Hamstring Strain Prevention in Elite Soccer Players

Anthony N. Turner, MSc, CSCS*D, Jon Cree, MSc, CSCS, Paul Comfort, MSc, CSCS*D, Leigh Jones, BSc, Shyam Chavda, MSc, CSCS, Chris Bishop, MSc, and Andy Reynolds, MSc

1London Sport Institute, Middlesex University, London, United Kingdom; 2College of Health and Social Care, University of Salford, Manchester, United Kingdom; 3Sport and Exercise Science Department, Huntingdonshire Regional College, Huntingdon, Cambridgeshire, United Kingdom; 4Medical Services, Harlequins RFC, London, United Kingdom

ABSTRACT

HAMSTRING STRAINS ARE A COMMON SOFT TISSUE INJURY IN ELITE SOCCER. THE INJURY AND REINJURY RATES FOR THIS ARE HIGH, AND EFFICACIOUS PREVENTION STRATEGIES ARE YET TO BE STANDARDIZED. AFTER THE RESEARCH HEREIN, TRAINING MODALITIES EMPHASIZING HAMSTRING ECCENTRIC STRENGTH TRAINING PROGRESSING FROM LOW-VELOCITY TO HIGH-VELOCITY ACTIVITIES AND THE PREVENTION OF FATIGUE (I.E., CONDITIONING DRILLS) ARE RECOMMENDED.

INTRODUCTION

The growth of soccer as a recreational and competitive sport has been evidenced through literature, and it is estimated that around 200 million people participate, including both sexes and across all age groups (30, 66, 70). Scandinavian studies documented a high risk of injury within sport, accounting for 10–17% of all injuries seen in an emergency room (26, 58, 96). It has also been reported that the risk of injury to professional soccer players is several times higher than for industrial occupations regarded as high risk (31, 38, 40, 91).

Hamstring strains are among the most common injury in sport and are most often observed in sports that involve sprinting, turning, and jumping (8, 38, 63). The prevalence of hamstring strains has been measured between 11 and 16% in studies of soccer, Australian rules football, and cricket (92). This can result in an average of 6 players per squad suffering a hamstring injury (defined as “preventing player participation in a match”) each season in professional soccer and Australian rules football (92).

DEFINING THE PROBLEM

The documentation for the occurrence of hamstring injuries is available primarily in soccer (38, 71, 86, 92), rugby (12), and Australian rules football (65), where a high prevalence has been reported (11–16% of total injuries). Work by the Football Association, who undertook an epidemiological study of injuries sustained in English professional soccer over 2 competitive seasons (1997–99), documented that 12% of all injuries were hamstring strains (40, 92). This is further supported by Dvorak and Junge (30) and Hawkins et al. (39) who found that more posterior upper leg injuries occurred in elite soccer players than lower leg, with the majority of them being acute traumatic strains. In addition, Rolls and George (71) conducted a prospective analysis of all academy-aged players from an English Premier League club during one season and found that of the 93 players assessed 20 suffered hamstring injuries that season (21.5%).

Arnason et al. (5) hypothesized a significant relationship between the total number of injury days per team and team performance. Throughout the duration of the 1999 Icelandic Football League season, 17 teams, spread over the 2 upper divisions, recorded approximately 10 injury days per player. They then suggested that injuries to key players would detract from team success. Furthermore, though players can be substituted for part or a whole match, or replaced by acquiring a new player from other clubs, the limited resources of most teams to be able to buy quality replacements, and in the age of transfer windows when even wealthy clubs are unable to do so, injuries may also be seen as a financial issue.

Despite its prevalence, the treatment of hamstring strains continues to be...
a frustration to medical personnel, not only because of high incidences but also because of the high reoccurrence rates that exist with this injury. Brooks et al. (12) recorded a 23% reoccurrence rate of hamstring strains and noted that these reoccurring injuries were significantly more severe than new injuries. This is corroborated by Hawkins and Fuller (38), Petersen and Holmich (67), and Verrall et al. (84) with the latter research team suggesting that athletes who have previously suffered a posterior thigh injury have a 4.9 times increased risk of a hamstring strain than those without. This higher risk of recurrence of injury may be attributable to incomplete rehabilitation practices that commonly neglect the eccentric and high-velocity requirements of the hamstring muscles during sporting activities (19).

