Hamstring Injuries in Sprinting—The Role of Eccentric Exercise

PETER STANTON, B App Sci,[1] CRAIG PURDAM, Dip Phty

This paper assesses a specific connective tissue insufficiency induced hamstring injury occurring in the late swing/early stance phase of sprinting and jumping activities.

A literature review related to hamstring injury demonstrates that eccentric muscle action is capable of producing very high forces within the series elastic component (SEC) of the hamstrings in this phase of sprinting. These high forces have been shown to be related to hamstring injury. The utilization of eccentric exercise training regimens can prevent this injury by strengthening the SEC, resulting in a musculotendinous structure theoretically capable of both generating and withstanding higher eccentric and concentric forces.

A clinical approach utilizing an eccentric exercise regimen designed to strengthen the hamstrings in the late swing/early stance phase is outlined. A pilot study investigating the exercise indicates it is a valid method of preventing and rehabilitating the hamstring injury in terms of the positions at risk while sprinting, the angular velocities achieved, and the torques produced.

Athletes involved in power based events such as the various sprints and jumps have long been frustrated by hamstring injuries despite attempts at prevention through stretching and strengthening. Also, sports medicine rehabilitation, on occasion, must be viewed as incomplete because of the number of persistent and recurring problems.

Many factors thought to cause or predispose to hamstring injury have been previously postulated:

1) Injuries influenced by lumbar spine and/or sacroiliac pathology—with or without tethering of the static neural tissue (centrally or peripherally) (14, 28, 37).

2) Injuries associated with a lack of flexibility or abnormal mobility such as
- — poor hamstring flexibility
- — poor flexibility of other postural muscles of the trunk and legs
- — joint hypo/hypermobility (i.e., hip, superior tibiofibular) (4, 29, 30, 45).

3) Injuries due to variables associated with the training program which include
- — poor conditioning
- — overtraining/fatigue
- — overstretching, etc.
- — muscle imbalances (8, 9, 15, 17, 30).

This paper will not assess all the various sible predispositions to injury, but will focus on a subgroup of hamstring injuries falling into the "poor conditioning" category, and particularly on a type of musculotendinous insufficiency that may be frequently overlooked.

The injury that will be assessed will be one where the athlete sustains injury while running full speed, hurdling, or jumping and may exhibit poor tolerance to repeated training sessions. In track athletes, this frequently occurs during the transition into a competitive season where a greater percentage of the training emphasis is on speed. Limb velocities and ranges of movement increase, while the times required for the muscles to accelerate and decelerate the limbs decrease during this training. Both the concentric and eccentric forces produced increase dramatically.

It is this required increase in eccentric muscle activity which appears to be related to hamstring injuries occurring in the late swing phase of gait

[1] Reprint requests should be addressed to: Peter Stanton, B.App.Sci. P.O. Box 176, Belconnen, A.C.T. 2616, Australia.

0196-6011/89/1009/0343$02.00/0
The Journal of Orthopaedic and Sports Physical Therapy

and as the foot strikes the ground. Analysis on a Kin-Com (Chattex Corp., Chattanooga, TN) of athletes who present with such injuries shows a characteristic deficit in knee flexion torques immediately before, during, and immediately after the eccentric-concentric "turnaround" at moderate speeds (180°/sec). The position employed for this testing used similar hip and knee angles to those occurring at the end of the swing phase while sprinting.

To further investigate these mechanisms of injury, and thereby develop a means of prophylaxis it is necessary to make a more detailed examination of both eccentric muscle function and hamstring function in sprinting.

PART 1: REVIEW OF THE LITERATURE

Eccentric Muscle Function

Eccentric muscle action has been shown by many authors to be more efficient than concentric muscle action (2, 23–25, 41). Eccentric muscle action is capable of producing higher forces (23, 25, 41) and uses less oxygen than a concentric contraction of comparable muscle unit activity (25). This difference between eccentric and concentric contraction has also been shown to be velocity dependent (2, 25). If the velocity of contraction is increased, the maximum eccentric force producible increases and the maximum concentric force decreases. So the faster the muscle contracts, the greater the difference in maximum tension between eccentric and concentric work becomes, while the corresponding muscle unit activity (EMG) remains fairly constant (24) (Fig. 1).

