

# The effectiveness of different exercises protocols to prevent the incidence of hamstring injury in athletes

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## Abstract

### Introduction

Hamstring strains are the most prevalent non-contact injury associated with participation in sports. In addition to the anatomical and functional characteristics of the hamstrings, such as the biarticular organisation or the dual innervations of biceps femoris, a number of alterable and non-alterable factors have been associated with the risk of hamstring injuries in athletes. Each of these variables would impact upon hamstring injury risk within an integrated approach, by which the possibility of sustaining an injury can vary depending on the particular circumstances of each athlete. The aim of this critical review is to examine the effects of current preventative exercise protocols and to provide basic guidelines for hamstring injury prevention in athletes.

### Discussion

Hamstring injuries occur during high-speed actions or extreme stretching; therefore, in order to prevent the incidence of these types of injuries, specific active lengthening, stretching exercises or sports-specific drills have been integrated into regular training programmes. The response to these intervention programmes has shown mixed results. A conceptual framework is presented proposing that an effective injury prevention programme should include a combination of different

specific and non-specific exercises. In addition, special consideration should be given to those eccentric exercises performed over a large muscle lengths and also emphasise the knee stabilising co-contraction actions of the hamstring.

### Conclusion

The protective effects elicited by a well-designed preventive programme could be obtained in four weeks, with only two sessions per week involving three sets of six to eight repetitions of three open- and closed-kinetic chain exercises.

Future research should analyse the specific structural and functional modifications elicited by the regular application of different types of exercises and protocols aimed to reduce the risk of hamstring injury.

### Introduction

Hamstring strain, the most prevalent non-contact injury in many team sports<sup>1</sup>, refers to any acute physical injury, in the region of the posterior thigh, irrespective of the requirement for medical attention or time lost from sporting activities<sup>2</sup>. In team sports, such as rugby, football and cricket, the incidence of hamstring injuries has shown an upward trend over the past two decades, and currently represents between 12%–17% of total injuries, with a high rate of recurrence<sup>1,3</sup>.

Several training methods involving eccentric exercises<sup>4,5</sup>, stretching<sup>6</sup> or unstable agility exercises<sup>7</sup> have been proposed to prevent the incidence of hamstring injuries. However, there are still some inconsistencies regarding the type of training programmes and their subsequent effects. The lack of uniform criteria for implementing injury prevention

exercise programmes could be also associated with the empirical beliefs or unfounded concerns about the low compliance, time required and perceived negative effects, such as excessive hypertrophy, loss of velocity and power<sup>8,9</sup>. In this critical review, after analysing the functional actions of hamstring and their injury mechanisms, we examine the effects of different exercises used to elicit protective adaptations to potentially reduce the incidence of hamstring injuries in athletes. Additionally, we will address some practical recommendations for integrating an injury prevention programme into the athlete's periodised training plan.

### Discussion

In this critical review, the authors have referenced some of their own studies. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees associated to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in the studies.

### Functional actions of hamstring

The biarticular nature of the hamstrings allows them to act simultaneously as hip extensors and knee flexors during concentric contraction or eccentrically during concurrent hip flexion and knee extension, as observed in running and kicking<sup>1</sup>. However, the requirements of the hamstrings in terms of force, velocity and power are limited during submaximal or low-speed movements compared to the significantly greater levels occurring in

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the late swing phase of the sprint or an explosive kick<sup>10</sup>. Such eccentric muscle activity may predispose the hamstrings to injury as the lengthening may exceed the mechanical limits of the muscle or lead to the accumulation of microscopic muscle damage<sup>11</sup>. In addition, when the hamstrings are considered within a functional kinetic chain, this muscle group appears to be associated with both upper body (pelvis, spine, shoulder and skull) and the lower-limb alignment and stabilisation (Figure 1)<sup>12</sup>. These anatomical links may be the reason by which the lack of stability of the back and/or pelvis has been proposed as one of the main contributors to increased risk of hamstring injury<sup>12</sup>. Additionally, the two heads of the biceps femoris

are innervated by different nerve branches of the sciatic nerve, with the tibial portion innervating the long head and the common peroneal branch innervating the short head. This dual innervation could possibly result in uncoordinated contraction and poor motor control leading to an increased rate of hamstring injury observed as fatigue progress during exercises<sup>1</sup>.