The literature demonstrates that hamstring strains within professional soccer are an ongoing quandary for players, coaches, and medical staff. It has been argued that the solution lies with prevention strategies rather than from treatment alone (8,39,83). Significantly, Woods et al. (92) revealed that some of the 91 English professional soccer clubs sustained very few hamstring strains over a period of 2 seasons, whereas other clubs reported very high rates. They suggest that these differences could be because of a variety of variables in injury diagnosis, training techniques, and medical management; however, it does at least suggest that the occurrence of these injuries can be reduced.

Despite the aforementioned prevalence, there is a surprising lack of research for the prevention of hamstring strains, perhaps because of the limited understanding of the pathophysiology and risk factors that predispose athletes to this injury (92). There is currently no consensus for the most effective prevention regime; however, there are several modalities in place that are generally regarded as appropriate and safe. These modalities are based on the predictive-causative factors of hamstring strains, namely, inadequate hamstring strength (8,11,35), strength imbalance between hamstrings and quadriceps (22,33,95), poor hamstring flexibility or reduced range of motion (8,24,67), early fatigue (35,92), and improper warm-up protocols (67,79). These factors, and more recent research on the beneficial effects of increasing eccentric hamstring strength (57,61), may hold the key to reducing the risk of hamstring strains.

PATHOPHYSIOLOGY AND MECHANISM OF INJURY

To reduce the risk of hamstring strains, it is important to establish the etiology and mechanics of the injury mechanism. If patterns can be determined in the events leading up to an injury, then this information may be applied to facilitate prevention and rehabilitation (8).

PATHOPHYSIOLOGY

The hamstring group consists of 3 individual muscles: biceps femoris, semitendinosus, and semimembranosus. The hamstrings work primarily to flex the knee and extend the hip. It is commonly hypothesized that one reason for the susceptibility of hamstring strain injury is because of its biarticular formation, whereby it crosses over 2 joints and is therefore subject to stretch at more than one point (28,40,65,92).

Also creating knee flexion, the hamstrings co-contract to minimize both anterior and lateral tibial translation (2,31,50) aiding knee stability (1). In addition, the biceps femoris muscle secondarily acts as a lateral rotator of the semiflexed knee and extended hip. Specific to soccer, it has been suggested that the hamstrings' main roles are to control the running action and stabilize the knee during turns or tackles (90). Given the rotational demands of soccer (multiple changes of direction), this may explain the specific predisposition of this muscle to injury as corroborated by the research of Hawkins et al. (40) and Woods et al. (92) who annotated player’s injuries over 2 seasons from 91 professional soccer clubs. Hamstring strains accounted for 12% of total injuries (40,92), of which 53% involved the biceps femoris (92). This is further supported by Connell et al. (20), who assessed hamstring injuries in 60 male professional football players. The biceps femoris was recorded to be the most commonly injured muscle, further confirming the findings of earlier reports by De Smet and Best (27) and Brandser et al. (10). More specifically, it is reported that it is the long head of biceps femoris that is most commonly injured during sprinting activities (20,53,77).

The biceps femoris has 2 heads, a long head that has an origin of the medial facet of the ischial tuberosity and a short head that has an origin of the lateral linea aspera, lateral supracondylar line, and the intramuscular septum. Both heads run down to form one common tendon at the head of fibula, the lateral condyle of the tibia, and the fascia of the leg. The 2 heads have the different nerve innervations, the long being supplied by the tibial branch of the sciatic nerve and the short head being supplied by the peroneal branch. This dual innervation has been postulated to cause asynchrony of the nerve stimulation to the muscle and therefore could predispose the biceps femoris to imbalances and subsequent tears (32,78).

MUSCLE STRAIN CHARACTERISTICS

Muscle strain injury is characterized by a disruption of the muscle-tendon unit, usually occurring at the proximal musculotendinous junction (20,27,76). Strains usually occur when the muscle is either elongated passively or activated during stretch (55). When the muscle is activated eccentrically, a greater magnitude of force can be generated (1.5–2 times greater) in comparison with either an isometric or a concentric contraction (55). Lack of preconditioning or larger than usual force can lead to injury to the muscle, myotendinous unit, or the tendon itself (55).

