Preventing Hamstring Injuries in Sport

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SUMMARY

HAMSTRING INJURIES CAN BE DEVASTATING FOR ATHLETES AND SPORTS TEAMS. RECENT ADVANCES IN TECHNOLOGY HAVE GREATLY ENHANCED OUR UNDERSTANDING OF HOW AND WHY HAMSTRING INJURIES OCCUR. BASED ON THIS INFORMATION, PROFESSIONAL SPORTS TEAMS HAVE IMPLEMENTED VARIOUS TRAINING INTERVENTIONS IN AN ATTEMPT TO REDUCE THE RATE OF HAMSTRING INJURIES WITH VARYING SUCCESS. REVIEWING THE RECENT LITERATURE ON HAMSTRING INJURIES AND THE STUDIES THAT HAVE REPORTED DECREASES IN INJURY RATES COULD GIVE FURTHER INSIGHT INTO HOW HAMSTRING INJURES CAN BE PREVENTED AND THUS IS THE FOCUS OF THIS ARTICLE.

Hamstring muscle strains are common injures in sports that require maximum sprinting, kicking, acceleration, and change of direction. The sports most commonly affected by hamstring injuries include soccer, rugby, track and field, Australian rules football, and American football. A significant amount of time is lost from competition and training (18 days on average) after a hamstring strain injury (28). In addition, coaches and athletes must deal with the frustration of persistent symptoms and a high percentage (12–31%) of reinjuries (11,28). Consequently, various training methods have evolved in an attempt to decrease hamstring injury rates. At this point, only eccentric exercise has been shown to reduce hamstring injury rates (60–70%) in various sports during a competitive season (1,3,9,13,23).

An increasing number of studies have documented sports injuries that occur during 1 to 3 seasons. Some of these studies have indexed the injuries by team position and when in the season they occur. It has been reported that hamstring injuries account for 16% to 23% (2,7,8,11) of all injuries in Australian rules football, rugby, and soccer. One study reported that hamstring injuries accounted for 29% of injuries among track and field sprinters (18). More hamstring injuries have been reported to occur during competition than during training and among the team positions that require faster running velocities, such as backs in rugby (7,14). Because of the recent interest in hamstring injuries and prevention strategies, this article explores the causes of hamstring injuries, the role of the optimum length of torque development in preventing muscle strain injuries, and the studies and exercise protocols that have reduced hamstring injury rates; introduces some alternative eccentric exercises that may prevent hamstring injuries; and provides a template for implementing these exercises into strength and conditioning programs for a variety of sports.

CAUSES OF HAMSTRING INJURIES

Muscle strain injuries are thought to occur when muscles are actively lengthened to greater than normal lengths. Simply stretching a muscle without activation or activating a muscle without lengthening will not result in injury. Only the combination of an active muscle being lengthened will produce the mechanical strain that can cause a muscle injury (12).

The anatomy of the hamstring muscle places it in a vulnerable position during running. The hamstring muscle is a biarticulate muscle, meaning it crosses 2 joints and has 2 major actions (i.e., hip extension and knee flexion). This also means that the hamstrings are stretched with hip flexion and knee extension. As the lower leg swings forward during the late swing phase of running, the hip flexes and the knee extends simultaneously. Thus, the hamstring muscle becomes actively lengthened to greater than normal lengths. Simultaneous hip flexion and knee extension also occur when kicking a ball placed on the ground or in the air. Kicking while running or running on an incline puts the hamstrings in an even more vulnerable position because of a forward trunk lean (25).

The biceps femoris muscle is thought be more vulnerable to injury than the semitendinosus and semimembranous muscles (25). The biceps femoris experiences greater active lengthening and electrical activity during the late swing phase of running (25). Onishi et al. (19) reported that electromyography activity varied among the 3 muscles at different muscle lengths. The biceps femoris was

KEYWORDS:
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Table 1
Studies documenting hamstring injuries in elite athletes

