Proprioceptive Training in the Rehabilitation of Lower Extremity Injuries

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Todays active lifestyle brings the benefits of health, well-being, and satisfaction to the participants. Unfortunately. activity also may cause injury. There are approximately 12 million runners in the United States' and 50% to 70% of them will be injured significantly during their career.2 Skiers are also injured at a high rate. A 6-year study on ski injuries found 1.700 injuries for every 400,000 skier days.2' Forty-two percent of the injuries were to the upper body while 58% involved the lower body. Youth sports also produce injuries at a high rate. Siagle found 28.5% of the boys participating in high school sports camps became injured. The majority of the injuries causing missed practice time were to the knee and ankle. Active people are also reinjured at an alarming rate. Pagliano and Jackson38 found that 29% of runners who had suffered a treatable injury would be reinjured.

The rehabilitation process following injury is of prime importance in trying to recover the normal function of the injured body part and its entire neuromuscular system. The almost immediate loss of muscular function. strength. power. and endurance can have a dramatic effect on not only the specific area of the injury but also on the muscle groups and joints proximal and distal to the injury site. If not rehabilitated properly, long- term chronic problems can develop.

Abnormal gait patterns following an injury may be a cause of foot. knee. hip, and back pain. It has been found that up to 33% of the patients suffering acute ankle sprains will have residual Jmptoms long after their rehabilitation programs have terminated.4 ' This functional instability' t 12 mav be due to lost and unrecovered joint, limb, and body proprioception.'

Proprioception, the body's ability to vary contractile forces of the muscles in immediate response to outside forces. may be an important factor in reducing the functional instability of all injured joints and the chance for

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Reinjury.’9 41 The ultimate goal of any rehabilitation process is the patient’s return to his or her normal function without residual functional instability or reinjury. Normal function differs from patient to patient and so should the rehabilitation process.
The runner, tennis player, triathiete. and professional baseball player all have a level of function they need to achieve. To achieve normal function for each patient. a four-phase rehabilitation process needs to be established with specific emphasis on the return-to-activity program through proprioceptive training tailored to the needs of the athlete.
Phase I, first aid and evaluation. may have a dramatic effect on return to normal function. If possible. rapid and proper evaluation of the injury should be done before the onset of the painspasm cycle. An accurate assessment at this time will help to establish early rehabilitation goals. Ice. compression, and elevation (ICE) need to be applied quickly and correctly to limit the amount of pain, swelling, and dysfunction.
Stimulation of the pain receptors through the mechanical and chemical effects of effusion causes a sufficient reflex inhibition of the muscle afferents. so atrophy results almost immediately.43 Only 60 cc of fluid in the knee joint has been shown to cause a 30% to 50% inhibition of the quadriceps with the vastus medialis being affected the most dramatically.S 23 4, The total healing time is also believed to be directly related to the amount of exudate in the doint. thus, the use of proper icing techniques may have a positive effect2 Curtailing and decreasing the amount of effusion and hemarthrosis as fast as possible is the primary goal of this phase.

The relaxation stage, phase II. is initiated 24 to 48 hours after the injury. The goals of this phase are to decrease the loss of range of motion in the involved joints and muscle groups and to decrease pain. If properly graded. this phase can begin within 24 hours. The longer the athlete is withheld from activity, the greater the loss in proprioception.3’ Early exercise will help decrease this loss. The use of ice, mobilization, high-voltage electrical muscle stimulation (EMS), and graded exercise is very beneficial in minimizing the effects on the propnoceptive systems. Mobilization techniques are particularly beneficial in decreasing pain and the loss of motion. High-voltage ems, although scientifically unproven, shows excellent clinical results in relieving pain and spasm and decreasing edema and effusion. The principles and techniques of proprioceptive neuromuscular facilitation (PNF) can be applied early in the rehabilitation process. The use of slow reversals to the uninvolved body parts and hold-relax with the muscles and joints involved will help decrease pain and spasm and promote relaxation, thus decreasing the loss of function.3°

Maintenance and return of strength, power, and endurance, phase III, is begun as soon as the athlete has pain-free range of motion. The patient need not have full range of motion if manual resistance techniques are used. However, the resistance offered the patient must be within his or her limits of pain and allow coordinated movement through the availabLe range of motion. Work should emphasize regaining full, active, pain-free range of motion.