Clinically, sport physicians will classify injuries into a 3-point grading system. Grade 1 being a mild injury where a few fibers are torn, grade 2 a moderate injury where several fibers are torn, and grade 3 is a complete tear (13). Magnetic resonance imaging or computerized tomography scan is often
used to determine the position and size of the injury because the size of the tear has been linked to the number of days lost to the injury (87). The position of the tear does change the level of pain felt by the athlete but does not seem to determine the length of injury (84).

**MECHANISM OF INJURY**

Schache et al. (76) were able to record biomechanical measurements using kinematic and ground reaction force data for pre- and post-hamstring injury suffered while sprinting. They demonstrated that the injured leg showed greater knee extension and hamstring muscle-tendon length during the terminal swing than the uninjured leg and before injury. This was in addition to an increased peak vertical ground reaction force and loading rate and an increased peak hip extensor torque and peak hip power generation during initial stance. They concluded that the injury most likely occurred before the foot strike during the terminal swing phase of the sprinting movement as a result of an eccentric muscle action where the biceps femoris was lengthened across both the hip and knee (76). This supports previous literature that hypothesized the temporal occurrence of the majority of hamstring injuries. For example, most studies suggest that hamstring strains occur most commonly during rapid sprint acceleration and during the later part of the swing phase (terminal swing) when the hamstrings are working to decelerate the limb and control extension of the knee (8,24,34,67,92). Here, the hamstrings must change from functioning eccentrically to decelerate knee extension and hip flexion and to functioning concentrically as an active extensor of the hip joint. It is stipulated that during this rapid changeover from eccentric to concentric function, the hamstring is most vulnerable to injury (85). These findings correspond to that of Thelen et al. (80) who provided a direct measure-ment for hamstring muscle kinematics. The study showed that peak hamstring muscle lengths, specifically the biceps femoris muscle, occurred in the late swing phase before foot contact and that biceps femoris excitation increased markedly between 70 and 80% of the gait cycle and continued through the end of the swing phase.

**RISK FACTORS**

Understanding the individual risk factors for hamstring strains is an important feature in preventing injury and is the basis from which preventative measures can be developed. Risk factors tend to be subcategorized into 2 main sections, nonmodifiable and modifiable. Nonmodifiable factors are issues that cannot be changed, whereas the modifiable factors can be.

**NONMODIFIABLE FACTORS**

The most common nonmodifiable factors in the literature are previous injury, age, and black or aboriginal ethnic origin (8,34,84,92).

*Previous injury.* It has been postulated that athletes who have previously suffered a posterior thigh injury have a 4.9 times increased risk of reinjury than those who have not (85). It was hypothe-sized by Verrall et al. (85) that the buildup of scar tissue around the musculature reduces its functional capacity, thus increasing the risk of injury. This correlates to Bhar and Holme (8) who state that a previous injury can lead to a reduced range of motion or reduced strength, thereby indirectly affecting injury risk. This is evidence of the cumulative injury cycle of Herring (43), in which inappropriately treated injuries can lead to recurring injuries. Essentially, the injury leads to scar tissue formation, which can cause a loss of range of motion at one or more body segments which in turn leaves the athlete susceptible to reinjury.

Alternatively, the athlete may be vulnerable to injury if they have not injured their hamstrings previously but have suffered an injury either proximally or distally to the hamstring—for example, from gluteal or calf musculature. The athlete will develop movement patterns to compensate for loss of range of motion at the injury site by moving excessively at adjacent segments. This concept is referred to as relative flexibility (a process by which the body finds the path of least resistance to motion), which links movement dysfunction to pathology (73). Essentially, during a multi joint functional movement, the stiff joint or muscle will prevent motion so the required movement is achieved by another joint movement through an excessive range of motion. This, in turn, leads to muscle imbalances that increase the risk of further injury (16).

