer players, 462 of whom were subjected to a proper follow-up study mid-season, and who were all evaluated isokinetically (in preseason) in an attempt to identify imbalances between the quadriceps and hamstrings at different speeds (high and low) as well as with concentric and eccentric movements.

One of this study's more interesting findings is that players with a significant imbalance in the mixed functional ratio (eccentric 30° H/concentric 240° Q) had a higher index of injuries in the prospective follow-up.

Another relevant piece of information is that soccer activities increased the risk in those players with untreated imbalances by 4.66 times, while in players with imbalances that were treated and monitored through isokinetic devices, the relative risk was only 1.44. This means, a player with a deficit is subject to risks that could be reduced with a correction of these ratios and a precise monitoring of said correction.

On the other hand, in keeping with the facts presented in the previous paper, the methods for evaluating concentric standards did not take into account around 30% of the players with eccentric deficits. This could lead us to underestimate the deficit if we were only to use these evaluation methods, since what the authors' proposal makes clear, in parallel with that of Aagaard et al. (1998), is that the functional ratio can give us more specific information when testing imbalances with the aim of reducing incidence of injuries in this muscle group.

Table 1: Standard for Description of Players with Force Imbalances (n=216)

Features of the Imbalances	Proportion of Players (% of *n*=216=100%)
Bilateral Differences	
Conc 60°/s	85/216(39)
Conc 240°/s	69/216(32)
Ecc 30°/s	130/216(60)
Ecc 120°/s	126/216(58)
Ratio H/Q	
Conc 60/conc 60°/s	118/216(55)

Conc 240/Conc 240°/s	82/216(38)
Mixed functional Ecc 30/Conc 240°s	187/216(87)
Key: conc = concentric; ecc = eccentric; s = second (;) H/Q = hamstrings/quadriceps; mixed functional ecc /conc = mixed functional eccentric hamstrings / concentric quadriceps	

Source: Crossier et al., 2008, pg., 1473

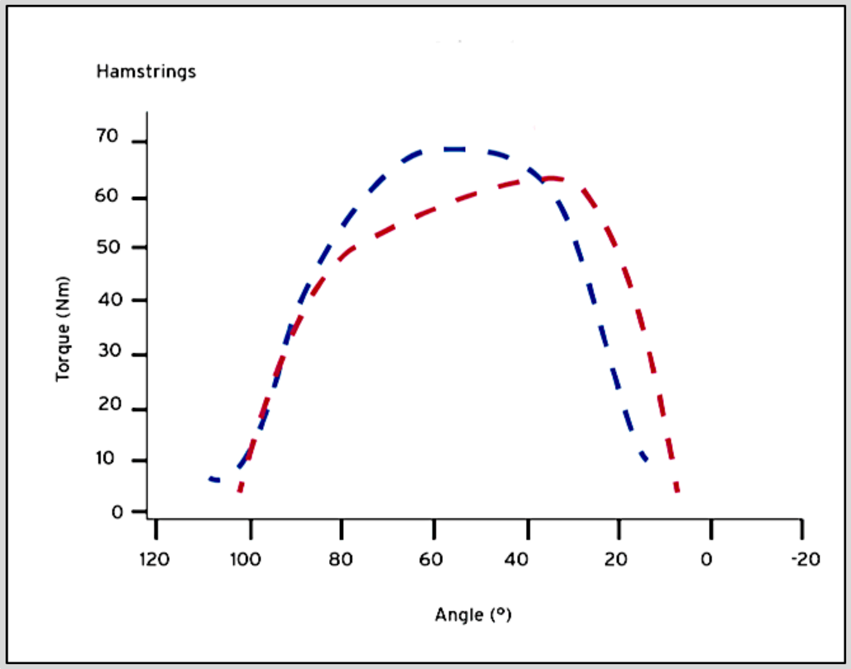
One of the findings produced by this study is that the players with functional ratios around 1.40 did not present hamstring injuries, allowing us to regard this ratio as an optimum level for reducing the risk of injury in this muscle group.

Finally, these authors suggest using this evaluation methodology to determine imbalances in these muscle groups after training or control deficit adjustment periods, in accordance with this methodology.

As far as the assessment of this muscle group and the attempt to assess at-risk subjects, it is also interesting to observe the properties of the torque curve or angle where peak torque is produced, in order to be able to assess if those players with more open peak torque angles could have a different relation to the injury index (Brockett, et al., 2004; Naclerio Ayllón, 2010)

As mentioned earlier, Brockett et al. (2004) find that subjects with a history of hamstring injuries had peak torque angles that were more closed than in the non-injured leg of the same subjects, thus posing a risk of repeated injury. However, these authors note that analyzing a larger sample is warranted in order to be able to estimate the safe ranges of angles within which peak torque should fall, as well as the risk areas, and to grant more authority to this analysis when identifying at-risk subjects (Brockett et al., 2004).

Figure 4: Superimposed Peak Angle-Torque Curves for Hamstrings



Source: Brockett et al., 2004, pg. 381. Leg with History of Injuries, Red Lines; Non-Injured Leg, Blue Lines.