Study	Subjects	Eccentric exercise groups	Exercise protocol	Results
Askling et al. (3)	Competitive soccer athletes (n = 30)	Yoyo Hamstring (Yo) group (n = 15) YoYo hamstring curl Control group (n = 15)	10 weeks 4 sets of 8 reps of additional Yo training 10 weeks regular training	Yo group = 3 out of 15 obtained a hamstring injury Control group = 10 out of 15 received a hamstring injury
Proske et al. (23)	Australian rules football atheltes (n = not reported)	Additional eccentric exercises: Straight leg deadlifts, knee curls, Nordic Hamstring	Pre-season training (not detailed)	2001 Control Season = 16 hamstring injuries 2002 Experimental Season = 5 hamstring injuries 2003 Experimental Season = 2 hamstring injuries
Gabbe et al. (13)	Amateur Australian rules football athletes (n = 220)	Nordic Hamstring (NH) group (n = 114) Control group (n = 106)	12 weeks 5 sessions of additional Nordic hamstring exercise (12 sets of 6 reps) 12 weeks Regular training	NH group = 4% of players sustained a hamstring injury Control group = 13.2% of the players sustained a hamstring injury
Brooks et al. (9)	English premier rugby union athletes 2002–2004 (11 clubs participated)	Strengthening (S) Group (n = 296) Static stretching and Strengthening (SSS) Group (n = 288) Stretching, Strengthening and Nordic Hamstring (SSN) Group (n = 400)	Concentric and Eccentric Exercise Additional Hamstring Stretching Additional Nordic hamstring exercise 2–3 sets of 6–7 reps	S group = 1.1 hamstring injuries per 1000 hours SSS group = 0.59 hamstring injuries per 1000 hours SSN group = 0.39 hamstring injuries per 1000 hours
Arnason et al. (1)	Elite soccer athletes (n = 24 clubs participated)	Nordic Hamstring (NH) group Control group	Additional Nordic hamstring exercise 3 sets of 8–12 reps Regular training	NH group = 0.22 hamstring injuries per 1000 hours Control group = 0.62 hamstring injuries per 1000 hours

maximally activated between 15° to 30° of knee flexion starting from full knee extension, and the semimembranous and semitendinosus were maximally activated between 90° and 105°. In 1 study, biceps femoris strain injuries accounted for 80% of the total 170 hamstring injuries analyzed (16).

THE OPTIMUM LENGTH OF TENSION DEVELOPMENT

All muscles have an optimum length for producing peak tension. As the muscle begins to actively lengthen, tension levels increase. There will be an optimum length at which tension levels peak. If the muscle continues to lengthen past its optimum length (i.e., the descending portion of the length–tension curve), tension levels will decrease. The optimum length can be used to describe muscle fiber length, whole muscle length, or joint angle (12). In addition, tension can be used to describe muscle force or joint torque (muscle force × moment arm) (12). For the purposes of this article, the optimum angle of torque development will be referred to as optimum length, and joint torque will be referred to as tension.

The descending portion of the length–tension curve is thought to be the region of vulnerability in which hamstring injuries occur. Many believe that athletes who produce peak tension at shorter lengths are more likely to be injured (6,9,17,23). A shorter optimum length would mean that more of the muscles available for tension-producing length would be on the descending portion and thus be vulnerable for a longer period. Brockett et al. (5) explored this idea by measuring the optimum lengths in athletes who had previously injured their hamstrings.

Table 2 Sample exercise template					
Off-season		Pre-season		In-season	
(4–5 Sets of 8–12 Repetitions)		(3 Sets of 5–10 Repetitions)		(2–3 Sets of 6–10 Repetitions)	
First cycle		**First cycle**		**First cycle**	
Monday		Monday		Wednesday	
Eccentric box drops (12 inch box)	5 x 12	Eccentric (SL) deadlifts	3 x 8*	Eccentric backward steps	3 x 8*
Thursday		Thursday			
Eccentric forward pulls	4 x 12*	Eccentric box drops (24 inch box)	3 x 10		
Second cycle		**Second cycle**		**Second cycle**	
Monday		Monday		Wednesday	
Eccentric backward steps	4 x 12*	Eccentric lunge drops	3 x 5*	Eccentric (SL) deadlifts	2x 8*
Thursday		Thursday			
Eccentric split zerchers	5 x 8	Eccentric SLD/concentric RDL's	3 x 5		
*Each leg should performs this number of repetitions.					

One leg served as the experimental leg (i.e., previously injured hamstring) and the other leg served as the control leg (i.e., noninjured hamstring). The previously injured hamstring produced peak tension at 12.7° less than the noninjured hamstring (i.e., shorter optimum length). It was also reported that the difference between eccentric and concentric hamstring strength was not different between the legs. The authors concluded that the optimum length of peak tension was a greater risk factor for future muscle strain injuries than strength ratios. Based on these findings, many have suggested that if the optimum length could be shifted to longer lengths, the

