

Training the hamstrings for high speed running

Part 1 – Theoretical Considerations

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In sports involving sprinting, a key concern is the reduction of hamstring strain injuries.^{16,22} There is a significant body of research concerning the nature and rehabilitation of hamstring injury^{1,2,5,7,8,12,14,18,19,22} and it is important that this research should inform the practice of strength and conditioning professionals. The purpose of part 1 of this article is to present the theoretical basis that should underpin the training of the hamstring musculature. Practical evidence based recommendations for the prevention of hamstring injuries have been advanced by previous authors^{1,7} and part 2 of this article will build on previous work in order to present a comprehensive system for training the hamstrings.

Hamstring function during high speed running

In order to provide recommendations for the prophylactic training of the hamstrings it is first essential to characterise the nature of their activity during the gait cycle. This exercise is problematic due to the difficulties in directly measuring in vivo the length of the hamstrings, the instantaneous force produced in the fibres and the contraction velocity during gait. Instead it is necessary to infer the function of the hamstrings from electromyography (EMG)¹⁰ and the results of studies involving detailed musculoskeletal models.^{8,17,18,19}

EMG has been used to study the activation of the hamstrings during the gait cycle.^{10,19} The hamstrings are silent at toe-off, becoming active during late swing phase when the hip is highly flexed and the knee is beginning to extend. They then remain active through terminal swing and the early and middle stance phases, before falling silent prior to toe-off.^{10,21} It has been proposed that the pattern of EMG activity suggests that the hamstrings function eccentrically to control hip flexion and knee extension during the swing phase and then act concentrically as a hip extensor during stance.¹⁰

Firstly, we will describe in more detail the role and action of the hamstring during the swing phase of gait. Recent work has evaluated the relative length of the hamstring muscle-tendon unit during the swing phase^{8,17,18,19} and this data is particularly useful in characterising hamstring function. This is because it is important to examine both the muscle and tendon, remembering that the active (muscle) and passive (tendon) components always act in concert. Often we only consider the function of the muscle in isolation. It has been shown that the peak stretch occurs during the late swing phase of sprinting principally due to hip flexion.^{18,19} This observation coupled with the evidence of EMG activity supports the idea that the hamstrings are acting eccentrically to control terminal hip flexion and prevent excessive knee extension during late swing.

Further muscle-tendon unit studies combining EMG data with kinematic data simulated the musculotendon mechanics of the biceps femoris during sprinting.¹⁷ During terminal swing, the activation of the biceps femoris acts to slow the lengthening of the muscle component of the muscle-tendon unit. Instead, lengthening is increasingly achieved through tendon stretch resulting in the storage of elastic energy in the tendon. Thus during late swing the biceps femoris exhibits stretch-shortening cycle behaviour. This simulation study also established that



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more compliant tendons reduce both the peak muscle stretch and the negative muscle work during late swing.

Musculoskeletal modelling has also been used to evaluate the impact of muscular coordination on muscle-tendon stretch.¹⁹ In particular, it has been shown that the force displayed by the contralateral hip flexors have a profound affect on the length of the hamstring muscle-tendon unit. This research demonstrates the importance of highly coordinated synergistic motor patterns in preventing hamstring injury and suggests that fine motor control of the pelvis may be important in optimal hamstring function.¹⁹

Musculoskeletal models have also been employed to study the impact of running velocity on hamstring length.^{18,19} Peak muscle-tendon length is invariant at speeds ranging from 80 to 100 per cent of maximum (although hip and knee flexion do increase). Equally, at speeds from 80 to 95 per cent of maximum speed, peak muscle-tendon length is achieved at the same point of the gait cycle. Interestingly, at maximal speeds, peak muscle-tendon length is reached significantly later in the gait cycle. This may indicate that the ability of the hamstrings to eccentrically control hip flexion and knee extension during late swing is a limiting neuromuscular factor to maximal sprinting.¹⁸