In an effort to find another hypothesis for the increased risk of hamstring injury due to previous injury, Slider, Reeder and Thelen (2010) applied biomechanical methods to study subjects with previous hamstring injuries, finding that the residual scar from a previous injury could negatively affect the local mechanics of the affected tissue in such a way as to contribute to an increased risk of re-injury during movements that involve active stretching of the muscle.

It is entirely possible that different factors could be the cause for the increased risk of hamstring injury with a previous injury, which establishes the importance of optimal rehabilitation after the first episode and the follow-up, as well as enhanced preventive measures for this group of athletes with a history of injuries, in order to significantly mitigate this risk factor.

The Relationship of Fatigue to Eccentric Torque in the Hamstrings

Given the importance of eccentric torque in the hamstrings and the ratio of concentric torques among antagonistic muscles in the thigh as they relate to the injury risk factor of this muscle group, it is interesting to research the dynamic of this torque in relation to fatigue produced specifically by these sports.

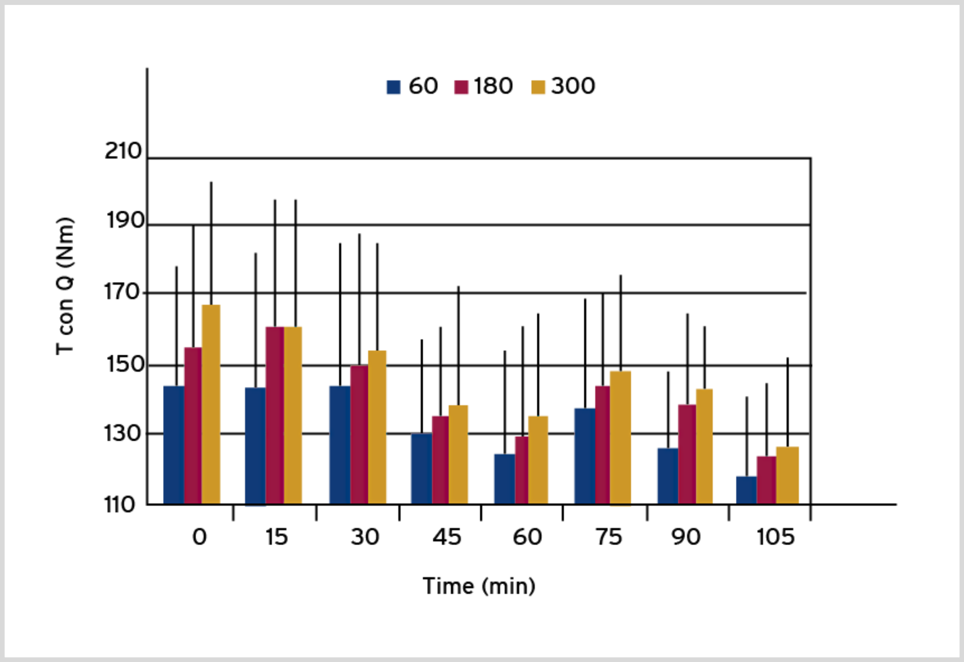
Accordingly, Greig (2008) evaluates the response of both concentric and eccentric Q/H isokinetic torques after a treadmill protocol that replicates the intermittent dynamics of soccer (105 min).

The weak point in this study can be attributed to the fact that it does not consider the changes of direction and brakes, or changes of speed that increase the development of neuromuscular fatigue in a player. Also, the functional torque is obtained by comparing equal eccentric and concentric velocities for the antagonistic muscle groups with other papers that relate 30 ecc H/240 con Q, especially that of Aagaard et al. (1998), the original authors of this ratio.

Though some facts can be inferred from the aforementioned, these authors found that the peak eccentric torque diminished as the exercise progressed, especially after the 15 minute break at halftime, while concentric torque remained relatively stable.

On the other hand, the functional ratio tends to diminish at speeds of 180 and 300°/s, while at 60°/s it remains relatively stable. The ratio at 180°/s fell from 1.05 at 0' and 1.14 at 15' to 0.81 at 105'. The ratio at 300°/s also underwent a significant reduction of 1.33 min 0 and 1.3 min 15 to 1.07 at 45 min and 1.03 at the end of the 105 minutes, as well as 1.07 at 60 minutes.