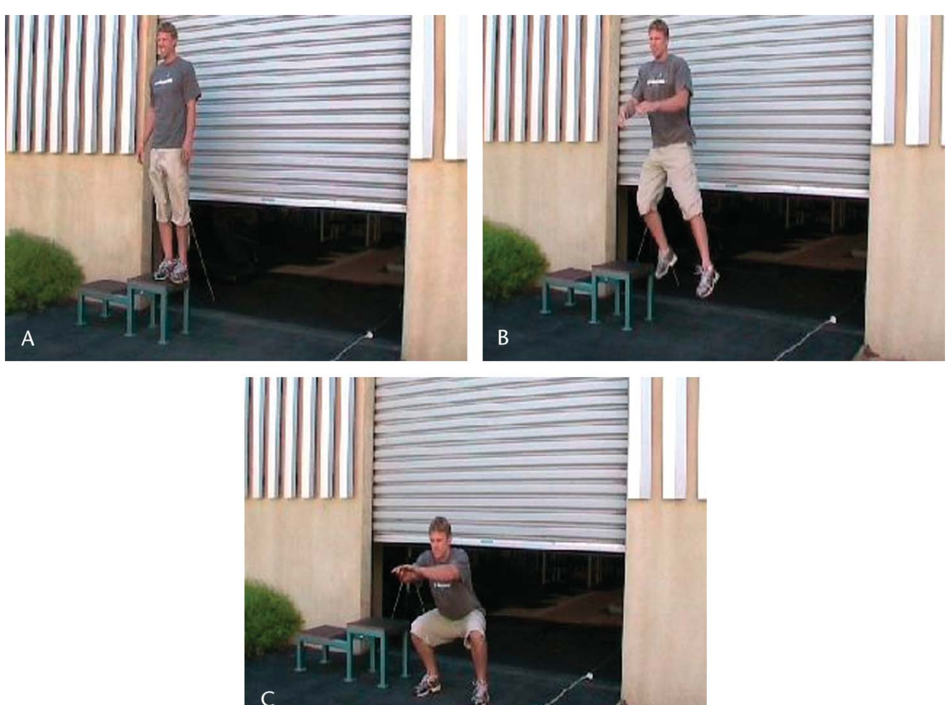

Figure 1. Eccentric box drops.

Figure 2. Eccentric backward steps.

descending portion of the length–tension curve may not be achieved during subsequent eccentric activities, such as sprinting, kicking, and jumping, and consequently, hamstring injury rates would be reduced (6,13,23).

CAN ECCENTRIC EXERCISE SHIFT OPTIMUM LENGTH?

Eccentric exercise has been reported to shift the optimum length of tension development to longer lengths. The shift has been shown to occur in the elbow flexors, plantar flexors, knee flexors, and knee extensors (4,5,10,21,26). The magnitude of the shift depends on 3 variables: the intensity of eccentric exercise, the volume of eccentric exercise, and the length of the muscle during eccentric contractions. Shifts in optimum length have varied from 3.9° (26) to 18° (22) after eccentric exercise. Three studies (15,26,27) used a low-intensity eccentric exercise (walking backward on a treadmill at slow velocities), which was performed at a moderate volume (1–2 hours) and at moderate muscle lengths (toe-to-heel action). This protocol resulted in a moderate shift in optimum length of the plantar flexors (i.e., calves) of 3.9° to 6.0° immediately after exercise.

Two studies (5,10) used a moderate-intensity hamstring exercise (Nordic hamstring exercise), which was performed at moderate muscle lengths. The Nordic hamstring exercise involves the athlete kneeling on the ground with his or her ankles fixed, followed by slowly lowering himself or herself to the ground by eccentrically contracting the hamstrings. Brockett et al. (5) used a very high volume (12 sets of 6 reps) single-session exercise protocol and reported an acute shift in optimum length of 7.7° immediately after and 8.5° 4 days after the exercise. Clark et al. (10) also used the Nordic hamstring exercise, but the protocol consisted of much less volume (2 or 3 sets of 6–8 reps) and was performed twice a day, 2 or 3 times per week, for a total of 4 weeks. Clark et al. (10) reported a shift in optimum length of 6.5°. This was the first study to report a sustained shift in optimum length and was the only training study (i.e., more than 2 eccentric exercise training sessions) reporting a shift in optimum length. The significance of this study was that the shift in optimum length was reported without high-intensity eccentric exercise, which may increase muscle damage. Every other study induced acute muscle damage to develop a shift in optimum length (4,5,20–22,24,26). Furthermore, the study by Clark et al. (10) was the only one to show a shift in optimum length and an increase in isokinetic strength (i.e., concentric and eccentric). All the other studies reported acute decreases in strength, which were associated with muscle damage and the shift in optimum length. The study by Clark et al. (10) was a pilot study and did not use a control group.