Maintenance activities are also started for the uninvolved body parts.
The final phase. return to activity, is started during phase 111. Once the athlete can bear weight without pain, phase IV is begun. Returning the athlete to his or her normal, functional level of activity is the foundation of this phase. A gradually progressing program tailored to the athlete’s sport will achieve this goal.
To develop the proper return-to-activity program. a thorough understanding of the muscle and joint receptors and their functions is needed. Through this understanding, the muscles, ligaments, joints, and soft tissues can be stressed, stimulating the various proprioceptive systems to bring about a return-to-normal function and activity. The systems to be stimulated and utilized are the muscle spindles, Golgi tendon organs. and joint receptors.

Muscle Spindles
Muscle spindles are sensory organs that lie in the muscle and run parallel to the fibers. They are concentrated in the center of the muscle and are more numerous in skill muscles. The muscle spindles’ overall function is to monitor length and velocity related to length but not to monitor changes in length. These parameters are reported on a moment-to-moment basis with high sensitivity.’6 21.37
The muscle spindle is supplied by a single. large sensory neuron that attaches the spindle to the central nervous system. This primary afferent nerve fiber divides as it approaches the spindle and gives off to each intrafusal fiber. 16 These fibers are more numerous than the motor axons innervating the same muscle.33 The primary afferent has a low threshold and is very sensitive to small stretches and velocity of movement.21 37 When stimulated by passive stretch, the primary afferent causes an excitation of itself called autogenic facilitation. At the same time, it facilitates the synergists and inhibits the antagonists (direct inhibition). 16 This reflex to passive stretch is found in the flexor and extensor muscles of the limbs but not in the abductors and adductors.

The 5econdary afferent fibers have a higher threshold than the primary fibers and have some differences in function. They monitor absolute muscle length and velocity of movement.21 37 In general the secondary afferents facilitate flexor muscles and inhibit extensors*’6 This is important where joint stabilization is necessary. If a single joint extensor is activated, it causes inhibition of itself and excitation of its antagonistic flexor. This inhibition is not enough to inactivate the extensor because the primary afferent is stilt functioning. This causes a co-contraction about the joint resulting in a stabilizing effect, especially at the proximal joints.The efferent innervation—motor pathway from the spinal cord to the muscle—makes up 60% of the nerve fibers going to a muscle. These fibers are made up of larger alpha motor neurons that go to the contractile fibers of the muscle and small gamma motor fibers that go to the muscle spindle. The alpha motor neurons cause a direct contraction of the muscle while the gamma fibers contract the polar ends of the spindle. This activates the sensory endings causing the alpha motor neurons to be stimulated.’6 This gamma loop is responsible for registering the difference between the desired and actual contraction of the muscle. This error detection system is important in posture and fine motor control and may be the preferred pathway for activation of a muscle when there is adequate time.

Golgi Tendon Organ

Golgi tendon organs are sensory organs that, unlike the muscle s6pind[e. lie in series within the muscle at the musculotendinous junction.’ Like the muscle spindle, the Golgi tendon organ registers moment-to-moment changes in muscle tension.’6 21. 23. Only a small fraction of the total number of fibers have tendon organ? yet the tension on a single fiber can have a significant effect on the discharge rate of its afferent nerve. tZ These discharge rates give the central nervous system a good estimation of passive stretch’6 of the total muscular force being developed.46 This allows the monitoring of force generation and protects from overcontraction of the muscle. The inhibition of the same muscle and its synergists is termed autogetiic inhibition. At the same time. the antagonist is excited to release the muscular tension.16 21
The muscle spindle and Golgi tendon organ are very important in proprioception because they register and regulate the muscle tension. I-low- ever, regulation of stress at the joints is also needed. This function is performed by the joint receptors.