Given that higher tensions are produced for the same amount of motor unit activity with quick eccentric contraction, the series elastic component (SEC) is placed under greater stress than with concentric contraction. Hence, this type of contraction is more likely to produce pathological forces within the SEC.

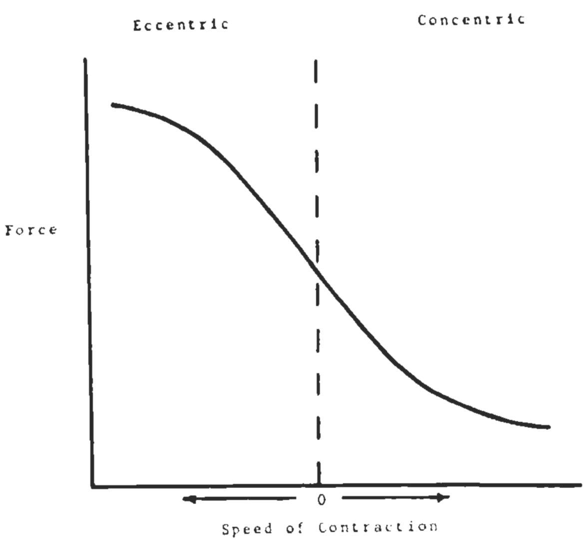

Figure 1. Generalized force velocity graph for muscle contraction.

Friden et al. (18) have shown that a single bout of intense eccentric exercise produces pronounced delayed muscle soreness which peaks from 24–72 hours after exercise and subsides several days later. This soreness is associated with reduced dynamic strength and myofibrillar disruption (notably broadening, streaming, or disruption of the Z bands, which are a component of the SEC).

The relationship of this eccentric exercise induced muscular soreness to connective tissue and hence SEC breakdown has been supported by Abraham (1) looking at connective tissue breakdown products, and also by Tullson and Armstrong (47, 48) while assessing connective tissue inflammatory response and hexose monophosphate shunt activity following exhaustive exercise.

Friden et al. (19) extended their experiment to observe the effect of 8 weeks of repeated (thrice weekly) eccentric training. Over a period of 2–3 weeks they found that subjects lost their postexercise soreness, and in 8 weeks increased their ability to perform eccentric work by some 375%. The Z band streaming and disruption was not present in these subjects, suggesting an adaptive response to the eccentric training. Schwane and Armstrong (43) also found that an eccentric training period of downhill running in rats prevented injury more effectively and produced a better training effect than level or uphill running.

Therefore, it seems that eccentric contraction is capable of producing pathological forces within the unconditioned muscle, and that a period of eccentric training allows the muscle to better withstand these potentially injurious forces.

Eccentric Preceding Concentric Muscle Contraction

Eccentric contraction immediately preceding concentric contraction will significantly increase the forces generated concentrically due to the apparent storage and recovery of elastic energy (26, 27, 46) coupled with reflex potentiation via muscle spindle discharge (7, 40). Examples of this eccentric-concentric coupling in muscle abound in most sports, especially in those events which demand a high speed of movement.

The violent extension of the foot and leg in the long jump take off is preceded at touchdown by a slight shock absorbing flexion of the take-off knee and ankle which imposes a stretch on the extensor muscles of the propulsive leg (Fig. 2).