#### Mechanism and localisation of non-contact hamstring injury

Hamstring strains occur through an over acute strain episode that could be represented by a continuum from microfibre damage (as seen in association with delayed onset muscle soreness) through a partial strain or complete muscle rupture<sup>12</sup>. This injury has been strongly associated

with high-eccentric muscular tension exceeding the mechanical limits of the tissue<sup>1</sup>. Based on the injury mechanisms and localisation, two types of hamstring injuries have been differentiated as follows:

1. Muscle fibre injuries, mainly in the biceps femoris long head and less often, in the distal semitendinosus muscle, resulting from explosive high-speed actions, such as kicking or sprinting<sup>13</sup>.
2. Tendon injuries, in particular, the proximal semimembranosus tendon occurring, when performing slow controlled stretching to an extreme position<sup>13,14</sup>.

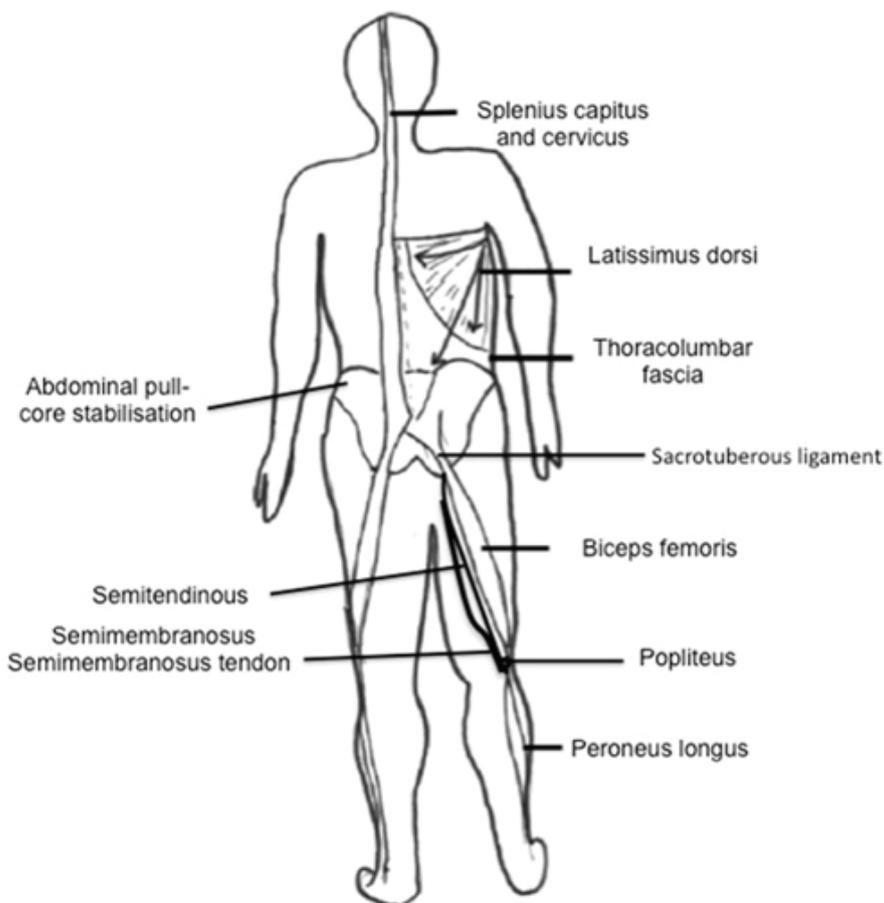
Potentially, an inter-relationship exists between eccentric force and muscle strain that dictates whether a muscle is injured. For example, the risk of strain injury would be significantly reduced when performing submaximal stretching exercises involving moderate-to-high levels of strain and low eccentric force. Similarly, the risk would be also reduced when controlling a heavy load during the eccentric phase while performing typical resistance exercises, such as bench press or squat<sup>1</sup>. Therefore, when athletes are regularly exposed to activities that simultaneously produce both high-strain and eccentric forces without appropriate preparation, the risk of injury is increased.