Joint Receptors

The body’s kinesthetic sense contributes to proprioception through the joint receptors. This ability to discriminate joint position, relative weight of body parts, and joint movement including direction, amplitude, and speed are monitored by the types I to III joint receptors.’8’ 29. 37. 52-55 the type IV receptor is also important because it monitors pain.’3 16. 17

Type I Receptors

The type I joint receptor lies in the superficial layers of the joint capsule and has increased density in the proximal joints. These always active receptors act as static and dynamic mechanoreceptors with a low threshold of activation and are slow to adapt. The primary functions are regulation of joint pressure changes and direction and amplitude and velocity of joint

Movement. 13. 29. 52-55 these changes are measured through the changes in capsular tension when changes in position occur.29 this allows the central nervous system to regulate postural muscle tone and muscle tone during joint movement.29

Type II Receptors

The type II receptors lie in the deeper layers of the capsule and articuLar fat pads. have a low threshold. And are rapid in adapting. The primary functions are to measure quick changes in movement such as acceleration and deceleration. These receptors are inactive in immobile joints, is. 29 3 52-55 They are in greater density in the more distal jointslS and are important in helping to initiate movement to overcome inertia.37

Type III Receptors
The type Ill receptors are dynamic rnechanoreceptors that have a high threshold and are slow adapting. They lie in the intrinsic and extrinsic ligaments of most joints and are sensitive to tension or stretch on the ligaments. 18. 29 37. 52-55 Their primary function is to monitor direction of movement and they are particularly active at the end range of joint movement. 29 ‘ They act with a reflex effect to provide a braking mechanism against over-stress of the joint.29

Type IV Receptors
The type IV receptors are high threshold. nonadapting pain receptors that are found in all joints. They are activated only with extreme mechanical or chemical irritation. They are found in the fibrous capsule. fat pads. intrinsic and extrinsic ligaments, walls of vessels, and the penosteum. 18. 29. 37. 32 They are not found in the articular cartilage. intraarticular fibrocartilage. and synovium.29
Proper stimulation of the muscle spindles. Golgi tendon organs. and joint receptors is the foundation of the return-to-activity program. This phase specifically involves flexibility, neuromuscular facilitation, balance, plyometrics. and sport-specific training.

Return to Activity
Flexibility
As effusion affects the various propnoceptors in the synovium, joint capsule, tendon, and ligament, so do tight, inflexible muscles acting on injured joints affect the various proprioceptors. Janda26 states that tight muscles act in an inhibitory way on their antagonists. He also felt that sometimes weakened antagonists will improve spontaneously after stretching the tight muscles. Inflexible hamstrings or triceps surae would be inhibited through autogenic inhibition from the Golgi tendon organ if they could not move freely through a normal. functional range of motion with strength and coordination. The type Ill joint receptors are Goli tendon like morphologically and have a similar effect on tight muscles. ‘

Before starting any strengthening program. it is imperative to lengthen the muscles involved.26 Numerous flexibility techniques are used in rehabilitation and several authors have investigated and reported on various stretching techniques.3 50 Tanigawa49 compared the hold-relax technique of PNF° to a passive mobilization procedure and found hold- relax a much more effective method for increasing the range of motion of the hamstrings. He felt that tension on the Golgi tendon organ overrides the muscle spindle inhibiting the muscle reflexively.

Moore and Hutton3 compared ballistic stretch, slow movements, static stretch, and PNF techniques. The PNF procedures were contract-relax (CR) and contract-relax with agonist contraction (CRAC). Their conclusion was that the CRAC technique was the preferred method for achieving maximum gain in flexibility.

Another group of researchers compared a modified CR technique to a ballistic flexibility technique and found the modified CR technique to be superior for increasing flexibility. It must be noted that the CR and CRAC technqiues as described by Moore and Hutton35 and the CR (modified) technique described by WallinDO are the hold-relax technique as described by Knott and Voss. The hold-relax technique is used for increasing muscle length and also is used in pain problems. The contract-relax with agonist contraction technique is the technique of choice for lengthening muscles and increasing the range of motion of nonpainful joints. It influences the Golgi tendon organs and the muscle spindles as well as the type UI receptors by reciprocal inhibition and autogenic inhibition.