The following focuses on the role and action of the hamstrings during the stance phase of running gait. The EMG and modelling studies suggest that during stance the hamstrings are shown to be shortening primarily as a result of hip extension.^{18,19} This supports the contention that the hamstrings are acting to create a hip extension torque. However, the hamstrings may also have a role at the knee joint, by helping to create the optimal knee joint stiffness for the storing and release of landing energy. During running it is useful to assume the leg acts like a spring and previous research has successfully modelled the motion of running with the application of a leg spring model. In this biomechanical model, the key property of the 'leg spring' is called its stiffness.⁶ A leg spring with optimal stiffness is able to effectively store and release energy, losing as little as possible to hysteresis. This model is attractive as it simply represents the stretch-shortening cycle behaviour of the lower limb during stance. Clearly the effectiveness of this theoretical leg spring is a result of a combination of a number of different processes and structures, including the important foot and Achilles tendons. However, one key variable will be the stiffness of the knee joint during the landing. The hamstrings, therefore, may play an important role in stiffening the knee joint during stance.¹

It has also been suggested that the role of biarticular muscles may include the transfer of

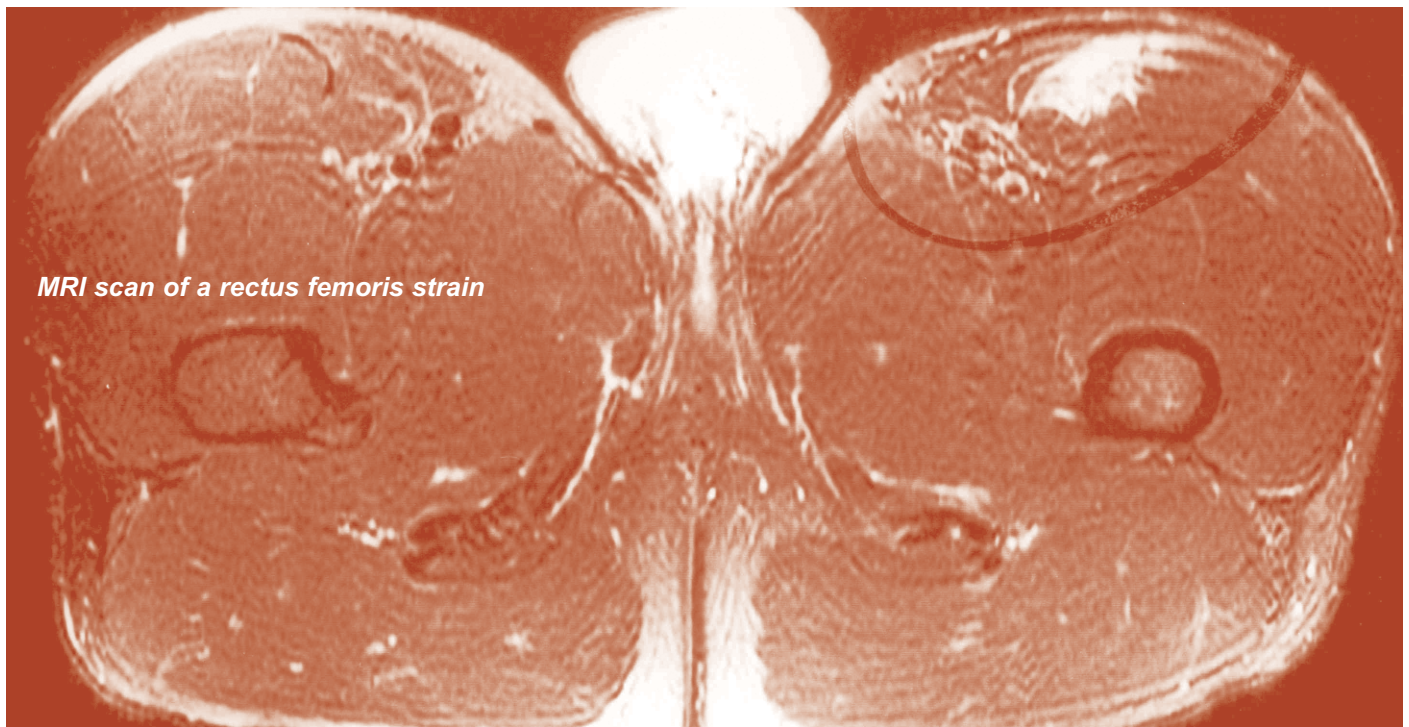
mechanical energy between joints.^{11,13,23} In running, the biarticular muscles have been found to transfer energy from the distal to proximal joints during the shock-absorbing phase of stance, and from the proximal to the distal joints during the thrust phase of stance.¹³ Although this study was restricted to an analysis of the rectus femoris and gastrocnemius muscle groups it does suggest that the hamstrings may also play a role in energy transfer between the knee and hip joints.