#### Potential risks factors associated with hamstring strain in athletes

Hamstring injury is a complex and multifactorial phenomena eventually sustained by the interaction of the following two types of factors<sup>1</sup>:

1. Alterable: fatigue, strength deficits, muscular imbalance, optimal peak torque angle, low flexibility, poor motor control or technique.
2. Non-alterable: age, ethnicity, anthropometric relationships, muscular fibre composition and previous injuries.

In order to further understand the sequence of events that eventually



**Figure 1:** Hamstring functional kinetic chain connection toward the upper torso and skull as well as to the knee, ankle and foot<sup>12</sup>.

lead to an injury, the causative effects of both alterable and non-alterable factors should be considered within an integrated approach. For example, the combination of age, with the lack of strength would dramatically increase the risk of injury in some athletes<sup>8</sup>. Therefore, under some circumstances, such as being an older or previously injured athlete, the effects of some modifiable risk factors as the lack of strength or poor motor control will increase the risk of injury with respect to a younger or previously uninjured athlete.

A successful hamstring injury prevention programme would attempt to reduce the negative influence of the alterable risk factors. However, as stated by Opar et al.<sup>1</sup>, a risk factor cannot be considered causative unless there is a reduction in the rate of hamstring injury following an intervention focused on ameliorating them. The following sections will discuss the effects of the most proposed exercises and protocols for reducing hamstring injuries in athletes.

### Stretching exercises

Whilst it has been reported that there is no relationship between static stretching and the risk of hamstring strain<sup>13</sup>, recent reports have suggested positive effects of stretching protocols involving several repetitions of more than 30 s (4 min in total) for reducing muscle strains<sup>6</sup>. In subjects with limited flexibility, it appears that the protective effects of stretching include a shift in the optimal muscle length at which the peak torque occurs towards a more open position i.e., a more extended joint angle<sup>6</sup>. However, caution should be taken when performing stretching exercises as a part of warm up, during and after training because a high volume of excessive hamstring stretching can be the cause of hamstring tendon strains<sup>14</sup>. The risk of this type of injury appears to be even greater after exercise, when a

fatigued muscle-tendon complex may be at more risk of damage by extensive stretching<sup>13</sup>.

### Active lengthening exercises

Active lengthening occurs when muscles are stretched while trying to contract. Studies suggest<sup>11,15</sup> that the optimum muscle length at which peak tension is recorded would be the best indicator for identifying athletes at risk of hamstring strain. Therefore, the more open the angle at which the optimal peak torque is achieved, the less the muscle will be at risk of injury<sup>15</sup>.

The functional and structural adaptations elicited by eccentric exercises depend on the magnitude of the resistance, movement velocity and amplitude i.e., the magnitude of muscle length achieved throughout the exercise<sup>16</sup>.

In both eccentric and concentric actions, as the magnitude of the resistance increases the capacity to modulate, the velocity decreases. Therefore, when using light to moderate loads (<80% 1 RM), the muscle fibres will progressively be extended during eccentric muscular action. This is the case of some active lengthening movements, such as kicking or the terminal swing of running, where biceps femoris long-head fibres would be extended close to 110% of their original length<sup>1</sup>. However, when using a heavy resistance (>80% 1 RM) throughout an eccentric action, muscle fibres will contract along a quasi-isometric action that is compensated by a greater elongation of the elastic components (tendons and elastic sarcomeric proteins). Thus, as the movement progresses, and the muscle-tendon unit continues to lengthen beyond its optimum length, the tension levels will decrease<sup>17</sup>. Therefore, if we consider that the maximal peak torque occurs always at the same fibre length<sup>17</sup>, the lighter the resistance, the more open the position the optimal peak torque will be produced and conversely,

the heavier the resistance, the closer position the optimal peak torque will be localised.