All flexibility techniques improve joint range of motion but each may be better suited to a particular situation. Zachazewski and Reischl5 feel that all of the techniques should be used during specific portions of a training program. Slow, static stretching should be done before and after activity. The preparticipation stretching may decrease the facilitation of the muscle spindle afferents and assist the facilitation of the Golgi tendon organs. Post- participation stretching has the same effect, but by maintaining the stretch while the muscle cools, the muscle tissue may maintain its new length longer. During the training session, ballistic techniques may be beneficial because they simulate the flexibility and stress of activity. They felt that the PNF techniques were beneficial but they needed to be administered by a trained professional to get the best results.56 Once flexibility has been regained. the physical training program can begin.

Facilitation of Proprioceptors

Leach3' emphasizes that the longer athletes are withheld from their sport or from beginning their rehabilitation, the more they lose their sense of proprioception. Therefore, it is imperative that the therapist not only start the athletes rehabilitation program as soon after injury as possible. but that the rehabilitatiDn program be designed to facilitate the proprioceptors found in muscle, ligament, tendon, and joint. However, the therapist and athletic trainer can not get caught in the trap of only being concerned with strength. Moritani and DeVries36 found that higher scores in strength were gained largely from the acquisition of skill on “neural factors.” Not until after 3 to 5 weeks of a rehabilitation program did muscle hypertrophy become the dominant factor. Ihara and Nakayama24 concur that simple muscle training does not increase speed or muscular reaction but dynamic joint control training has the potential to shorten the time lag of muscle reaction. The neural factors” and dynamic joint control training are propnoceptive facilitation. Using the techniques and principles found in the concepts of PNF3° will achieve the best results. Patterns of motion, manual contact, approximation. elongation, maximal resistance, timing, and verbal and visual stimulation all should be utilized when appropriate.

Most authors agree that the vastus medialis, vastus medialis oblique, and the quadriceps in general are inhibited by pain, swelling, and hemarthrosis. 3 10. 2S. 31. 43. The restoration of function in those muscle groups is imperative if therapists are to achieve optimal gain for the injured athlete.
Soderberg and Cook45 state that quadriceps setting exercises are best for the vastus medialis. This exercise is also considered beneficial because the terminal extension range of motion causes the least pressure to the patellofemoral joint. However, the greatest distention of swelling in the knee occurs with terminal extension, therefore. the most inhibitory afferent discharge. However, at 30 degrees of knee flexion, less afferent discharge was found.28 The best place to start facilitating the mechanoreceptors in the capsule and the muscle spindles in the muscle belly and inhibiting the type IV pain receptors may be at 30 degrees of knee flexion (Fig 1). As the knee extensors become more responsive, work can progress to 0 degrees of knee extension. At terminal knee extension, the joint is in a close- pack position and maximal afferent flow is elicited by types 1. 11. and Ill fibers and the type IV fibers are inhibited.28 Following this progression will lead to effective propnoceptive stimulation.

If the injured athlete has difficulty eliciting a quadriceps contraction in early rehabilitation. EMS may be indicated to help facilitate the quadriceps. 3 20. 28 Kennedy et al.28 and l-Iartsell2° feel that EMS may bypass the afferent inhibition caused by capsular distension. Beck and Wilderrnuth3 feel that the use of EMS will help the athlete “feel the contraction and regain kinesthetic awareness.”

FIG 1.

Hold-relax for knee extension, external rotation at 30 degrees of knee flexion. Resistance is applied isometrically against knee extension and external rotation simultaneously to facilitate the vastus medialis and vastus medialis oblique while decreasing the stress on the knee joint.

To further facilitate or influence the joint receptors of the knee in full extension, the therapist may add approximation to the resistance exercises. The hold-relax technique in terminal extension is used at the same time heel strike is simulated by striking the heel as the contraction intensity is increased (Fig 2). This causes increased afferent flow from the primary and secondary afferents of the muscle spindles.’6

The next progression is to active motion through the available range of motion. Pesvner et al39 prefers short-arc quadriceps exercises. Beck and Wildern,uth3 also endorse the short-arc quadriceps exercises, but recommend gradually increasing the amount of extension until full active-resistive, pain-free range of motion is achieved.