*Age and exposure.* Verrall et al. (85) demonstrated hamstring strains to be more common in older athletes. This supports evidence from Arnason et al. (4) who undertook a comparative epidemiological study of injuries in youth and senior football club players. They concluded that the occurrence of injuries was higher at a senior club level. Both studies fail to offer an explanation; however, a study by Gabbe et al. (34) proposed that the increased risk was attributed to a loss in skeletal muscle mass. They suggest that as the body ages, there is a reduction in the cross-sectional area of skeletal muscle and an increase in nonmuscular connective tissue; this may further explain the increased risk of reinjury. As the force that a muscle can generate is proportional to the cross-sectional area, a reduction in muscle strength is therefore seen. These changes combined with age-related degeneration of muscle fibers may increase the risk of hamstring injury. However, for the population concerned, that is, elite athletes, this is not likely to be a causative factor as the level of atrophy and degeneration reported by these studies concern more senior athletes (>40 years).

Rolls and George (71) studied elite soccer players from 9 to 19 years and found that the older subjects suffered more hamstring injuries. They attributed this to the fact that those subjects were in full-time training, whereas the younger subjects had their exposure limited. The authors conceded that although this was a plausible theory, they lacked the quantitative data to compare training exposure with injury prevalence. However, Dvorak and Junge
(30) conducted a literature review of injury rates in soccer players and found an incidence rate ranging from 0.5 to 45 injuries per 1,000-hour exposure. Regardless of the actual rate, however, this may be evidence that the increased exposure of soccer players contributes to their increased rate of injury. It may be hypothesized that this creates more time to develop the muscle imbalances discussed later in this text.

Ethnicity. The studies from Woods et al. (92) and Verrall et al. (85) both show that players with a black or aboriginal ethnic origin are more at risk of sustaining a hamstring strain than Caucasian players. Verrall et al. (85) suggest that because aboriginal players are considered to be the fastest and most skillful players, they are more likely to have a greater proportion of type II (fast twitch) muscle fibers that in turn may predispose them to injury. This specific predisposition is not fully understood; however, it has been postulated that type II muscle fibers are more susceptible to injury because of the faster contraction times or stretch being placed upon a muscle when it is contracting (9).

Conversely, Woods et al. (92) suggest that the increased risk of injury could relate to the anterior tilt of the pelvis usually seen in black or aboriginal ethnicities. Therefore, because of the biaxial formation of the hamstring group attaching onto the ischial tuberosity, an anterior tilt of the pelvis would cause the hamstring complex to be placed at a greater stretch, thus increasing the risk of injury. Similarly, Russek (72) demonstrated that individuals from Asian and African backgrounds exhibit joint hypermobility more so than Caucasian populations. In addition, evidence has been submitted that hypermobile individuals have compromised proprioceptive acuity, especially at the knee (36). This combination of joint hypermobility, decreased proprioception, and increased anterior pelvic tilt may lead to greater stretch of the hamstring muscular-tendon unit and thus a strain.

MODIFIABLE FACTORS

Although a number of risk factors have been proposed for hamstring strains, such as poor posture, neuromeningeal tightness, decreased muscular control, and poor technique (8), there are only limited data for these variables. Therefore, in this discussion, we will focus on the most prominent and researched factors: low hamstring strength, fatigue, and quadriceps flexibility.

Quadriceps flexibility. The study by Gabbe et al. (34) was the only study found which discussed the possibility of quadriceps flexibility as a risk factor for hamstring injury. Despite this, however, the arguments put forward by the authors were significant enough to include in this article. They suggest that the relationship is because of an alteration in the mechanics of running and sprinting. At the pre-swing position, the rectus femoris muscle is lengthened and acts eccentrically to arrest extension of the hip and flexion of the knee (64). In this stretched position, its tendon absorbs energy to be released during the active flexion of the hip and knee, when the leg is accelerated forward. Before initial foot contact, the hamstrings must contract eccentrically to decelerate this forward momentum. If the rectus femoris muscle is tight, however, there may be a rise in the passive elastic recoil of the tendon, further increasing the acceleration of the leg. This increases the load on the hamstrings, thereby increasing the risk of injury. It should be noted, however, that this is speculative, and the relationship between the increased tightness of the rectus femoris and the resultant increase in force production needs to be researched further to support such a claim.