Bowers et al. (4) reported a greater shift in optimum length of 15.4° in the knee flexors (i.e., quadriceps) after eccentric exercise. The protocol consisted of 240 reps of stepping down from a box, which was performed at elongated muscle lengths. Prasartwuth et al. (22) and Phillippou et al. (21) reported the

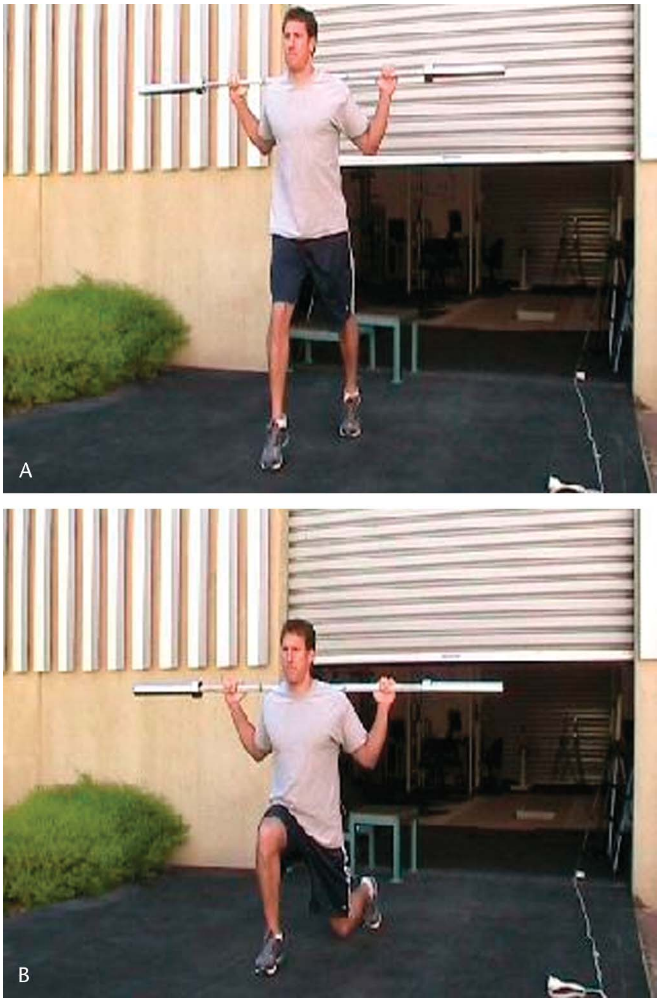

Figure 3. Eccentric loaded lunge drops.

greatest shifts in optimum length of 16.7° and 18° after eccentrically training the elbow flexors (i.e., biceps brachii) at elongated muscles lengths and at high intensities (i.e., maximum effort contractions). It can be concluded from these studies that eccentric exercise can cause a shift in optimum length and that the magnitude of the shift depends on volume, intensity, and muscle length at which the individual exercises.

TRAINING STUDIES AND HAMSTRING INJURIES

Since the Nordic hamstring exercise was described in 2001 by Brockett et al. (5), 5 studies have documented the effects of eccentric exercise on hamstring injuries in elite soccer, rugby, and Australian rules football players (1,3,9,13,23). None of these studies measured the optimum length of the hamstrings; thus, the shift in optimum length was not quantified nor was its significance investigated. Four of the studies used the Nordic hamstring exercise, and 1 study used the yo-yo hamstring curl exercise (3). The yo-yo exercise involves the athlete performing eccentric leg curls in the prone position. The yo-yo device is basically a flywheel that is accelerated during the concentric contraction and then decelerated during the eccentric contraction of the hamstrings. Similar to the Nordic hamstring exercise, the yo-yo leg curl is a bilateral, open-chain exercise.

A study by Askling et al. (3) was the first study (Table 1) to report a decrease in hamstring injury rate after a period of eccentric exercise. In this study, 30 competitive soccer players were divided equally into a control group and an experimental group. The experimental group performed the yo-yo hamstring curl exercise in addition to their normal training, and the control group continued normal training without the yo-yo exercise. After 10 weeks of training, the experimental group suffered 67% fewer hamstring injures than the control group.