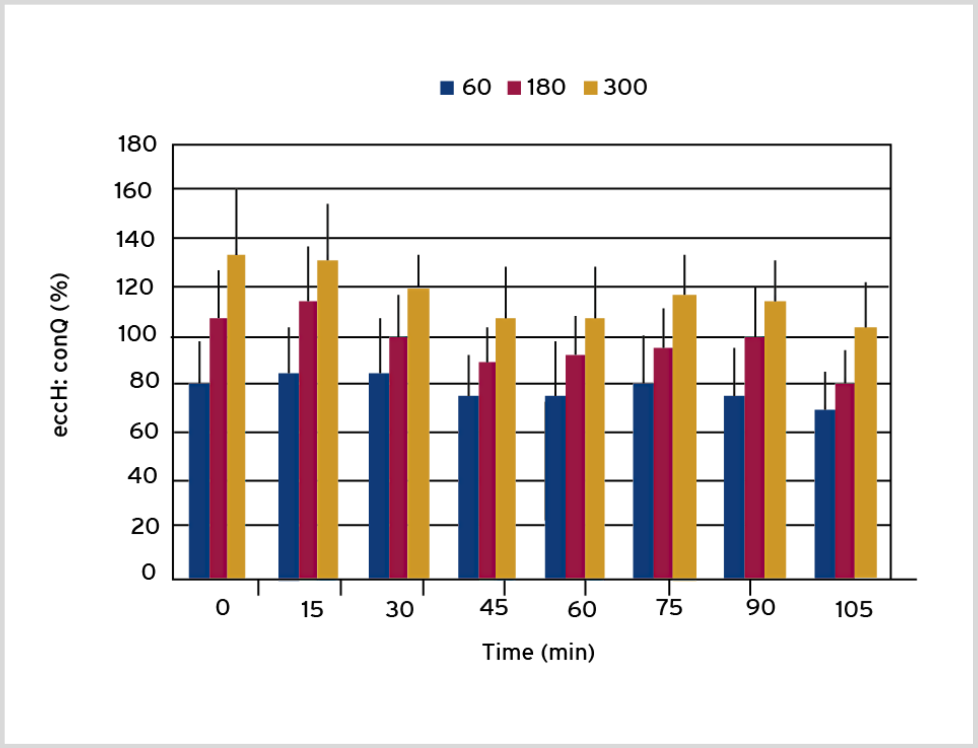
Figure 5: Background of Isokinetic Eccentric Peak Torque of the Knee Flexors during the Intermittent Protocol Specific to Soccer



Source: Greig, 2008, pg. 1406. Key: T ecc H = hamstring eccentric torque

The most relevant part of this study is the attempt to correlate the reality of specific fatigue in the game and the progress of the hamstring's eccentric torque, where a tendency to progressively lose torque shows up in this muscle group, unlike in the antagonist group.

Figure 6: Background of the Functional Force Ratio during the Period of the Intermittent Protocol Specific to Soccer



Source: Greig, 2008, pg. 1406. Key: ecc H: con Q = eccentric hamstring: concentric quadriceps.

Furthermore, it would be interesting, drawing from this study, to carry out more research in line with the functional ratio proposed by Aagard et al., (1998) and considering other methods for evaluating the decline in performance in soccer, as for example with a field test with changes of direction (i.e., yo-yo test), as well as the progress of this ratio after having performed a set of specific trainings, such as repeated sprints, which could directly affect the eccentric torque of the quadriceps.

As mentioned before, the paper by Andrews, Dawson and Steward (2005) evaluated the conventional and functional ratios of these muscle groups before and after a test of repeated sprint activities (RSA) (6*40 m [131 ft] with 30 s of brief pauses), identifying a 12% loss of conventional torque due to the acute fatigue produced by the test, but without finding a reduction in the functional torque.

We can infer from this paper that the acute fatigue produced by only a single series of RSA (observing the protocol of the test, 1*6 sprints of 40 m [131 ft]) is insufficient to chart the reality of the fatigue produced by the repetition of high-intensity movements in a game in which, regardless of position, the meters run just in the act of sprinting (more than 23 km/h [14.29 miles/hour]) are found to be between 200 and 460m [656 and 1509 ft] per game, without considering the context in which these movements are undertaken (total m, m at high-intensity greater than 19 km/h [11.8 miles/hour], at high-intensity greater than 23 km/h [14.29 miles/hour]) which could influence the functional torque in different ways, making it necessary to find a different methodological design to be able to assess the relationship.

The electromyographic (EMG) responses of the hamstrings, rectus femoris, tibialis anterior and calf were all evaluated in a study by Rahnama and Manning (2005) in the period before, during, and after a treadmill protocol that randomly replicated the intensities of running in soccer, in an attempt to reproduce the specific fatigue produced by this sport. The muscles studied here presented higher EMG activity before the physical activity than after. This suggests that fatigue reduces the levels of electrical muscular activity, and that this reduction of activation levels (which translates to a deficit of force) is owing to a reduction of neural activity in the muscles, leading to a drop in performance.

In light of these results, and connecting them with everything we have been developing here, we can conclude that neural fatigue is also involved in eccentric or concentric torque deficit in the hamstrings and that this represents an injury risk factor towards the end of an athletic event.

Finally, it is interesting to consider that this relationship between torque and local fatigue could be studied in greater details with records of torque before and after more soccer-specific activities such as intense small-sided games, friendly matches, and after a training of multiple series RSA with different stimulus-pause densities. Based on these assessments, more specific conclusions may emerge about the relationship and influence of fatigue on the functional ratio, due to the presence of soccer-specific elements such as changes of direction, brakes and starts, which directly influence fatigue and the production of force in the main affected muscles and, therefore, the subsequent conclusions about injury prevention.

Flexibility as a Risk Factor Associated with Hamstring Injury

This empirical study of this subject has been underway for many years, where it was suggested that the shortening of this muscle group or the flexibility deficit in the group was an important factor in injury risk. However, the scientific literature about this topic has not found clear evidence supporting this fact, whereas other risk factors like age, previous injuries, and the deficit of eccentric torque have been supported with evidence.