Fatigue. Woods et al. (92) reported that most strains occurred at the end of matches and training sessions. This is corroborated by Price et al. (69), who documented that 36% of injuries sustained in competition occurred during the last third of each half. Moreover, evidence from Pinniger et al. (68) suggests that when soccer players become fatigued during maximal sprinting, early activation of the biceps femoris and semitendinosus muscles occurs during the swing phase of the cycle. This is in agreement with Verrall et al. (85) who states that this recruitment pattern may be because of local muscle fatigue and may be causative to hamstring strains. In agreement, the recent study of Wright et al. (94) demonstrated that as fatigue increases so does biceps femoris activity during knee extension (concentric quadriceps) movements in recreational soccer players.

These studies highlight a possible positive relationship between fatigue and hamstring strains. Despite this plausible link, however, there is yet to be a study that examines these variables within elite athletes. However, in vitro animal studies by Mair et al. (60) may provide further support to such a hypothesis. The extensor digitorum longus muscles from 48 rabbits were fatigued to different levels of severity, then stretched to failure, and compared with their nonfatigued contralateral controls. The results demonstrated that fatigued muscles are able to absorb less energy before reaching the degree of stretch that causes injury, suggesting that fatigue is an important factor in the pathogenesis of acute muscle strains. However, it should also be noted that muscles were injured at the same length, regardless of fatigue.

Strength. It seems logical to suggest that the body must be appropriately conditioned to combat the physical demands of sport and that prevention strategies should, in part, be based on an analysis of variables, such as an athlete’s ability to produce and absorb force. In addition, the fact that low hamstring strength, particularly in comparison with quadriceps strength, has been proposed as a potential risk factor (8,21,33,95) may further corroborate this.

Quadriceps to hamstring strength has invariably been determined by comparing the concentric strength of each
muscle group isokinetically (7,14,95). Fowler and Reilly (33) analyzed injured professional soccer players and found that the hamstring to quadriceps concentric strength ratio (H:Q) of the injured leg (0.5) was approximately 0.13 lower than that of the uninjured leg (0.63). This was in agreement with several other studies which reported that a concentric H:Q of <0.6 was an indicator of an increased risk of hamstring injury (32). This verifies the principle that an H:Q lower than 0.6 may incline a soccer player toward injury (90). Not surprisingly, the literature suggests that players at higher competitive and skill levels have higher concentric H:Q ratios (90), in the vicinity of 0.72–0.83 in professional, semiprofessional, and college levels (17).

Though widely analyzed and reported, it has been argued that H:Q concentric strength is not a functional assessment and thus not related to the mechanisms of injury (19). A more functional assessment of strength is to express the H:Q in terms of hamstrings eccentric strength to quadriceps concentric strength because of the primary role of the hamstrings to brake knee extension and tibial translation, as outlined previously in this article. With this in mind, the eccentric torque produced by the hamstrings (Hecc) would need to match the concentric torque of the quadriceps (Hconce) to prevent possible injury, that is, a Hecc: Hconce of 1:1. This has been supported by previous research (14,21,95). Additionally, when sprinters with previous hamstring injuries were compared with those without previous injuries, the injured runners’ hamstrings were weaker at all speeds eccentrically and at low speeds concentrically and were also less flexible (48).

As previously stated, most hamstring strains occur during rapid acceleration. It is conjectured that if the forces necessary to resist knee extension and begin hip extension are too high, the tolerance levels of the muscle-tendon system could be surpassed which would ultimately lead to a musculoskeletal lesion (21,95). It is perhaps this movement for which the hamstrings are not functionally conditioned. Several articles have therefore suggested that because this movement occurs during eccentric muscle actions, eccentric strength training could hold the answer in the prevention of these injuries (3,25,49,61,92). This is also supported by LaStayo et al. (55) who note that muscle and tendon appear very capable of adapting to such high forces, as long as the muscle experiences the stimulus progressively and repeatedly. This adaptation of tendon and skeletal muscle occurs through an increased reorganization and synthesis of collagen structures (51). Kjaer (51) showed that heavy resistance exercise, specifically eccentric exercise, improved symptoms within patients and that an increase in collagen structures would be present with this intensity and type of modality. This study, along with that of LaStayo et al. (55), correlates with several other authors (92,93) who have emphasized high-velocity eccentric exercise (with inherent high forces) during the late stage of rehabilitation, which should be used in conjunction with exercises for both directly above and below the hamstrings—for example, gluteals and calf complex.