The 4 other studies (1,9,13,23) that documented sports-related hamstring injuries after eccentric exercise programs used the Nordic hamstring exercise and reported similar reductions in injury rates (60–70%). Proske et al. (23) investigated the effects of eccentric exercise on hamstring injuries in professional Australian rules football players during a 3-year period. These results were not published but appeared in a review article by Proske et al. (23). It was reported that during the 2001 season (no eccentric exercise), there were 16 hamstring injuries. During the 2002 season, when the eccentric exercise protocol was performed, there was a 69% reduction in hamstring injuries. The 2003 season reported another 60% reduction in hamstring injuries after the eccentric exercise protocol (Table 1).

Gabbe et al. (13) also documented hamstring injures in Australian rules football players. A total of 220 players were recruited for this study and were divided into an experimental group and a control group. The control group performed regular sports training and stretching protocols. The experimental group performed the Nordic hamstring exercise protocol 5 times (i.e., 3 before the season and 2 during the season) in addition to regular sports training stretching. The experimental group suffered 70% fewer hamstring injures than the control group. However, unlike the other studies that performed multiple eccentric exercise sessions with moderate volumes (Table 1), Gabbe et al. (13) used an eccentric exercise

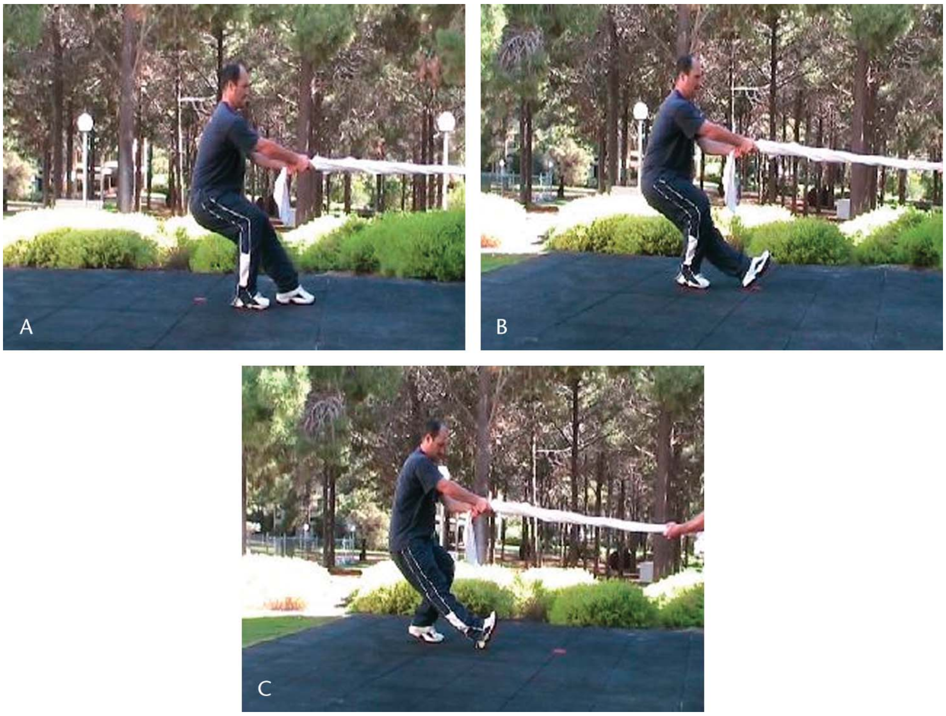

Figure 4. Eccentric forward pulls.

protocol that was meant to induce acute muscle damage (12 sets of 6 reps). This protocol is not necessary because the shift in optimum length has been shown to occur after a sustained period without the need for excessive muscle damage. As a consequence, only 48% of the participants in this study completed more than 1