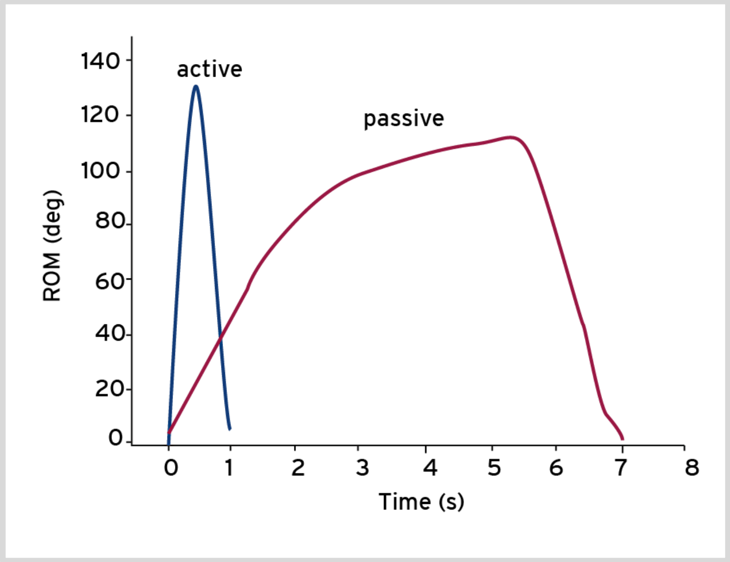
On this subject, Arnasson, Sigurdsson, Gudmunsson and Holmelngar (2004) interestingly determined that the reduction of the ROM (Range of Motion) in the hamstrings was not associated with an enhanced risk of sustaining injuries in this muscle group, unlike the adductor muscles, where this factor can be classified as a risk for injuries in that muscle group. Despite this, authors like Witvrouw, Danneels, Asselman, D'Have & Cambier (2003), and Bradley and Portas (2007) argue otherwise. The main criticisms made about these papers are rooted in the use of static tests to observe the ROM of the hamstring, a situation that differs from the specific demands placed on the hamstring during running.

Figure 7: Example of a Static Flexibility Test of the Hamstring

Source: Askling, et al., 2010, pg. 1800.

In that sense, it seems clear that it would be a mistake to try to correlate the passive stiffness of this muscle group with predominantly static tests (H test, PKE, (Passive Knee Extension) and AKE (Active Knee Extension) to determine the injury index of this muscle group, since the behavior of dynamic stiffness, which is more similar to the reality of this muscle group while running, is significantly different.

Figure 8: Performance of Active and Passive ROM in Hamstrings



Source: Askling et al., 2010, pg. 1801.

On the other hand, Arnasson published an interesting paper in 2008, wherein he evaluated the reduction of the number of injuries in this muscle group, applying only flexibility training, and combined eccentric and flexibility training in warm-ups. His results showed that the group that performed eccentric training had significantly fewer injuries compared with the group that did not perform this kind of training and was limited only to the flexibility training, attributing this fact to the positive effect of eccentric training on this muscle group. This fact is supported by systematic reviews, like that of Thacker, S. B., Gilchrist, D. F., Stroup, C. D., & Kimsey, Jr. (2004), who propose that there is no consistent relationship between flexibility in this muscle group and reduction of the incident.

While there are other studies that demonstrate that flexibility training can play an important role in prevention programs for this muscle group (Dadebo, White & George, 2004), the current trend shows us that eccentric training for this muscle group turns out to be more effective in preventing injuries (Arnasson et al., 2006; Naclerio Ayllón, 2010; Lieber, 2002).

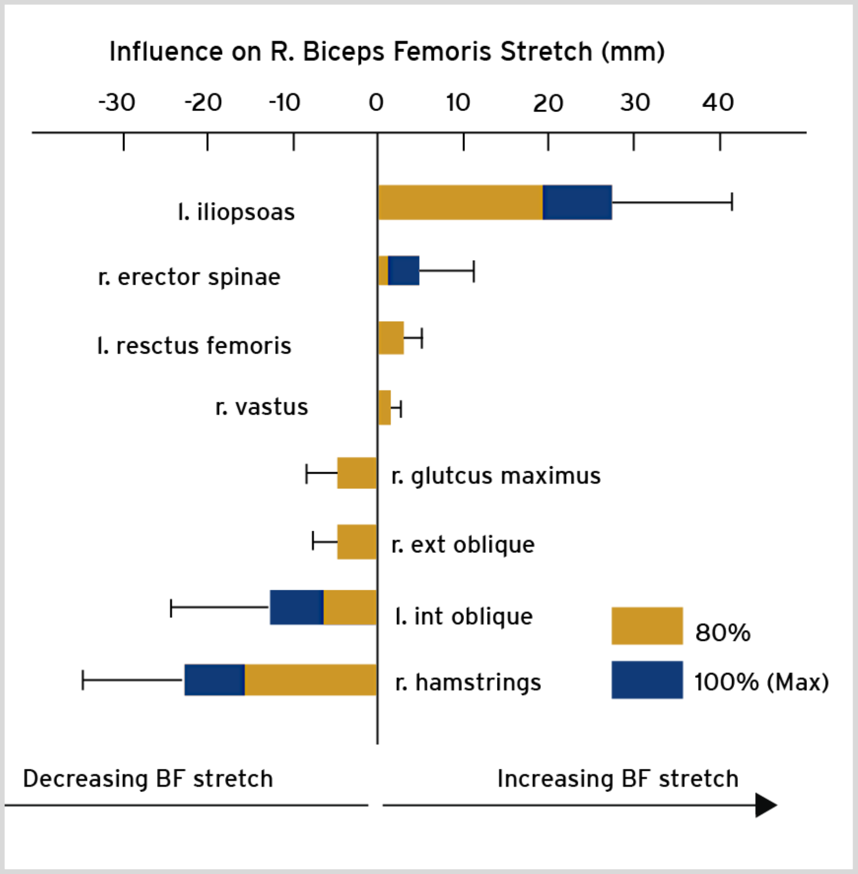
However, the decisive piece of data for this section is based on the fact that there is no conclusive evidence (or at least contradiction-free evidence) that supports the fact that a lack of flexibility in this muscle group is an important injury risk factor.