This shock absorbing movement, or eccentric contraction, before concentric contraction is also present in throwing, sprinting, and other jumping

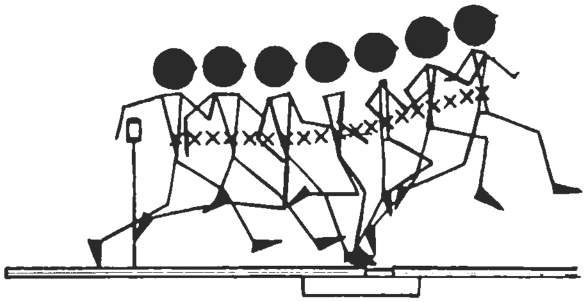

Figure 2. Stick figure diagram of a long jump take off demonstrating the eccentric contraction (lengthening) of the quadriceps and ankle plantaflexors prior to concentric contraction.

events. Luhtanen and Komi (31), in their study of mechanical factors influencing running speed, recognized the eccentric-concentric coupling of the muscles involved in running, and subsequent studies have confirmed the enhancement of concentric performance that this coupling realizes (26, 27). It has been found by Cavagna et al. (10, 12) that as the speed of running increases, the contractile component of muscles plays a progressively less important role in contrast to the elastic component (as one would expect from analysis of the aforementioned force-velocity curve for muscle).

Incorporating this coupling of movements (eccentric/concentric) into a training regimen has been shown by many investigators to produce superior results in terms of attainable power and speed, over other methods of training (5, 39, 49). This forms the basis of plyometric methods (quick eccentric "catch" before concentric contraction) of training such as bounding, hopping, and depth jumping that are frequently a part of training for power-based athletic events.

Enhancement of concentric performance in this manner is most effective when the preceding eccentric contraction is of a short range (21, 22) and performed quickly (6) without delay preceding the concentric contraction (3, 11, 34, 46).

Therefore, it seems that quick eccentric training may provide a means of strengthening the series elastic component of muscle via progressive overload principles in a similar way to that advocated by Curwin and Stanish (16) for strengthening tendons. This may then enable the muscle to more readily withstand the explosive forces encountered just prior to and during the competitive athletic season.

Quick eccentric-concentric coupling incorporated into training drills will not only provide a means of strengthening the SEC, but may also significantly enhance the subsequent concentric contraction and therefore improve performance as some of the aforementioned studies have shown.

By contrast, poor eccentric muscle capabilities may manifest as injury in power-based/speed events via two mechanisms. The SEC may not have the ability to withstand the forces needed to decelerate the moving limb and if the eccentric/concentric storage and recovery of elastic energy is inefficient, the concentric performance may be less than optimal.

Hamstring Function in Sprinting

Hamstring function in sprinting has been investigated by several authors and a brief review of hamstring function is relevant to this discussion on mechanisms of injury (32, 51, 52). As little individual difference has been found between the three upper leg muscles while sprinting, they will be treated as one for the present purpose.

Hamstring muscle activity during running can be considered to serve three functions (45).

1) The hamstrings work eccentrically to decelerate the thigh and lower leg during the last half of swing phase with movement halting at a point approximately 30° from terminal knee extension. This action prepares the limb to support the weight of the body as the foot descends to contact the ground at foot strike and limits the horizontal braking action created during this period. During this phase the hamstrings effectively store elastic energy which is recovered in early stance phase (Fig. 3).

2) Foot strike occurs with the hamstrings elongated across the hip and knee joints. Through a concentric contraction, the hamstrings assist in extending the hip while at the same time adding to the stability of the knee by preventing knee extension. During this early stance phase the hamstrings and gluteals are also cocontracting with the quadriceps group in absorbing downward forces of 6–7 times bodyweight through the stance leg (Fig. 4).

3) The hamstring muscles then assist the quadriceps to achieve push-off. At approximately 20° of flexion, the mechanical efficiency of the quadriceps extending the knee declines. As a result, the synergistic action of gastrocnemius, the hamstrings, and the vasti create a paradoxical extension moment at the knee during the last part of stance phase (44). Hamstring activity in very late stance also serves to protect the extending knee from hyperextension injury (33).