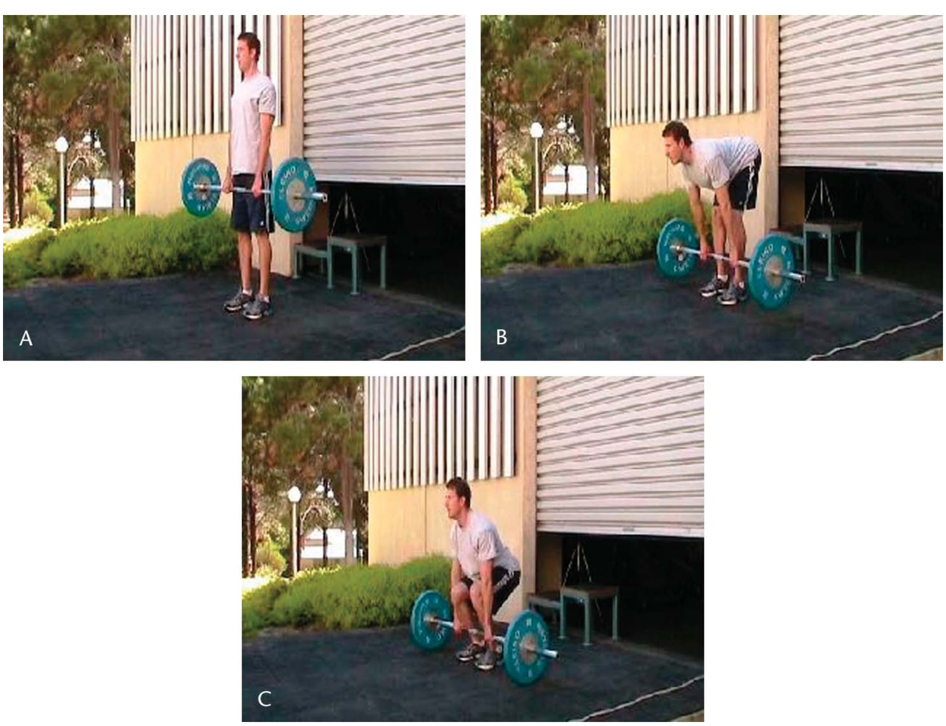

Figure 5. Eccentric stiff-leg deadlifts and concentric Romanian deadlifts.

Figure 6. Eccentric single-leg deadlifts.

training session, and the number that completed all training sessions was not reported. This would be expected because the pain and damage suffered by the athletes would not be motivation for completing a nonmandatory training protocol. The training protocol in this study (12 sets of 6 reps) should not be used in future research, if injury prevention is the goal, because it is not specific for sports and will have a low retention rate.

Studies by Brookes et al. (9) and Arnason et al. (1) are the most recent studies investigating the effects of eccentric exercise on hamstring injury rates during a significant amount of time. Brookes et al. (9) documented hamstring injuries during a 3-year period among English premier rugby union players (11 teams). The participants were divided into 1 of 3 groups: regular strength training; strength training and stretching; and strength training, stretching, and Nordic hamstring exercise. The group performing the Nordic hamstring exercise with regular strength training and stretching suffered 65% fewer hamstring injuries than the group performing only regular strength training. The back position players (i.e., the faster athletes) suffered significantly more hamstring injuries than the forwards (i.e., the slower and bigger athletes). Arnason et al. (1) also documented hamstring injuries, but during a 4-year period. The participants consisted of teams for the top Icelandic and Norwegian leagues. A total of 24 teams participated with a total of more than 650 athletes. In this study, the control group consisted of the 1999 and 2000 seasons for the Icelandic teams and the 1999, 2000, and 2001 seasons for the Norwegian teams. The experimental groups (i.e., seasons 2001 and 2002 for the Icelandic teams and season 2002 for the Norwegian teams) performed the Nordic hamstring exercise 3 times per week during before the season and once or twice per week during the season. Overall, the participants who performed the eccentric exercise protocol suffered an average of 65% fewer hamstring injuries.

A few limitations of these studies include the following: higher than normal injury rates (3), unpublished results (23), poor compliance (13), and only 1 type of eccentric exercise being used (i.e., open-chain, bilateral) (1,3,6,9,13,23). Despite these limitations, more than 1,200 athletes were monitored in these 5 studies, and each study reported significant reductions in hamstring injury rates.

PROBLEMS WITH THE NORDIC HAMSTRING EXERCISE

Brockett et al. (5) showed that eccentric exercise (e.g., the Nordic hamstring exercise) does not need to involve only plyometric exercises or heavy lifts. Traditionally, athletes and coaches have not used eccentric exercise because of the difficulties of multiple spotters, expensive and specialized equipment, and a high risk of injury. The Nordic hamstring exercise avoids these difficulties, but it still has a few inherent problems. First, it is an open-chain, unilateral exercise, possibly allowing 1 leg to take up more of the strain than the other leg, which could lead to asymmetries between legs. Brockett et al. (5) and Clark et al. (10) reported differences in optimum length between legs. Clark et al. (10) reported that after 4 weeks of training with the Nordic hamstring exercise, the asymmetry became greater. It was speculated that the stronger leg probably experienced most of the strain and thus had the greater shift in optimum length (10). Leg asymmetries are thought to increase the risk of future injury (10). Second, the Nordic hamstring is a single joint exercise. The problem is that the hamstrings are a biarticulate muscle, which is stretched with hip flexion and knee extension. It would be more specific to perform multijoint eccentric exercises that involve more muscle groups working together. Finally, after a few weeks of training, trainees are capable of lowering themselves nearly to the ground; therefore, it may be tempting to overload this exercise with more mass or higher velocities, which may increase the risk of injury. Because of these limitations, new eccentric exercises may be needed to prevent hamstring injuries. Doing so, however, may be contraindicated because of the asymmetries that could be created between legs with the Nordic hamstring exercise. In addition to the Nordic hamstring exercise, new eccentric exercises that will not create asymmetries between legs are needed.