With respect to movement amplitude, it has been demonstrated that the protective effects of eccentric exercises will be only produced over the trained range of motion, but not at longer amplitudes<sup>18</sup>. Thus, if eccentric exercises are performed over short ranges, smaller than those where the injury commonly occurs e.g., the last 30° of terminal swing phase, the optimal peak torque would be moved towards a closer knee angle and therefore, instead of being protective, might even be increasing the risk of hamstring strain. In order to obtain the optimum benefits, eccentric exercises should be conducted throughout the largest possible range of motion.

Different eccentric exercises using a fly wheel eccentric leg curl<sup>19</sup>, Nordic Curl alone<sup>8,20</sup> combined with other strengthening<sup>21</sup> or stretching exercises<sup>21,22</sup> have been successfully applied for reducing the incidence of hamstring injuries, enhancing hamstring eccentric strength<sup>23</sup> or shifting the optimal peak torque in non-previously injured athletes<sup>24-26</sup>. However, the loading patterns and the appropriate training protocols continue to be determined.

Nordic Curls have recently been criticised because of their lack of specificity, with respect to the mechanical action where the injuries occur<sup>16</sup>. This exercise, require athletes, from kneeling position, to gradually lower their trunk, representing about 90% of body weight, towards the ground. For many, not well-conditioned athletes, the overload placed on the hamstrings will be excessive, especially when the trunk approaches the end of the movement. As a consequence, when the athlete is unable to control the movement, they will stop applying force and fall forward. Performing uncontrolled Nordic Curls would not elicit positive adaptations for reducing hamstring

strain, because the effective trained range of motion will be restricted to the closer angles ( $<30^\circ$  of knee extension) and not transferred to the longer muscle length. In fact, it has been observed that the biceps femoris long head and semimembranosus were significantly less active than the semitendinosus and gracilis during a heavily loaded eccentric leg curl<sup>1</sup>. Therefore, in order to maintain an appropriate activation on the biceps femoris long head and semimembranosus, other alternative exercises, such as the eccentric single or two stiff-legged dead lifts and assisted band Nordic Curl (Figure 2) could be recommended.

#### Unstable-core and sport specific exercises

An effective injury prevention programme should consider the specific condition that more accurately reflects the situation where injuries occur. In addition, to the active lengthening observed during sprints or kicking, the hamstring acts as knee stabilisers counteracting and balancing the actions of the quadriceps during sport-specific activities, such as landing, deceleration or change of direction. Therefore, specific drills involving, repeated sprints, jumps, hops combined with unstable core-exercises, namely one-leg squat or lunges unstable surfaces have been

proposed as effective methods for preventing hamstring injuries<sup>24,27,28</sup>. Verral et al.<sup>28</sup> reported a significant reduction of hamstring injuries in Australian football players after a four-year high-intensity interval-training programme combined with passive isometric hamstring stretching. In order to simulate the situation where hamstring strain occurs, athletes were instructed to forward incline the trunk when sprinting. Conversely, Daneshjoo et al.<sup>27</sup> observed no effect of two typically recommended specific injury prevention programmes (FIFA 11 + and Harmo Knee) to enhance hamstring strength in professional football players. More recently, Naclerio et al.<sup>24</sup> reported that four weeks (12 sessions) of an injury prevention programme comprising three sets of eight repetitions of the Nordic curl, forward lunges on a Bosu®, balance trainer and eccentric single-leg dead lifts was effective in improving the maximal isometric force at both closed ( $80^\circ$ ) and open ( $35^\circ$ ) knee angles. Figure 3, depicts the torque-angle profiles determined before (for all participants  $n = 20$ ) and after the training programme differentiating the training ( $n = 10$ ) and control group ( $n = 10$ ). Before training, all participants tended to produce the maximum torque at  $45^\circ$ ; however, after the training intervention, a plateau from  $35^\circ$ – $80^\circ$  of knee

flexion was observed only for the training group that exhibited a more consistent torque, which was maintained over a greater range of knee flexion angles.