In this regard, training studies have primarily focused on the Nordic hamstring curl (Figure) (75). A 10-week preseason hamstring strength training program incorporating eccentric overload demonstrated significant improvements in hamstring injury rate, isokinetic strength, and maximal sprint speed in elite male soccer players during the following 10-month season (6,61). Mjølnes et al. (61) examined the effects of a similar 10-week training program, comparing the traditional hamstring curl (concentric training) and the Nordic hamstring exercise (eccentric training) on well-trained soccer players. The results showed that the Nordic hamstring group showed an 11% improvement in eccentric hamstring torque and isometric hamstring strength, whereas the hamstring curl group observed no change. However, with respect to injury strain rates, no comparison was made. It is also significant to point out that the Nordic hamstring curl is very difficult to perform without a specific strength base. Consequently, and until the athlete is able to perform the exercise, they are advised to perform the concentric portion of leg curls (i.e., leg flexion) bilaterally, followed by the eccentric portion unilaterally, thereby increasing the relative load (18).

Furthermore, the effects of a standardized warm-up protocol incorporating either the Nordic exercise or a proprioceptive neuromuscular facilitation (PNF) flexibility routine on hamstring injury rates during a 2-year period in elite Scandinavian soccer teams were conducted (5). The study was over 4 consecutive seasons (1999–2002), with the first 2 seasons being used as a baseline from which comparisons could be made. The concluding 2 seasons incorporated the intervention program whereby only the Nordic exercise group had significantly fewer hamstring injuries and on average fewer injuries than they had for the previous 3 years. The flexibility group showed no improvements.

It is essential with any training program that it works toward the specificity of movement in terms of velocity. Sale (74) claims that knee angular velocity during a sprint gait cycle is as high as 600–700°/s. However and despite these high velocities, electromyographic activity of the hamstrings is high during the swing phases (48). With this in mind, Table 1 provides recommendations on frequency, volume, and periodization of the Nordic hamstring curl. The program should take place over at least a 10-week period in the preseason. Initially, loading is increased by attempting to control the eccentric contraction for longer and over a fuller range of motion. A dramatic increase in repetitions is not required because of the resultant increased forces exerted, as the athlete is able to control the exercise through a greater range of knee extension, thereby creating overload.

As previously mentioned, hamstring strains are also reported to occur at
During the Nordic hamstring exercise, however, the proximal/hip attachment of the muscle stays in a relatively constant position, whereas the distal/knee insertion moves through a range of up to 90° (75). The stiff-leg/Romanian deadlift, where the knee angle is kept relatively constant while the hamstrings contract at the hip attachment, may therefore provide an appropriate addition for hamstring strength because this exercise targets the proximal insertion. One criticism of the stiff-leg/Romanian deadlift would be that it does not address the eccentric role of the hamstrings in decreasing anterior tibial translation and increasing knee stability (18). The tibial translation problem could be addressed by including both eccentric movements of the stiff-leg/Romanian deadlift and Nordic curl in a program (18).

After these strength-based exercises, and in the opinions of the authors, the athletes may benefit from a progression to higher velocity eccentric exercises, for example, weightlifting (emphasizing the catch phase) and plyometrics (emphasizing the landing phase; discussed later in this text). Moreover, Olympic-style lifts should, by consensus, be taught with a top-down approach (29). This will also help to initially emphasize the posterior chain musculature and minimize the anterior quadriceps activity (29). Once a competent movement with a hang start position has been achieved, a fuller range of motion will need to be taught (e.g., starting from the floor and finishing in a deep squat position) and conducted to facilitate a higher maximal load (29). Moreover, plyometric training, within this context, should principally address landing mechanics via the use of drop lands. The intensity can be increased by gradually dropping from greater heights and progressing to unilateral landings. For a review of plyometric training, see Turner and Jeffreys (81).