ALTERNATIVE EXERCISES FOR HAMSTRING INJURY PREVENTION

Based on this review of literature and from a functional standpoint, eccentric exercises for hamstring injury prevention should include as many of the following characteristics as possible: high forces, maximal muscle elongation, high velocities, multiple joint movements, closed-chain exercises, unilateral exercises, and cost-effective and easily implemented exercises. Because the hamstrings are not the only muscle groups susceptible to muscle strain injuries in the lower body, exercises should be designed with the hip flexors, plantar flexors, and hip adductors in mind. The exercises below were designed to include as many of these factors as possible. The first 4 exercises can be performed on the field or in the weight room with little equipment. The final 3 exercises should be performed in the weight room under close supervision.

1. Eccentric box drops: The trainee begins by stepping up onto a box (12 to 36 inches). He or she then steps off the box and lands in a squat position (Figure 1). Key points are as follows: Do not land in a static position. Allow for full flexion of the hips, knees, and ankles upon foot contact. To end the exercise, place the hands on the knees and push up into a standing position; do not jump out of the bottom position. Do not perform more than 12 drops in 1 set.
2. Eccentric backward steps: The trainee gets into the starting position (Figure 2). One trainee pushes forward while concentrically contracting the muscles in his or her lower body. The other trainee will apply resistance but still allow himself or herself to be pushed backward while eccentrically contracting the muscles in his or her lower body. Key points are as follows: Do not allow the trainees to raise their upper or lower backs during this exercise; they should have their backs parallel with the group the whole time. This exercise should be performed with cleats or a surface that has a lot of friction. Perform approximately 10 to 15 steps with each leg.
3. Eccentric loaded lunge drops: The trainee rises up onto his or her toes while taking a lunge stance, with or without resistance. He or she then quickly drops onto the ground with his or her feet landing flat and balanced. Then he or she will resist the downward forces into a deep lunge position while maintaining good posture (Figure 3). Key points are as follows: Do not perform this exercise if good posture cannot be maintained in the bottom position. Do not come upward out of the bottom position; instead, slowly lower to the ground until the back knee is touching the ground, thus allowing the muscles a break from the contraction, before standing up. Do not perform more than 5 drops with each leg.
4. Eccentric forward pulls: The trainee gets into the starting position (Figure 4). He or she bends down, while maintaining this position throughout the exercise, and slowly pulls the load backward. This exercise forces the hamstring muscles to be activated, and then it actively stretches the hamstrings with hip flexion and knee extension. Key points are as follows: Do not rise up from the starting position. Do not perform more than 15 steps with each leg.
5. Eccentric stiff leg deadlifts and concentric Romanian deadlifts: The trainee performs a Romanian deadlift (RDL) with a barbell to get into the starting position. Then he or she simply performs a straight leg deadlift (SLD) during the eccentric phase (to the ground and reset for the RDL) and an RDL during the concentric phase (Figure 5). Key points are as follows: Make sure to perform the straight leg deadlift to the ground and then reset. Reset by getting into a clean stance and perform the concentric RDL, thereby breaking this exercise into 2 separate exercises. Maintain good posture with a neutral spine.
6. Eccentric single leg deadlifts: The trainee gets into a starting position with a plate or dumbbell (Figure 6) and performs the eccentric phase of the single leg deadlift only. He or she then resets and repeats. Key points are as follows: Perform the eccentric phase of this exercise all the way to the ground and then relax and reset. Maintain a good posture with a neutral spine.
7. Eccentric split-stance Zerchers: The trainee gets into the starting position (Figure 7). This exercise is similar to a good morning variation except the load is in front of the trainee. The key point is as follows: Maintain good posture with a neutral spine.

It should be noted that these exercises are designed mainly for the hamstrings and are performed in the sagittal plane. Exercises can also be used in the frontal plane to train other muscle groups eccentrically.