As the patient continues to improve in strength and function, reciprocal knee flexion and extension and slow reversals should be initiated. In the slow-reversal technique. the athlete continually moves from a loose-pack to a close-pack range of motion stimulating afferent discharge of types I, II, and Ill fibers. Approximation and elongation of the extremity are superimposed over the top of the slow-reversals as he or she flexed with gravity.

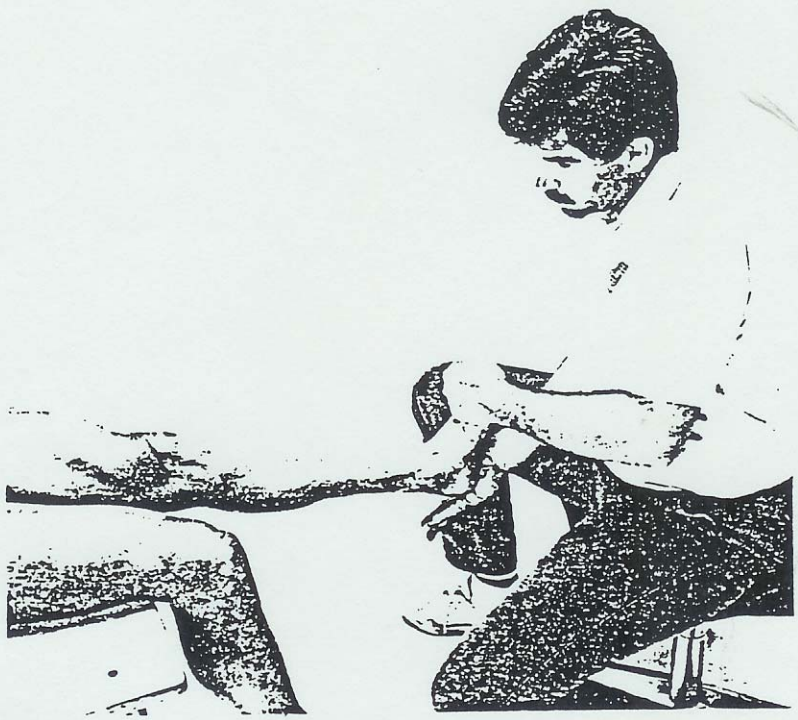

FIG 2.
Hold-relax for knee extensionexternal rotation at terminal knee extension with approximation. Resistance is applied isomethcally against extension and external rotation while striking the heel to simulate the heel strike of gail

assistance (elongation) and extended (approximation). These reciprocal movements will cause stimulation of the muscle spindles.

As the athlete's joint effusion is resolved, pain is alleviated and muscle control, coordination, and function begin to return, progression to more rigorous types of activities is indicated. Isokinetic exercise, which offers accommodating resistance at a fixed speed. is an excellent treatment choice at this time. Facilitation of the types I and II receptors in the ligaments and tendons and the muscle spindles will increase with this higher intensity exercise. The change of direction, going from flexion (a loose-pack position) to extension (a close-pack position) increases afferent discharge of the joint propnoceptors. This high-speed change of direction training stimulates the proprioceptive control needed to help decelerate a moving limb and change the direction of force and movement. One must be cautious not to train at one end of the speed spectrum. Sherman et al.43 believe that strength gains are specific to the training velocity and the program should contain work at numerous speeds. However, it is recommended that higher speeds (greater than 180 degrees per second) be used to decrease the patellofemoral stress of maximal isokinetic loading at low speeds.

Stationary bicycling has also been shown to be a beneficial rehabilitative exercise.34 The repetitive motions of hip and knee extension and hip and knee flexion stimulate the types I and II joint receptors as well as the muscle spindles and Golgi tendon organs. Isokinetic equipment and bicycles can be used effectively to simulate the demands of an athlete's sport. Recreating the rest and work periods of competition situations can be done easily. For instance, the football pla'er can recondition by watching game films and do high-intensity work on the bicycle during each play and ride easily between plays. The same can be done using isokinetic equipment by performing work bouts for 10 to 15 seconds and resting for 60 seconds.