Although there have been no direct epidemiological studies examining the effects of plyometric training (or Olympic-style lifting) on hamstring muscle strain, Hewett et al. (44) identified an increase in hamstring torque under plyometric training protocols. Indirectly, this may suggest that plyometric exercises could potentially reduce the risk of injury and provide eccentric strength adaptations similar to that of the Nordic hamstring exercise. Furthermore, as these exercises apply both high velocities and forces throughout the stretch-shortening cycle (45, 82),

<table>
<thead>
<tr>
<th>Week</th>
<th>Sessions per week</th>
<th>Sets</th>
<th>Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3–4</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5–6</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>7–8</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>9–10</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>11 onward</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
they inherently duplicate the muscle activation pattern during the reported mechanism of injury. As many studies have also shown improvements in performance parameters, such as speed, strength, vertical jump height, and decreases in lower extremity injuries, as a consequence of a plyometric program, its integration should be welcomed by most clubs (15,41,82).

**Muscle imbalance.** Because of the previous injury or postural predisposition, the activation patterns of muscles in specific movements change. This change can cause extra load or prolonged load to a muscle and therefore be a cause of injury (47).

In relation to hamstring injuries, hip flexion and the activation of gluteal muscles have been well discussed (56,57,62). Lewis and Sahrmann (57) showed that the muscle pattern can be changed via verbal cues and the hamstring muscles are activated throughout hip extension. With this said, an athlete who has been previously injured or has learned to alter their running style might overload the hamstring and therefore cause injury. Particular attention should be focused on exercises that allow the gluteals and the hamstring complex to function as one.

Weimann and Tidow (88) among others discuss the need for synergy between the gluteal muscles and the adductor magnus. Adductor magnus has 2 branches, one that acts to adduct and flex the femur and one that helps to extend the femur. Previous electromyogram studies have not looked at the activation or imbalances of the adductor magnus solely because of the technical difficulty of inserting the electrode because of its deep position in the posterior part of the leg. However, it is theorized that if the gluteal and adductor magnus are not activating correctly, there is altered rotation and pull on the femur, which can cause increased stress to the pelvis and subsequent load to the hamstrings. In addition, the adductor magnus has a secondary function of extending the femur, which means that a weak adductor magnus will also put additional load on the hamstring complex.

A second form of imbalance that has very little review is the different activation patterns of medial (semitendinosus and semimembranosus) and lateral (biceps femoris) hamstring muscles. Hubley-Kozey et al. (46) reported that the medial to lateral hamstring ratio was increased with patients with previously diagnosed knee arthritis. It could be postulated that a similar change occurs with other knee injuries or previous hamstring injuries. This additional activation of the medial hamstrings could be a causative factor in the medial hamstrings being the most commonly injured muscle.

Lynn and Costigan (59) showed that the position of the ankle changes the activation of the hamstring complex. They found that external rotation in open chain exercises increases the activation of biceps femoris and medial rotation increases the activation of the medial hamstring muscles leading the author of this article to suggest that by selecting or adapting routine exercises with medial rotation of the ankle we could strengthen and lessen the effect of muscle imbalances between the different hamstring muscles.

**Hamstring flexibility.** Flexibility protocols are consistently included into an athlete’s training schedule to improve performance and more importantly reduce the risk of injury (24). Dadebo et al. (24) noted that 40% of the total training time was dedicated to flexibility training in English Premiership soccer clubs. Despite this, however, the role of stretching in enhancing flexibility and reducing injury remains contentious.

Witvrouw et al. (89) examined 146 male professional soccer players before the 1999/2000 Belgian soccer season. They found that players who sustained a hamstring strain had significantly less hamstring flexibility before their injury compared with the uninjured players. They concluded that players with increased hamstring muscle tightness have a significantly higher risk of a subsequent musculoskeletal lesion. In addition, Cross and Worrell (23) examined the effects of static stretching on the incidence of lower extremity musculotendinous strains in 195 division III college soccer players in the 1994 and 1995 seasons. All variables were consistent between the 2 seasons except for the incorporation of a lower extremity-stretching program in the 1995 season. The results indicate that the number of lower extremity musculotendinous strains was reduced significantly (48.8%) in 1995 compared with 1994 (43 versus 21 injuries). However, no data were presented demonstrating whether the players improved their flexibility. It is therefore likely that a multitude of factors may have contributed to the reduction in the injury rate (63).