In the prediction of hamstring injury occurring at or just after the end of swing phase, the first and second functions described are important. It is during these phases of activity that the hamstrings generate peak torque values over the hip and knee.

Wood et al. (51) investigated these peak torques and found:

1) In late swing phase (eccentric knee flexion) peak torque values were typically 150 Nm at the

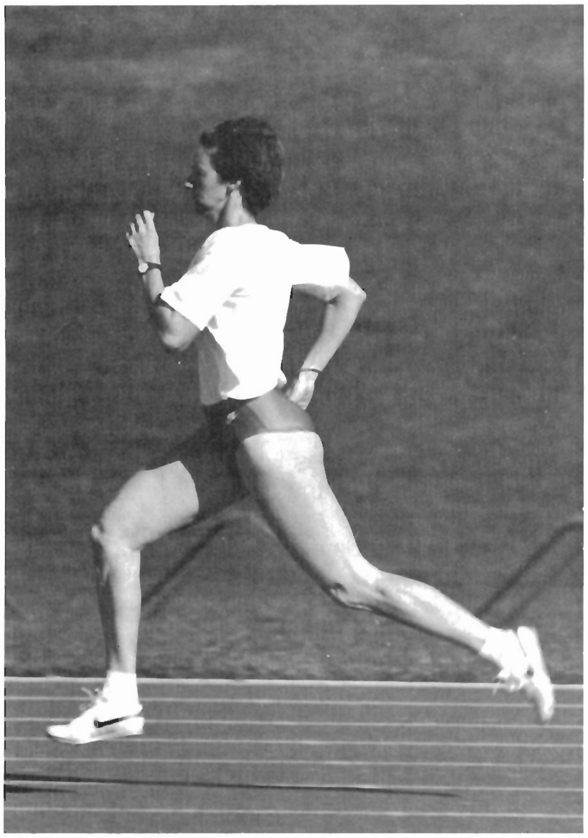

Figure 3. Right leg late swing phase.

knee and 250 Nm at the hip. This powerful contraction controls the momentum of the leg in preparation for an efficient foot strike and in doing so "stores" elastic energy. These late swing phase forces have been found to limit running speed because of an inability to elevate the peak eccentric hamstring muscle moment at the knee prior to foot strike (13). This limits how late in recovery hamstring function can decelerate the lower leg and appears to result in an inability to increase running speed by elevating stride frequency.

2) In early stance phase (following the eccentric/storage and concentric/recovery of elastic energy) Wood et al. (51) found a simultaneous peak of 160 Nm at the knee and 300 Nm at the hip as the hamstrings work concentrically to provide forward propulsion.

These results are supported by Mann et al. (32, 33) who found the greatest effort generated by the hip extensor/knee flexor group to be during the initial portion of ground contact. The ability of different athletes to generate these forces was inversely related to horizontal velocity loss (braking) during the stance phase—so the high forces at foot strike seem necessary to minimize this horizontal velocity loss.

Thus, the ability to produce high hamstring muscle moments just before and during foot strike appears related to athletic performance. Since these forces have also been related to the hamstring injury (33) it is evident that the better sprinter may be at greater risk. [Mann and Sprague (33) estimated muscle moments during sprint running and found a significant correlation (r = 0.7) between magnitude of the knee flexor moment at foot strike with a history of hip extensor/knee flexor injury.]

The injury risk is potentially exacerbated by two other factors:

a) The hamstrings are biarthrodial muscles (crossing two joints). This means that at various stages of sprinting the hamstrings lengthen over two points simultaneously, while at others they shorten over two joints simultaneously. As a result, the hamstrings undergo greater changes in length than muscles crossing only one joint.

b) The hamstring muscles are shown to have a relatively high proportion of "fast twitch" or Type II fibers (20, 38). As Type II fibers are more involved with exercise of higher intensity and force production, it has been postulated that the hamstrings are capable of high intrinsic force production (20).

Therefore the high levels of intrinsic tension developed by the hamstrings, combined with the extrinsic stretch involved with length changes over two joints, may also make them prone to injury during high intensity sprinting/jumping activity.