Balance

Balance is affected by injury, and balance activities certainly have a role in the rehabilitation of athletes. Beck and Wildermuth3 noticed an impaired ability to do a stork test and Freeman et al.'2 used the Romberg test to assess propnoceptive deficits. Various methods of reestablishing balance and coordination can be used.

In the beginning, standing, two-leg activities should be used. The athlete's goal is to maintain normal total body posture while resistance is applied to the pelvis by the therapist in forward, backward, side to side. and rotary directions (Fig 3). Approximation through the pelvis should be applied as direction changes are made in order to facilitate the types I and II receptors. Initially, the resistance should be increased gradually and held long enough for the athlete to gain control of the involved muscles. Generally. the involved side of the body will show weakness, and verbal and visual stimulation can be used to help recruit the weaker muscle groups.

Single-leg balance activities should follow with the resistance applied in such a manner as to cause the athlete to begin to lose balance and have to recruit different muscles in order to regain balance (Fig 4). Once adequate balance ability is achieved in all motions, stronger resistance should be applied with more rapid changes in the direction of force. Additional challenges can be made by having the athlete close the eyes.

Many authors3 ' 19 advocate the use of balance boards as part of the rehabilitation regimen. Burton6 has found that the best board for stimulatirig activity in the lumbar erector spinae as well as lower limb musculature is 350 mm in diameter, set on a ball 50 mm high of 55 mm radius allowing an omnidirectional tilt of 15 degrees.

Balance activities cause changes in joint rotations and pressures. The ligaments, joint capsules, muscles, and tendons are stressed by the changes in direction. These stresses stimulate the muscle spindles. Golgi tendon organs, and types I to Ill joint receptors in a controlled. Nonloco-

FIG 3.
Two-leg standing trunk rotation. The therapist applies resistance for trunk rotation to the athlete’s pelvis. As the direction of resistance is changed. approximation should be applied through the pelvis to stimulate the extensor reflex.

Motor activity. This training prepares the proprioceptive systems for more vigorous activities.

Plyometrics

Plyometrics are a form of propnoceptive training that involve repetitive propulsion of the body using functional movements. These exercises are only limited by the imagination of the athlete and the therapist. The recommended progression would be from horizontal movements to vertical movements, followed by a combination of the two.

The horizontal program starts with double leg, forward hopping in a straight line. Once this is mastered with coordination and control without pain, side-to-side hopping should be added. A combination of forward and side-to-side hopping with both legs would follow (Fig 5). A similar progression using only one leg would follow. At times it is beneficial to start with

FIG 4.
Single leg standing trunk rotation. The therapist applies resistance to the athlete's pelvis. As the direction of resistance is changed. approximation should be applied through the pelvis to stimulate the extensor reflex.

The uninvolved leg rather than the involved. Foot-eye coordination cart be enhanced by asking the athlete to hop onto various targets while moving forward or from side to side. The distance of horizontal movement should be increased as power and coordination improve.

The vertical challenges involve the use of sturdy boxes 6. 12, 18. and 24 inches in height. The athlete is asked to jump from the floor to a box and back down. As power increases, larger boxes are used. Once skill and coordination are improved the athlete can jump through a progression of various height boxes. Jumping from one height box to the floor then to another height box stimulates muscular power but most important balance, proprioceptiort, and foot-eye coordination (Fig 6).

Landing and jumping again causes an eccentric force to be applied to the muscle, which prestretches the quadriceps and stimulates the muscle spindles. This causes a facilitation of the quadriceps and its synergists and