Rolls and George (71) conducted a prospective analysis of 93 players between the ages of 9 and 19 years at an English Premier League club during one season (2001–02), investigating the relationship between injury and length of the hamstrings. They measured hamstring length using a variety of common assessments, including modified sit and reach, straight leg raise, active knee extension, passive knee extension, and seated knee extension. They found no significant correlations between injured and noninjured legs or between injured and noninjured subjects. Similarly, Hennessey and Watson (42) noted that the differences in hamstring flexibility were not evident between the injured and the noninjured groups in 34 top-level athletes from rugby, hurling, and Gaelic football, and thus, it was suggested that hamstring flexibility was not a risk factor for hamstring injuries. This is also supported by Larsen et al. (54), who showed a static stretching regime to be ineffective at improving hamstring flexibility with healthy volunteers. As previously highlighted, these reports also corroborate with Arnason et al. (3), who found a 2-year stretching intervention to be ineffective at reducing injury in elite soccer players.

A possible explanation for the discrepancies in results is the methodological dissimilarities. All studies stretched
and/or assessed the hamstring muscle group in a different way. The study by Hartig and Henderson (37) was a paired exercise, where stretching was performed standing. Cross and Worrell (23) focused on individualized static stretching, where the subject had to grasp their ankles, and the study by Arnason et al. (3) was based on a partner PNF stretching exercise. It is therefore interesting to note that the justification for stretching to prevent hamstring strains appears largely unfounded. In studies that do support a beneficial effect, this relationship should be viewed with caution as correlations do not mean cause and effect, especially in injuries that have a multifactorial etiology.

CONCLUSIONS AND PRACTICAL APPLICATIONS

The injury and reinjury rates of hamstring strains within professional soccer have proven to be a frustration to medical personnel. Consequently, prevention strategies should be considered key and may be achieved through adequate exercises focusing on eccentric strength at both high and low velocities and conditioning drills focusing on the reduction of fatigue. Appropriate low-velocity strength training may include the Nordic hamstring exercise, but it is suggested that the stiff-leg/Romanian deadlift should also be incorporated to target the proximal insertion. Specific knowledge of muscle imbalances around the posterior chain is important for particular athletes. Simple modifications to an athlete’s program, in respect to foot rotation or gluteal/abductor magnus activation, can lead to an improvement of function around the pelvic girdle.

High-velocity strength training should focus on plyometric exercises with initial emphasis on landing and the safe dispersal of high forces. These drills may then be progressed to depth jump drills whereby reactive strength is incorporated after the acceptance of high eccentric loads. It is also recommended that Olympic-style lifting be included, progressing from the hang start position to the full movement to facilitate greater absolute load and thereby emphasizing the catch position where high eccentric loading is experienced and progressively accommodated (Table 2).

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

Table 2
Suggested hamstring strain prevention exercises based on the evidence presented herein

1. Nordic hamstring curls (see Figure and Table 1)
2. Stiff-leg/Romanian deadlift
3. Bilateral drop landing
4. Bilateral depth jumps
5. Hang power clean/hang power snatch
6. Squat clean/squat snatch (emphasizing a deep catch)
7. Single leg, multiplanar variations of exercises

Anthony N. Turner is a strength and conditioning coach and is the Programme Leader for the MSc in Strength and Conditioning at the London Sport Institute, Middlesex University, England.

Jon Cree is a strength and conditioning coach and the Programme Leader for the BSc Strength and Conditioning at the London Sport Institute, Middlesex University, England.

Paul Comfort is the Programme Leader for the MSc Strength and Conditioning at the University of Salford.

Leigh Jones is the curriculum coordinator for sport and exercise sciences at Huntingdonshire Regional College and the managing director of Future Fitness Training Academy.

Shyam Chavda is an academy strength and conditioning coach for British Fencing and QPR Football Club and the Sport technician and weightlifting coach at the London Sport Institute, Middlesex University.

Chris Bishop is the lead strength and conditioning coach for Optimum Elite Fitness and a lecturer on the BSc Sport & Exercise Science Program at the London Sport Institute, Middlesex University.
REFERENCES


35. Greg M and McNaughton L. Decrease in eccentric hamstring strength during...
simulated soccer match-play: 617 board


76. Schache AG, Wrigley TV, Baker R, and Pandy MG. Biomechanical response to...
Hamstring Strain Prevention in Elite Soccer Players