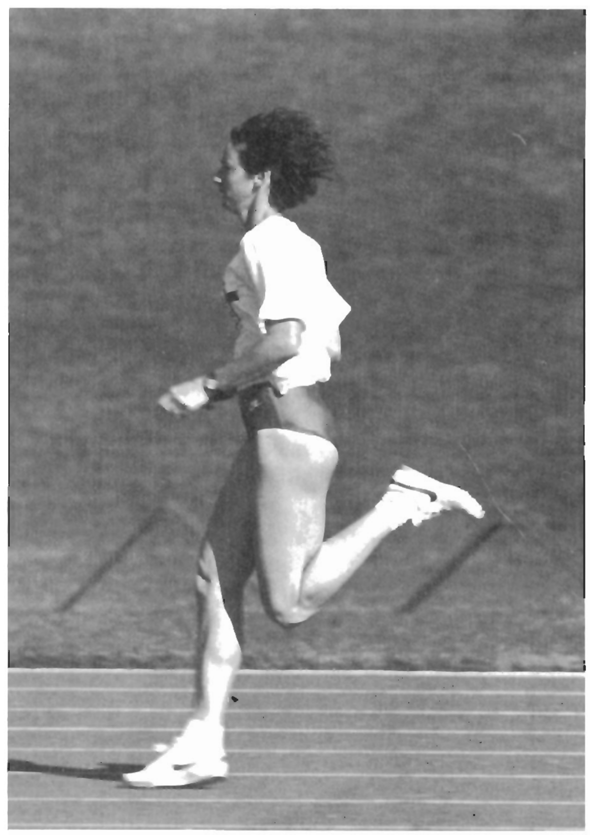

Figure 4. Right leg early stance phase.

Improving Eccentric Hamstring Function

It would, therefore, appear that improving eccentric hamstring function could serve several purposes.

Injury Prevention

Quick eccentric hamstring training allows greater stress to be placed on the SEC. This can serve as a basis for the application of progressive overload principles to strengthen the SEC. Simultaneous eccentric/concentric coupling in the training will enable enhancement of concentric performance so that the hamstrings are also better equipped to cope with the forces experienced at foot strike.

Improved Performance

An improvement in eccentric hamstring capability also means there is potential to decrease the time spent in leg recovery, thereby increasing cadence. At the same time, an improved storage and recovery of elastic energy via more efficient eccentric/concentric coupling is also a means of improving the concentric power generated by the hamstrings.

PART 2: CLINICAL APPLICATIONS

The authors' experience in treating patients with eccentric exercise regimens has been most encouraging, as has instituting a preventative program of eccentric exercises for the sprint/hurdles/jump athletes to reduce the occurrence of hamstring injuries over the precompetitive/competitive season.

In prescribing eccentric exercise there are several points worthy of note:

1) A muscle will generate higher forces eccentrically than concentrically for a given velocity, with this difference becoming greater as faster velocities are utilized. Therefore the stress on the SEC can be increased by increasing the speed of eccentric contraction.

2) Training effects have been found to be specific to limb position, joint angle, limb velocity and type of contraction (36, 42, 50). Therefore, training should approximate the sprinting action as closely as possible.

The Exercise

The patient rapidly extends the knee and decelerates at approximately 20–30° via an eccentric hamstring contraction, followed by a quick concentric contraction (Fig. 5). The athlete/patient commences the exercise with either no weight or ½ kg and performs 3 sets of 15 repetitions every second day. Progression is initially made by progressing from slow "catches," through medium speeds to fast catches over several training sessions. Once the athlete experiences no discomfort during or after the fast catches, weight is added to the foot and the athlete returns to a slow catch speed before again progressing to fast catches.