In conclusion, we can determine that isolated flexibility training, without complimentary restoration of eccentric force levels in the muscle group, will be incomplete in reducing the incidents of hamstring injuries.

Hip Flexor Flexibility as an Injury Risk Factor for the Hamstrings

In the past years, drawing on the analysis of this muscle group's injury mechanisms and the impact that biomechanics of the pelvis during running could have on the active stretching of the hamstring in the final swing phase of running, especially at high speeds, it has been proposed that hip flexor flexibility could impact the injury risk of the hamstrings. As described by Chumanov, Heiderscheit and Thelen (2007), and Schache, Blanch, Rath, Wrigley and Bennell (2005), the flexibility of contralateral hip flexors has a big influence on hamstring tension, which tends to increase as running speed increases.

Figure 9: Individual Influence of the Different Muscle Groups in the Stretching of the Hamstrings while Running at Different Speed Percentages



Source: Chumanov et al., 2007 pg. 3560.

Just as with the hamstrings, the same question arises from this line of questioning; which is to say, even if there are positive correlations between passive ROM tests for hip flexors (Thomas test) and an increase in injury risk in the hamstrings, the conclusions found in static evaluations cannot be transfered to dynamic and high-speed situations (Gabbe, Finch, Bennell, & Wajsweiner, 2005). Ratios of force with hip flexors/eccentric hamstrings could yield better conclusions on this topic.

2.1.4 Extrinsic risk factors for hamstring injuries

Level of Competition

Some papers, like that of Verrall, Slavotinek and Barnes (2005) on Australian rules football, indicate that the level of competition increases the risk of injury for the hamstrings; which is to say, a higher level athlete will have a higher risk of sustaining hamstring injuries. The reason behind this fact is not entirely clear. However, it is possible that it is due to the increased level of training and the demands on the hamstrings in high-level competitions.

Competition vs. Training

It has been proven that the risk of sustaining a hamstring injury is greater in competitions than in trainings, with a ratio of ten times greater incidence for this muscle group in high-risk sports, such as soccer or Australian rules football (Verrall, G. M., Slavotinek, J. P., & Barnes, P. G. 2005). It seems that the greater demand and strain during matches for longer periods of time can negatively affect this muscle group with regards to fatigue, and therefore, the risk of injury.

The Player's Field Position

In sports like rugby there is a substantial difference with regard to the risk of sustaining a hamstring injury depending on field position, wherein the backs sustain more injuries in this muscle group than the forwards (Brooks J H M, Fuller C W, Kemp S P T, Reddin D B. (2005). In soccer, the mid-fielders are the player with the highest risk of sustaining hamstring injuries (Arnason, Sigurdsson, Gudmundsson, Holmelngar, Engebretsen, & Bahr, 2004). The explanation for this is that these positions make use of the fastest players, and therefore those players whose primary activity is highly associated with sprinting.

Insufficient Warm-Up

There is a nearly unanimous perception that poor warm-up is a risk factor for hamstrings. This is likely due to inadequate pre-game preparation leading to hamstring muscles being less prepared to absorb the eccentric stress generated during the course of the game. However, while it is clear that an adequate warm-up is necessary, there is no consensus about what is the best way to prepare this muscle group for reducing the risk of injury.