Finally, it is important to note that the EMG studies show the hamstrings are silent during push-off and early swing. This suggests that they are not involved either in push-off, or in the recovery of the trailing leg. Instead, the EMG evidence suggests that the hip flexors may be key in ensuring a timely and efficient recovery of the leg during early swing.¹⁰ To this end it should be noted during stance the hamstrings will assist in controlling the anterior tilt of the pelvis and will thus indirectly affect the length-tension relationship of the contralateral hip flexors.

In summary it is apparent that the role of the hamstrings during gait is complex and multifaceted. During late swing phase the hamstring muscle-tendon unit acts eccentrically to control terminal hip flexion and knee extension. In this phase, the role of the stretch-shortening cycle is important as much of the negative work is achieved through tendon stretch. The coordination of the hamstrings with the contralateral hip flexors is vital due to their profound influence on the magnitude of the muscle-tendon stretch. At top speed the ability of the hamstring muscle-tendon unit to eccentrically control hip flexion and knee extension may be a limiting factor to increased speed. During stance the role of the hamstrings is twofold: to assist the gluteus musculature in hip extension; and to assist in stiffening the knee to allow the efficient transfer of force from the proximal musculature of the body to the ground. During stance, the coordination of the hamstrings with the contralateral hip flexors may also be important in ensuring the optimal length tension relationship of the hip flexors during early swing.

Mechanism of injury

The exact instance during the gait cycle at which the hamstrings become injured is the subject of some debate.⁸ Muscle strain injury is associated with excessive muscle lengthening coupled with an eccentric muscle action.^{8,9,19} It is apparent that during the late swing phase of gait the muscle is contracting eccentrically while in a lengthened position and thus at a risk of strain injury. The difficulties with observing muscle injuries in vivo mean that there is limited evidence of the time occurrence of hamstring strain injuries. However, it seems likely that the hamstring is at most risk



MRI scan of a rectus femoris strain

of injury during late swing^{12,19} and one case study has specifically documented a hamstring muscle injury occurring during this point of the gait cycle.⁸

The majority of hamstring strains occur in the biceps femoris.^{5,12} A comparison of the degree of stretch experienced by each of the hamstring groups reveals that the biceps femoris is stretched by a significantly greater amount during the swing phase of gait than either the semimembranosus or semitendinosus.¹⁸ This evidence supports the contention that hamstring strain injuries occur when the muscle is in a lengthened position and acting eccentrically during late swing.

A consideration of the role of biceps femoris in controlling rotation at the knee allows a further explanation for the high incidence of biceps femoris injuries to be elucidated. In a study of 13 muscles that cross the knee, Buford and colleagues found that in a functional range of motion (i.e. at 30° flexion) biceps femoris was the sole external rotator of the knee.⁴ It has been suggested that the imbalance between the muscle mass of the internal and external rotators of the knee (due to external rotation being primarily controlled by biceps femoris alone without the action of synergists) may predispose biceps femoris to injury. This suggests that a hamstring training programme should also consider rotational components of movement.¹⁵

The hamstrings may also become injured during the stance phase of gait. These types of injury may be associated with poor running mechanics. For instance, overstriding may force an athlete to work harder with their hamstrings during early stance in order to bring the foot beneath the hip.⁷ Alternatively, an athlete who has been inappropriately taught to use their hamstrings to

recover their leg in early swing may also be predisposed to a hamstring injury.

Factors associated with hamstring injuries

A number of factors have been identified that may be associated with a hamstring strain injury.^{2,5,12,14} Extrinsic factors that have been identified include a lack of adequate warm up, fatigue as a result of inappropriate training load and the effect of the playing environment. Factors intrinsic to the athlete include agonist/antagonist strength imbalances, lack of flexibility, age, low back pain, sacroiliac joint dysfunction and a history of hamstring injuries.^{5,12,14}

Recent research has studied the optimal length-tension relationship of the hamstring in injured and non-injured athletes.² It was observed that the only significant difference between previously injured hamstring and healthy hamstrings was in the optimal length of the hamstrings. Previously injured hamstrings showed a decrease in optimal length even when the quadriceps to hamstring strength ratio had been recovered. This finding may explain why a previous hamstring injury significantly disposes an athlete to repeated hamstring injuries. This finding also fits with the proposed injury mechanism above, that a hamstring (biceps femoris) strain is most likely to develop during late swing when the muscle is lengthened and acting eccentrically. If the optimal length of the hamstring is reduced, the ability of the muscle to perform negative work in this position is likely to be compromised, increasing the risk of a hamstring injury. It has also been demonstrated that the hamstrings adapt to an eccentric exercise protocol by increasing their optimal length.³ It has been suggested that this adaptation may decrease the risk of hamstring

injury and reduce exercise-induced muscle damage. The results of these two studies, considered in the light of the function of the hamstrings during late swing phase, imply that the optimal length of the hamstring may be a key factor in hamstring strain injuries.