PROGRESSION OF EXERCISES AND INTENSITY

As shown in Table 2, the lower-intensity eccentric exercises are performed in the first cycle of the off-season. As the

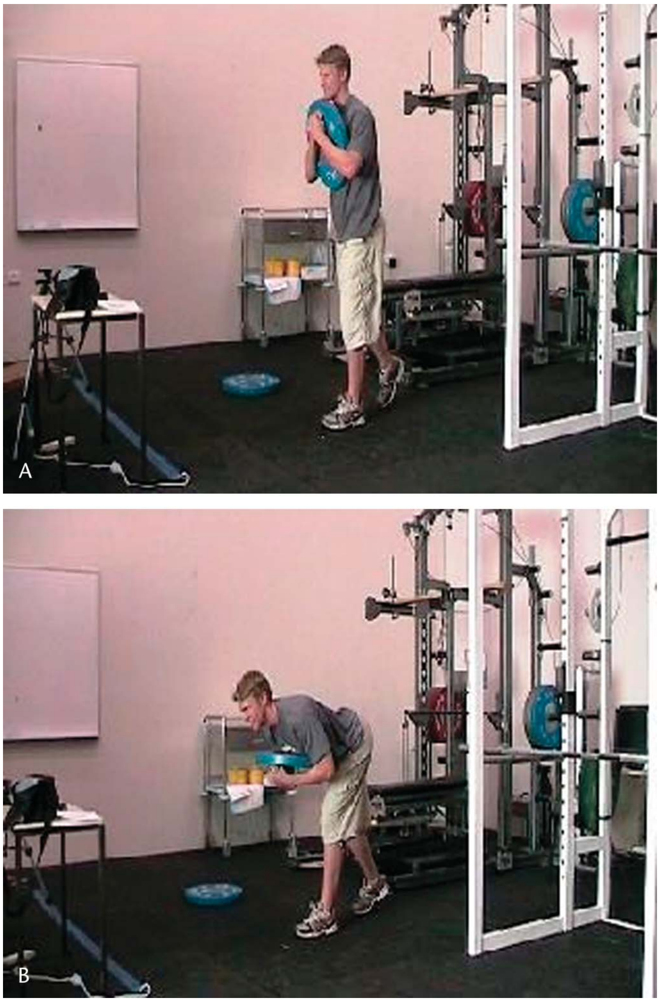

Figure 7. Eccentric split-stance Zerchers.

season progresses, the volume of eccentric exercise decreases, and the intensity increases. Athletes must always use proper techniques when performing these exercises. It is important that the muscles contract eccentrically at elongated lengths. Otherwise, the benefits of eccentric exercise may not be experienced. Once the correct technique is learned and the athletes have a solid eccentric base, the exercises can be overloaded progressively with greater resistance or higher speeds. For example, the eccentric box drops can be overloaded by adding a load to the athlete (e.g., holding weights or wearing a weighted vest) or increasing the height of the box. Throughout the season, a moderate intensity should be maintained, and the volume should be decreased.

The reader must be aware that eccentric exercise can lead to muscle damage and soreness if the intensity of training is not appropriately monitored. Unlike traditional forms of training (e.g., strength training, power training, weightlifting, and plyometrics), soreness is not felt during the eccentric training session but is delayed for 24 to 48 hours (i.e., delayed onset of muscle soreness). Therefore, in terms of progressive overload, the best approach is to start with minimal intensity and concentrate on technique and then increase the intensity, volume, or both with time and experience. More than the recommended number of repetitions from the previous section should not be performed.

EXERCISE TEMPLATE

This template was designed for coaches and athletes to implement in their own training program without having to make drastic changes (Table 2). The eccentric exercises can simply be added to a current program or can be exchanged for other exercises. The eccentric exercises should be switched every 3 to 5 weeks. This template includes a total of 8 to 10 sets performed per week in the off-season, 6 sets per week before the season, and 2 or 3 sets per week during the season. In the off-season and before the season, the 2 exercises can be performed on separate days or on the same day.

CONCLUSIONS

Hamstring injury rates can be reduced if an appropriate eccentric exercise protocol is followed. The exercises presented in this article have been developed based on the current literature that has shown increases in optimum length of tension development and reductions in hamstring injury rates. In addition to the reductions in injuries, a few studies have reported that hamstring injuries were less severe after an eccentric exercise protocol. Furthermore, the inclusion of such eccentric exercises may accelerate the recovery from hamstring injury and return to play. Both contentions, however, must be monitored in some fashion to be certain of the efficacy of the inclusion of eccentric exercises. These new and alternative exercises are not meant to replace any other modes or methods of training. Instead, they can simply be added to current training programs. The addition of 2 eccentric exercises per week (1 per session) should be an easy adjustment to the training program, which could lead to dramatic decreases in muscle strain injury rates.■

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