The weight is slowly progressed according to tolerance up to a point just below where a noticeable drop in catch speed is encountered. Several strong, uninjured male international level athletes progressed up to a maximum of 5 kg over a period of approximately 8 weeks—less "elite" people have taken longer to achieve these levels. Care must be taken with the exercise, as progressing the speed or weight of the exercise too quickly will result in pronounced delayed muscle soreness.

The exercise may be done either in standing, lying prone, or as we have been doing—lying over a couch (Fig. 6) to more closely approximate the hip and knee angles during late stance phase.

A recent pilot study investigated the torques and angular velocities produced with this exercise.

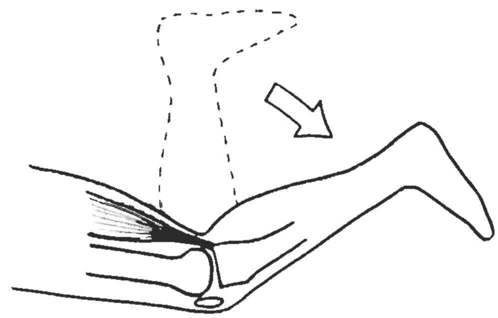

Figure 5. Quick active knee extension is rapidly decelerated at 20–30° via eccentric hamstring contraction. This is followed by a quick concentric contraction.

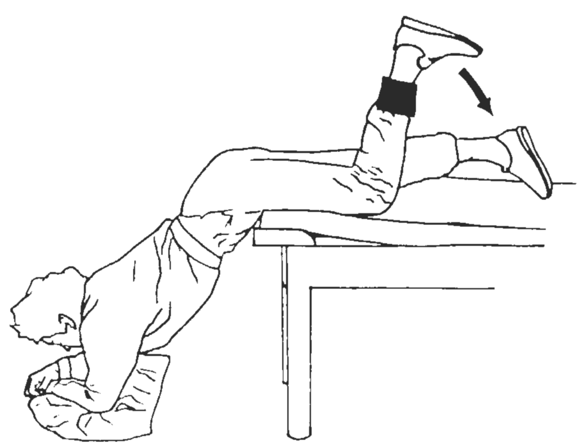

Figure 6. "Catch" exercise performed laying prone over the edge of a bed.

Pilot Study

One male athlete, age 28 years, weight 85 kg, was filmed using a Photosonics high speed camera (Photo Sonics Inc, Burbank, CA) at 100 frames/sec. The athlete was positioned prone over a couch such that the thigh was supported on the couch and the torso was supported by the arms on the floor. This gave a hip angle of approximately 30°. Following a start signal, the athlete performed the exercise as described previously with no weight and with weights of 0.6 kg and 2.5 kg affixed to the lower leg just above the malleoli.

Points marked on the lateral malleolus, the center of the knee joint laterally, and the greater trochanter of the exercising leg were digitized from the film with a calcomp digitizing table (Sanders, Scottsdale, AZ) and analyzed using a Vax. 750 laboratory computer (Digital Equipment Corporation, Maynard, MA). The computation of the knee torque was based upon the D'Alembert principle of dynamic equilibrium (35).

The results gave peak torque values of between 225 and 300 Nm during late eccentric/early concentric knee flexion at angular velocities close to 1000°/sec. These values are greater than the torques and angular velocities noted by Wood et al. (51) to be associated with similar eccentric/ concentric knee flexion at the end of swing phase and commencement of stance phase while sprinting, although it should be remembered that the present study only measured and exercised across the knee.

CONCLUSION

The exercise described should be valid for both retraining and preventing hamstring injury resulting from connective tissue insufficiency and possible performance enhancement (as described above) in terms of the torques produced, joint positions utilized, and angular velocities achieved.