The impact of hamstring flexibility on hamstring strain injury is equivocal. Some authors have argued that a lack of flexibility may dispose an athlete to hamstring injury.^{5,12} As previously described, the biceps femoris tendon undergoes a significant stretch during late swing phase, and a less compliant tendon will increase the muscular stretch of the hamstring, theoretically increasing the likelihood of a tear.^{5,17} Previous injury may result in scarring of the tendon, reducing compliance and increasing the risk of recurrent injury. Equally fatigue could affect tendon compliance.¹⁷ It should be noted that a tendon that is too compliant may not allow the efficient storage and reuse of elastic energy during high speed running, and that there may therefore be an optimal tendon compliance for performance and injury prevention.

A discussion of the role of hamstring flexibility in hamstring injury should also consider neural tightness. Excessive neural tightness may result in sustained irritation of the hamstring during activity. Equally, neural tightness may have implications for the synchronicity and efficiency of hamstring function increasing injury risk.

Implications for training

We have presented evidence of the function of the hamstrings during high speed running, which focuses on the eccentric muscle action during late swing to control hip flexion. We have also argued that a likely mechanism of injury is the peak lengthening of the muscle during late stance whilst eccentrically loaded. Thus, it is clear from the research that prophylactic hamstring training should be aimed at increasing the hamstrings resistance to eccentric contraction injuries when the hamstrings are in a lengthened position. From a muscular standpoint, eccentrically strong hamstrings with an optimal length-tension relationship may be the most resistant to injury. Research has shown that eccentric exercise may increase the optimal length of the hamstrings and that this may serve a protective effect.³ The involvement of the stretch-shortening cycle in late swing should also be noted, as training this ability may improve a prophylactic hamstring strengthening programme.

Equally, the fact that biceps femoris is most likely to be injured due to its increased peak length during late swing and/or its functional role as a lateral knee rotator suggests that special exercises to strengthen this portion of the hamstring group may be important.

In addition, tendon compliance is likely to be a critical factor in reducing the magnitude of the

muscular stretch. Finally, neural tightness may also predispose an athlete to a hamstring injury. Thus promoting optimal tendon compliance and neural relaxation with specific flexibility exercises could be an effective part of the hamstring injury prevention strategy.

The results of musculoskeletal modelling studies illustrate that the synchronous timing of the hamstrings with other muscle groups may be particularly important. In terms of training considerations, in conjunction with the principle of dynamic correspondence proposed by Verkoshansky.²⁰ This highlights the importance of training the ability of the hamstrings and hip flexors to function together efficiently and safely. Equally, the role of the hamstrings in gait is clearly complex, and highly developed inter- and intra- muscular coordination of the hamstring muscle groups is of paramount importance. Some coaches believe that training the hamstrings with a wide variety of exercises may promote this coordination.¹

Training the hamstrings to improve their resistance to eccentric stretch may also have implications for performance. The ability to control hip flexion and knee extension in late swing may be a neuromuscular factor that restricts top speed. If this is the case, then improving this ability may allow an athlete to run faster.

Although this article has focussed on the action of the hamstrings during late swing, it is important not to overlook the other roles of the hamstrings. During stance the hamstrings may contribute to the hip extension torque, stiffen the knee or be involved in the energy transfer between joints. All of these functions will be important in optimizing the performance of an athlete. However, most strength and conditioning programmes include a variety of hip extension exercises which will train these properties, and thus supplementary work for these aspects of hamstring function may not be necessary.

Hamstring injuries are common in modern sport. However, the research does provide some indication as to the mechanisms by which hamstring strain injuries occur. This information should allow the strength and conditioning coach to design programmes that are effective in reducing the likelihood of hamstring injuries. In Part 2 of this article an evidence based system for the prophylactic training of the hamstrings will be presented.

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