Unit 2.2 The preventive approach to muscle injury prevention

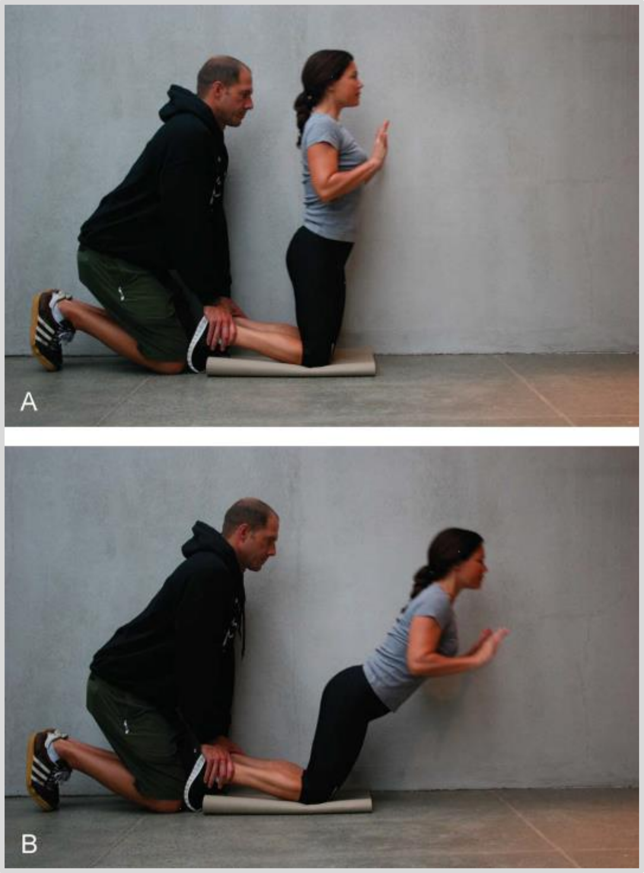
Hamstring muscle injuries have multi-factorial characteristics. While it is clear that the main injury mechanism is eccentric tension in the final swing phase of running, and especially running at high speed or sprinting in sports with intermittent dynamics (without ignoring other less common injury mechanisms), there are a variety of intrinsic risk factors that make an athlete susceptible to sustaining this injury (See Chumanov et al., 2007; Schache et al., 2005; Woods et al., 2004; Schache, Kim, Morgan, & Pandy, 2010).

2.2.1 Eccentric training in muscle injury prevention

As reviewed in the previous sections, there is a large amount of literature that analyzes the risk factors associated with hamstring injuries (See Arnansson et al., 2004; Croisier et al., 2002; Croisier, Ganteaume, Binet, Genty, & Ferret, 2008; Gabbe et al., 2005; Mendiguchia, Alentorn-Geli, & Brughelli, 2012; Brughelli, Cronin, Mendiguchia, Kinsella & Nosaka, 2010; Hägglund, Waldén, & Ekstrand, 2006) in which the deficit in the ratio of concentric and eccentric forces between antagonists (hamstrings/quadriceps) are highlighted, among others, and the deficit of eccentric hamstring force, as well as the influence of fatigue on the eccentric hamstring force and its relationship with increased risk.

One of the first preventive measures proposed for this muscle group is the application of eccentric training in such a way as to create a protective effect against those same movements that are recognized as potentially risky. The first paper that established the application of low-load and low-volume eccentric training as an efficient preventive strategy was authored by Arnason, Andersen, Holme, Engebretsen and Bahr (2008), using the Nordic curl in addition to flexibility strategies as an effective preventive exercise in the reduction of incidence of hamstring injuries.

Figure 10: Nordic Curl Exercises



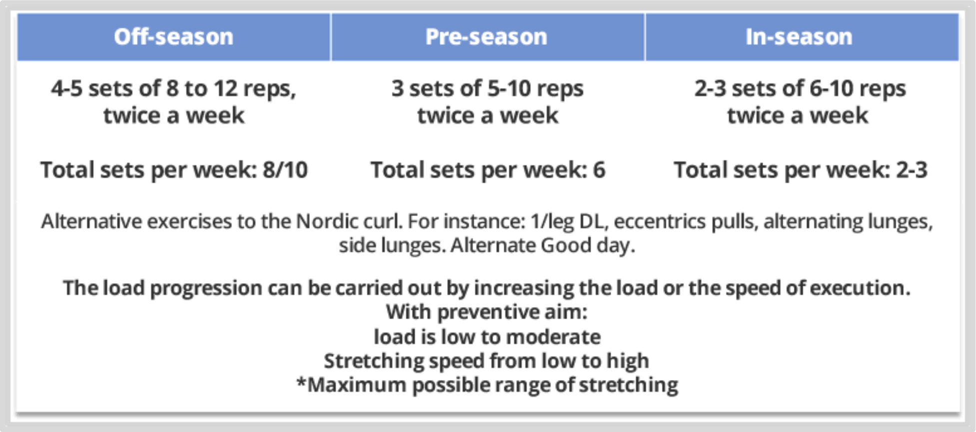
Source: [Untitled image of Nordic curl]. (n.d.). Taken from http://goo.gl/uo41RK

The paper by Arnason et al. (2008), one of the most cited in all the literature, proposed an incremental progressive training routine with this exercise for ten weeks, starting with only one weekly stimulus of 2*5 repetitions in the first week, progressing towards three weekly stimuli of 3*12-10-8 repetitions from the fifth week and so on. As a result, a 57% reduction of hamstring injuries was achieved, when compared with the teams that did not use this exercise.

According to different authors' analyses, it is likely that the application of eccentric training generates stress-induced muscular damage, and that the muscle responds to the damage produced by the eccentric low-load and high-velocity movements in more open angles by modifying the TPA (Torque Peak Angle) towards angles that are more open. Some theorize that this adaptation is due to an increase in the number of sarcomeres in series without changing the fiber length (See Butterfield, Leonard, & Herzog, 2005; Lynn, Talbot, & Morgan, 1998; Brockett et al., 2004; Proske & Allen, 2005). Thus, after this adaptation, a reduction in stretching and individual stress would be achieved for each sarcomere with the same degree of lengthening (Proske & Allen, 2005). This effect is therefore associated with a higher tolerance of high-speed active stretching in the hamstrings (Brockett et al., 2001; Brockett et al., 2004).