The modification depicted in Figure 3 indicates a trend to increase the capacity of the hamstring to apply higher levels of force over a larger range of motion. Possibly, the effects on the knee angle–torque would be manipulated by an appropriate exercise selection. For example, the benefits of performing Nordic Curls would depend on the range of motion achieved during its execution. When performing lunges, a more quasi-isometric action of the hamstring will be required and therefore, a predominant strengthening at closer knee angles would be elicited. The single-leg dead lifts involves both an active stretch and a knee stabiliser co-contraction actions of the hamstrings that in turn will be stimulating an strength enhancement of the hamstring at both the closer and the open knee angles positions<sup>24</sup>.

#### Key point for designing a hamstring injury prevention programme

- The positive effects of a low-volume injury prevention programme could be obtained over a four-week period, with only two sessions per week involving three sets of six to eight repetitions of three open and closed kinetic chain exercises<sup>24,25</sup>.



Eccentric single stiff-legged dead lift



Eccentric two stiff-legged dead-lift

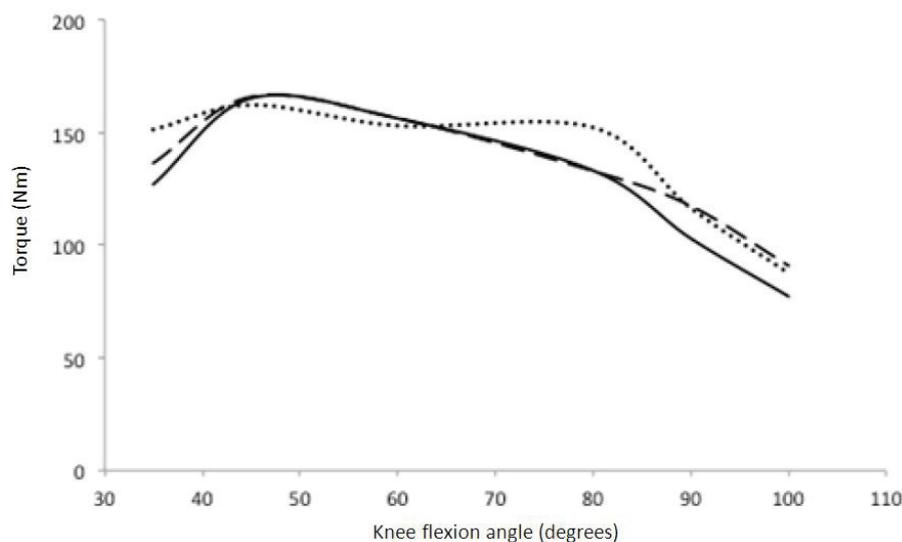


Assisted band Nordic Curl

**Figure 2:** Three exercises proposed for prevention hamstring injuries in athletes.

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**Figure 3:** Torque-knee angle profiles. Solid line depicts the profile obtained from all participants before the training intervention. Dashed and dotted lines, depict the profile obtained from the trained and control groups, respectively after the training intervention (non-published data).

- The selected exercises should involve eccentric and quasi-isometric hamstring muscle actions<sup>24</sup>.
- Eccentric muscle actions should be performed at moderate-to-high velocity, using light-to-moderate loads and along the largest possible range of motion<sup>18</sup>.
- The injury prevention programme should be included at the end of warm up or training session.

### Conclusion

In order to prevent hamstring injuries, programmes must be designed so that they include both eccentric activity and co-contracting knee stabiliser exercises.

No single approach should be considered as gold standard for hamstring injury prevention. In addition to the functional improvement recommended in this review, coaches should also consider the importance role of correcting good sports specific technique and motor control.

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