The exercise regimen may then be added to other methods of strength training and rehabilitation for hamstring injury in an attempt to achieve more complete recovery and decrease the incidence of reinjury. ❑

REFERENCES

1. Abraham WM: Exercise-induced muscle soreness. Phys Sportsmed 7:57–60, 1979
2. Asmussen E: Positive and negative work. Acta Physiol Scand 28:364–382, 1953
3. Asmussen E, Bonde-Petersen F: Storage of elastic energy in skeletal muscles in man. Acta Physiol Scand 91:385–392, 1974
4. Baker BE: Current concepts in the diagnosis and treatment of musculotendinous injuries. Med Sci Sports 16:323–327, 1984
5. Blattner S, Noble L: Relative effects of isokinetic and plyometric training of vertical jump performance. Res Q 50(4):583–588, 1979
6. Bosco C, Komi PV, Ito A: Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiol Scand 111:135–140, 1981
7. Bosco C, Viitasalo JT, Komi PV, Luhtanen P: Combined effect of elastic energy and myoelectrical potentiation during stretch shortening cycle exercise. Acta Physiol Scand 114:557–565, 1982
8. Brewer BJ: Athletic injuries; musculotendinous unit. Clin Orthop 23:30–37, 1962
9. Burkett LN: Causative factors in hamstring strains. Med Sci Sports 2:39–42, 1970
10. Cavagna GA, Komarek L, Mazzoleni S: The mechanics of sprint running. J Physiol 217:709–721, 1971
11. Cavagna GA: Storage and utilization of elastic energy in skeletal muscle. Exerc Sport Sci Rev 5:89–129, 1977
12. Cavagna GA, Thys H, Zamboni: The sources of external work in level walking and running. J Physiol 262:639–657, 1976
13. Chapman A, Caldwell G: Kinetic limitations of maximal sprinting speed. J Biomech 16(1):79–83, 1983
14. Cibulka MT, Rose SJ, Delitto A, Sinacore DR: Hamstring muscle strain treated by mobilizing the sacroiliac joint. Phys Ther 66:1220–1223, 1986
15. Coole WG, Gieck JH: An analysis of hamstring strains and their rehabilitation. J Orthop Sports Phys Ther 9(2):77–85, 1987
16. Curwin D, Stanish E: Tendinitis: Its Etiology and Treatment. Lexington, MA: Heath & Co, 1984
17. Dornan P: A report on 140 hamstring injuries. Aust J Sports Med 4:30–36, 1971
18. Friden J, Sjostrom M, Ekblom B: Myofibrillar damage following intense eccentric exercise in man. Int J Sports Med 4(3):170–176, 1983
19. Friden J, Seger J, Sjostrom M, Ekblom B: Adaptive response in human skeletal muscle subjected to prolonged eccentric training. Int J Sports Med 4(3):177–183, 1983
20. Garrett WE, Califf JC, Bassett FH: Histochemical correlates of hamstring injuries. Am J Sports Med 12(2):98–103, 1984
21. Haugen P, Sten-Knudsen O: The dependence of short range elasticity on sacromere length in resting isolated frog muscle fibres. Acta Physiol Scand 112:113–120, 1981
22. Hill DK: Tension to interaction between the sliding filaments in resting striated muscle. The effect of stimulation. J Physiol 199:637–684, 1968
23. Kaneko M, Komi PV, Aura O: Mechanical efficiency of concentric and eccentric exercises performed with medium to fast contraction rates. Scand J Sport Sci 6(1):15–20, 1984
24. Komi PV: Relationship between muscle tension, EMG and velocity of contraction under concentric and eccentric work. In: Desmedt J (ed), New Developments in Electromyography and Clinical Neurophysiology, Vol 1, pp 596–606. Basel: Karger, 1973
25. Komi PV: Measurement of the force-velocity relationship in human muscle under concentric and eccentric contractions. Med Sport: Biomechanics III 8:224–229, 1973
26. Komi PV, Bosco C: Elastic energy in leg extensors by men and women. Med Sci Sports 10:261–265, 1978
27. Komi PV, Bosco C: Potentiation of the mechanical behaviour of human skeletal muscle through prestretching. Acta Physiol Scand 106:467–472, 1979
28. Kornberg CM: The incidence of positive slump test in Australian Rules football players with grade one hamstring strain. Proceedings of the Tenth International Congress of the World Confederation for Physical Therapy, Sydney, Australia, May 1987
29. Kuland DN: The Injured Athlete, pp 358–359. Philadelphia: JB Lippencott Co, 1982
30. Liemohn W: Factors related to hamstring strains. J Sports Med 18:71–76, 1978
31. Luhtanen P, Komi PV: Mechanical factors influencing running speed. In Asmussen E, Jorgenson K (eds), Biomechanics VIB, pp 23–29. Baltimore: University Park Press, 1978
32. Mann R: A kinetic analysis of sprinting. Med Sci Sports Exerc 13(5):325–328, 1981
33. Mann R, Sprague P: A kinetic analysis of the ground leg during sprint running. Res Q Exerc Sport 51(2):334–348, 1980
34. Margaria R, Cavagna GA, Saibene FP: Possibilita di struttamento dell 'elastica del musculo durante l'esercizio muscolare', Bolletino della Societa Italiana di Brologica Sherimentale 39:1815–1816, 1963. Cited in Cavagna GA: Storage and utilisation of elastic energy in skeletal muscle. Exerc Sport Sci Rev 5:95, 1977
35. Merriam JL: Dynamics, Ed 2, pp 174–176. New York: John Wiley & Sons Inc, 1971
36. Moffroid M, Whipple R: Specificity of speed of exercise. Phys Ther 50:1692–1700, 1970
37. Muckle DS: Associated factors in recurrent groin and hamstring injuries. Br J Sports Med 16:37–39, 1982
38. Polgar J, Johnson M, Weightman D, Appleton D: Data of fibre size in thirty-six human muscles. An autopsy study. J Neurol Sci 19:307–318, 1973
39. Polhemus R, Burkhardt E: The effects of plyometric training drills