More recently, Brughelli and Cronin (2008) have proposed a progressive application of eccentric training with varied exercises targeting prevention goals for the hamstrings, while trying to more comprehensively influence the different muscles that make up the hamstrings, also taking into account the current stage of the season.

Table 2: Eccentric Training Schedule with Prevention Goals



Off-season	Pre-season	In-season
4-5 sets of 8 to 12 reps, twice a week	**3 sets of 5-10 reps twice a week**	**2-3 sets of 6-10 reps twice a week**
Total sets per week: 8/10	**Total sets per week: 6**	**Total sets per week: 2-3**
Alternative exercises to the Nordic curl. For instance: 1/leg DL, eccentrics pulls, alternating lunges, side lunges. Alternate Good day.		
The load progression can be carried out by increasing the load or the speed of execution. **With preventive aim:** **load is low to moderate** **Stretching speed from low to high** ***Maximum possible range of stretching**		

Source: Adapted from Brughelli and Cronin, 2008.

While in the past few years there appears to have been a consensus regarding the inclusion of eccentric training for the protection of hamstrings and for the reduction of incidents of injury, this strategy in isolation does not solve the problem and should be understood within a comprehensive framework that deals with the rest of the risk factors that we have considered in this module. It is also worth highlighting that this, like the rest of the prevention measures, has more or less sensitivity according to the adherence or compliance with the intervention program and the frequency of its application (Good et al., 2015). Furthermore, one aspect to bear in mind and consider is the timing of the session, that is, where it would be most appropriate to place this intervention. According to Small, McNaughton, Greig and Lovell (2009) this turns out to be more effective in connection with induced adaptations towards the end of the training session.

2.2.2 The importance of core stability in the muscle injury prevention

Another aspect to consider is the relationship between lumbo-pelvic stability during running and hamstring injuries. It has been suggested that previous injuries, fatigue, and certain imbalances of length (i.e., in the psoas) or from activation deficit (i.e., in the gluteus maximus) can cause an increase in the eccentric demands on the hamstring during running (Chumanov et al., 2007; Silder, Reeder, & Thelen, 2010; Brughelli et al., 2010).

It would seem that poor lumbo-pelvic stability could affect the biomechanics of the hamstring and place it in a stressful situation predisposing the muscle to injury.

According to authors such as Heiderscheit, Sherry, M. A., Silder, A., Chumanov, E. S. & Thelen (2010), and Sherry, Best, Silder, Thelen and Heiderscheit (2011), the preventive approach should aim to incorporate hamstring activation into core stability through comprehensive and functional exercise programs that demand this kind activation (as much as possible, eccentric activation or active hamstring stretching) to the lumbo-pelvic stability exercises. Furthermore, we should also keep in mind the correct normalization of hip flexor chain length, which can generate inhibitions and negative influences in the eccentric demand on the hamstring (Chumanov et al., 2007).

Figure 11: Comprehensive Exercise Programs that Demand Core Stability

Source: [Untitled image of comprehensive exercise program] (n. d.). Taken from http://goo.gl/uo41RK

2.2.3 Flexibility as a preventive measure

There is no consensus about the application of flexibility training itself in the reduction of the incidence of injuries in this muscle group, probably due to the lack of a strong association establishing this aspect as a risk factor (McHugh & Cosgrave, 2010).

However, it is likely that flexibility training of other muscle groups like hip flexors, which affect the kinematics of running and increase eccentric stress on the hamstrings, would be appropriate within a comprehensive preventive approach.