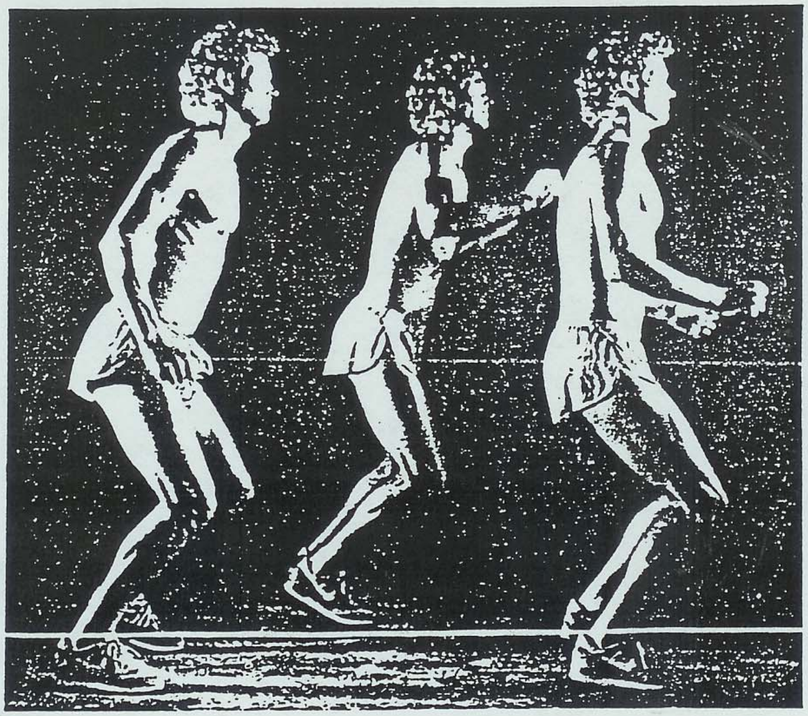

FIG 5.
Forward hopping across a line. The athlete hops back and forth across a line while moving forward.

Inhibition of the antagonists. The types I and II joint receptors are also stimulated by the change in joint pressure and the change in joint velocity and acceleration and deceleration.

The most difficult progression is forward hopping, with direction changes, and also vertical jumping on and off various height boxes. Additional challenges can be added with the addition of sport specific drills. For instance, if the athlete catches an object as part of the sport, have him or her do so white progressing through the various stages of plyometric training. A basketball player may dribble or shoot during the drills, Increased challenge and stimulation create increased propriocephve training and prepare the athlete to return to activity.

Sport Specific Training

During plyometric training the return-to-activity program can begin. This must be a gradually progressing, sport-specific program that places the

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FIG 6.
Forward jumping with various height boxes. The athlete propels himself forward while ‘umping from one box to the floor then to another box. Varying heights and numbers of boxes should be used.

Stress of the athlete’s sport upon his or her cardiovascular, neuromuscular. and proprioceptive systems. Rose et al.42 point out. “theoretically, muscle dysfunction may give rise to joint dysfunction. which may make muscle fiber type predominance important clinically.” Making a sprint sport athlete do predominately endurance work during his return to activity program may cause muscle fatigue and injury.

The progressions should be similar to those in plyometric training. First. straight-ahead running at 60% to 70% speed should be started. The progression begins with running (not jogging) the straights and walking the curves on a track and proceeds to running the entire track in both directions. Once the athlete can do this for 20 to 30 minutes 2 days in a row followed by one day off for one week, he or she is ready for changes in direction.

Figure eight running over a 50-yard course at 60% to 70% speed should start next. As the athlete progresses without discomfort the figure eight gets smaller and faster. The goal is to have the athlete run a 10-yard- long figure eight at full speed. During this progression, straight-ahead sprinting and running and sprinting uphill can be started. Caution should be used in downhill activities, but with proper controls they can be very beneficial.

Sport specific drills should also be added to the program. The basketball player should progress from shooting to one on one then half-court and finally full-court work with various drills included. The tennis player should hit ground strokes against a backboard or with an experienced partner so side-to-side movement can be controlled. Gradual increases in forward and back and side-to-side movements should be added until the athlete is ready for play.

Continually moving the athlete forward at the right time at the right pace is the key to an aggressive rehabilitation program. Utilization of flexibility. proprioceptive facilitation, balance training. plyornetric training, and sport- specific training at the right time and in the correct amounts is the key. If physical therapists and athletic trainers are both artists and scientists,'6 then they will facilitate or inhibit the various proprioceptors found in the joints, ligaments, muscles, and tendons to get the desired response from the athlete. When the art of rehabilitation is accomplished the athlete will return to his or her sport with strength, power, endurance, coordination, and optimal function.

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