on the physical strength gains of collegiate football players. Strength Conditioning Assoc 2(1):13–15, 1980
40. Prochazka A, Westerman RA, Ziccone SP: Ia afferent activity during a variety of voluntary movements in the cat. J Physiol 268:423–448, 1977
41. Rodgers KL, Berger RA: Motor unit involvement and tension during maximum voluntary concentric, eccentric and isometric contractions of the elbow flexors. Med Sci Sports 6:253–259, 1974
42. Sale D, MacDougall D: Specificity in strength training: a review for the coach and athlete. Can J Appl Spt Sci 6(2):87–92, 1981
43. Schwane JA, Armstrong RB: Effect of training on skeletal muscle injury from downhill running in rats. J Appl Physiol 55:969–975, 1983
44. Simonsen EB, Thomsen L, Klausen K: Activity of mono- and bi-articular leg muscles during sprint running. Eur J Appl Physiol 54:524–532, 1985
45. Sutton G: Hamstrung by hamstring strains: a review of the literature. J Orthop Sports Phys Ther 5:184–195, 1984
46. Thys H, Faraggiana T, Margaria R: Utilization of muscle elasticity in exercise. J Appl Physiol 32:491–494, 1972
47. Tullson P, Armstrong RB: Muscle hexose monophosphate shunt activity following exercise. Experientia 37:1311–1312, 1981
48. Tullson P, Armstrong RB: Exercise induced muscle inflammation. Fed Proc 37:663, 1978
49. Verkhoshanski Y, Chomowsov G: Jump exercises in sprint training. Track Tech 60:1909–1919, 1975
50. Winter D: Moments of force and mechanical power in jogging. J Biomech 16(1):91–97, 1983
51. Wood GA, Marshall RN, Anglim J, Strauss GR: Electro-musculo-mechanical action of the lower limb in sprinting—insights into hamstring injury potential. Presented at the IV Meeting of the European Society of Biomechanics, Davos, Switzerland, September 1984
52. Wood G: Optimal performance criteria and limiting factors in sprint running. New Studies in Athletics 2:55–63, 1986