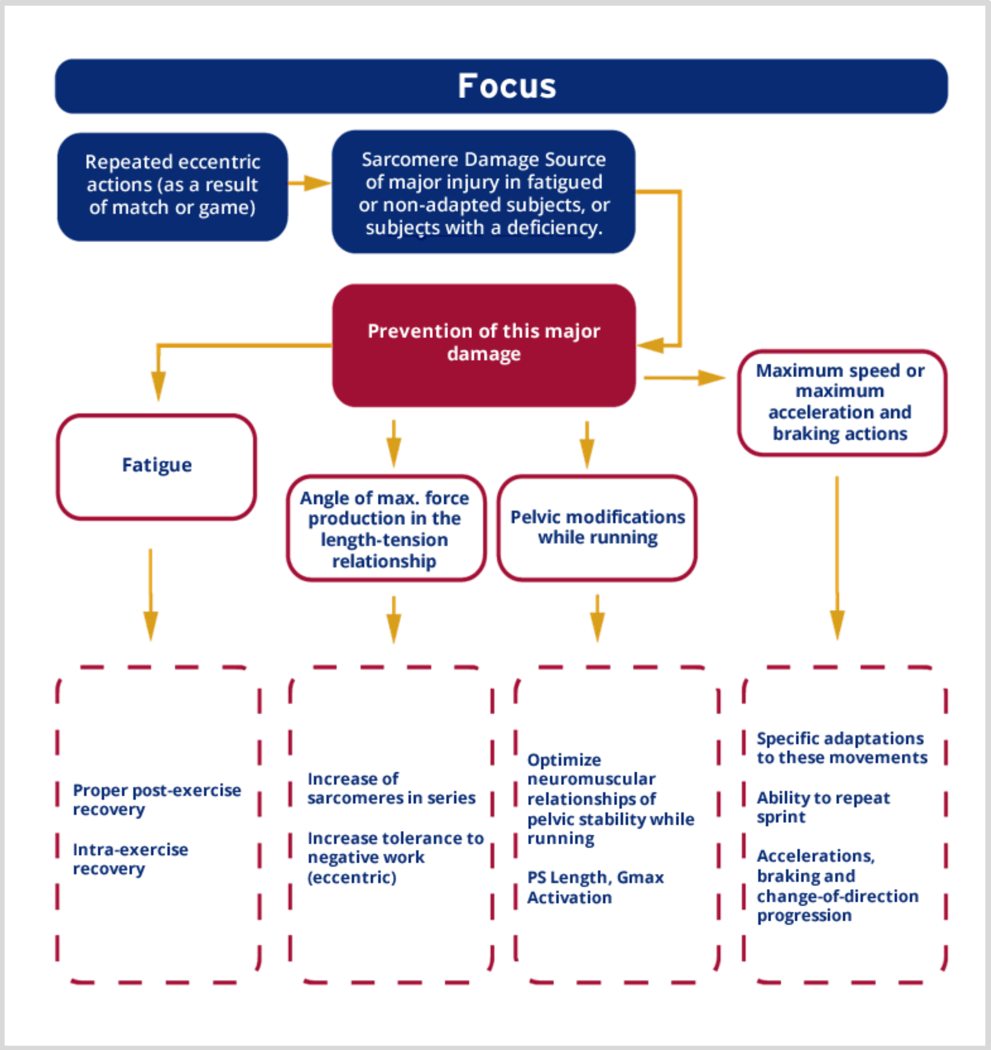
On this point, it is relevant to look into the effects of other flexibility training techniques that could contribute to a comprehensive injury prevention approach, such as self-directed myofascial inhibition or hamstring stretching that eliminates neural tension (Orishimo & McHugh, 2015).

2.2.4 Tools for detecting players with risk of muscle injury

Keeping in mind this range of risk factors and the different interrelations that have been established among them, it would be illogical to designate only one exercise (i.e. the Nordic curl) as the solution to the problem. Even if this exercise has demonstrated certain levels of efficiency in the reduction of incidents of hamstring injuries (Arnansson et al., 2008), the latter has maintained relatively high rates over the last several years, being the most common injury among injuries stemming from overuse in sports like soccer (Ekstrand et al., 2011 b).

In this sense, it is crucial to draw from an analysis of the risk factors that our athletes experience in order to develop a prevention program based on an assessment of their weak spots.

Figure 12: Conceptual Diagram of the Prevention of Hamstring Injuries



Source: Prepared by the author(s)

In Figure 12 one can see the line of thinking that, broadly speaking, can guide interventions. Keeping this chart in mind, we can conclude that repeated eccentric movements (such as sprinting movements), when occurring in subjects not correctly adapted to this type of actions and suffering fatigue with deficits stemming from previous injuries, could be responsible for harm or larger muscle injuries (here referring to injuries with anatomical disorders: strains and tears, for example). Consequently, to reduce the risk of sustaining hamstring injuries, we should attempt to positively impact fatigue, the hamstring's production of eccentric force and its length-tension ratio, as well as the kinematics modifiers for the pelvis in running and training, adaptation to sprinting and related movements.

In that sense, knowing that fatigue enhances other risk factors such as previous injuries, movements attempting to counteract fatigue will also act as prevention boosters. The use of all those measures that ensure recovery post-exertion will reinforce prevention. One measure worth mentioning is cold water immersion, best applied after activities that cause adaptive muscle damage.

Regarding more specific aspects of the hamstring's biomechanics, it seems clear that the application of low-load, high-speed eccentric training carried out in open angles of ROM could positively reinforce the protection of this muscle group. This application should not be limited to the exclusive use of exercise for this goal, but rather for the design of exercises that functionally and comprehensively stress this muscle group, thus resulting in greater benefits (Cowell et al., 2012). For example: single-leg dead lifts, lunges with jumping jacks, eccentric decelerations in one-footed bridge position while in supine decubitus, etc.

Regarding the relationship between lumbo-pelvic stability in running and hamstring injuries, as outlined in previous paragraphs, this aspect should be considered and dealt with comprehensively in a manner that not only stimulates the hamstring, but that also integrates it into the chain of movement and with the stabilizing synergy of the core.

Finally, specific training of variables that alleviate local fatigue as well as generating positive adaptations for this musculature will also contribute to the prevention of injuries; which is to say, if our athletes are well-adapted to the multiplicity of motions that place stress eccentrically on the hamstring during a game, they will surely be more prepared to withstand this stress and reduce the impact of unplanned movements.

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