Refining Rehabilitation With Proprioception Training: Expediting Return to Play

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In Brief: Although definitions of proprioception--sense of joint position--may vary, its importance in preventing and rehabilitating athletic injury remains constant: Restoring it after injury allows the body to maintain stability and orientation during static and dynamic activities. Any type of joint injury can interrupt position sense. Proprioceptive programs need to be tailored to the individual patient, but exercises can include balance training, closed-kinetic-chain exercises such as the leg press or single-leg hops, back-strengtheners, and quadruped stabilization. Sport-specific training is also crucial in regaining proprioception; an example is defensive slide drills in basketball.

Impaired joint "position sense" is overlooked in many rehabilitation programs and may be a major risk factor for recurrent injuries after the integrity of the muscles and ligaments has been restored (1). Physicians, therefore, need a general understanding of the afferent proprioceptive system, its importance to joint integrity, and how to emphasize it during rehabilitation and training.

The terms "proprioceptive deficit," "proprioceptive training," and "proprioceptive rehabilitation" are being used increasingly in sports medicine. Despite the popularity of this terminology, multiple definitions for proprioception exist. Many researchers have defined proprioception as the afferent input of joint position sense (ie, awareness of position or movement), whereas others consider proprioception in a broader sense that includes neuromuscular control. In addition to detection of an afferent stimulus, neuromuscular control includes processing the stimulus and a reactive efferent output mediated via the neuromuscular system (see "Proprioception: General Concepts," below).

Proprioceptive training and rehabilitation attempt to maximize protection from injury and provide optimal functional restoration. Joint laxity itself does not necessarily predict the presence or severity of functional instability (2). Studies (3,4) have shown that proprioception-based rehabilitation programs improve objective measurements of functional status independent of changes in joint laxity. These studies also showed that proprioception can be improved through training.

Injury and Proprioceptive Loss

Injury to a joint may cause direct or indirect alterations in sensory information provided by mechanoreceptors (see "The Role of Mechanoreceptors," page 95). Direct trauma may lead to ligament and capsule tearing, which may rupture the nerve fibers because they have less tensile strength than collagen. The consequent destruction of the messages to and from the joint receptors then causes "deafferentation" and proprioceptive loss (5-7).

An indirect disruption may result from the effects of an effusion or hemarthrosis. Receptors are still intact, but they provide incorrect information because of the pressure stimulus (5). The effort of the quadriceps (particularly the oblique fibers of the vastus medialis) can be inhibited up to 60% by a small (20-mL) knee infusion (8). This inhibition can deactivate the neuromuscular pathway and result in insufficient or uncoordinated muscle group activation. Leach (9) has shown that the longer an athlete is unable to compete, the greater the loss of proprioception. Thus, it is important to control the inflammatory phase of acute injuries via

early use of PRICE (protection of the joint, relative rest, icing, compression, and elevation of the limb above heart level) so that the patient can return to play as early as possible.
Regardless of the mechanism of injury, any damage to muscle spindles, Golgi tendon organs, or joint receptors has a significant impact on function and dynamic joint stability (see "Dynamic Joint Stability," below). In fact, these effects may be comparable to the deficit from the actual anatomic disruption of the ligament or tendon.

Ankle Proprioception

Freeman and Wyke (10) in 1967 demonstrated that the tibial, sural, and deep peroneal nerves terminate in mechanoreceptors in the capsule and ligaments of the ankle. In describing ankle injuries, they used the term "functional instability" to describe the results of deafferentation and the higher incidence of recurrent sprains in patients with previous ankle sprains. Injury results in deafferentation, and patients report "looseness" without gross mechanical instability. This functional instability can impair performance and increase the risk of reinjury.
Proprioceptive deficits have been documented in injured ankles via two methods: joint position sense and stabilometry. Glencross and Thornton (11) were the first to demonstrate proprioceptive deficits in patients who had a history of recurrent ankle sprains. A correlation was made between the severity of ankle injury and the inability to accurately reproduce joint positions.
In stabilometry, quantitative measures of equilibrium using changes in postural sway are obtained. Using stabilometry as a measure of functional ankle instability, Tropp et al (12) found that soccer players who had an increase in postural sway greater than 2 standard deviations above normal had a statistically significant higher risk of injury.
In a prospective study of the value of wobble board training and injury reduction, Tropp et al (13) demonstrated improved stabilometry and also reduced injury rates in previously injured soccer players given a 10-week treatment with ankle disk training. Such training may also affect more proximal joints: Proprioceptive training with five different phases of balance training on various boards that challenged the balance system was shown to significantly reduce the incidence of anterior cruciate ligament (ACL) injury in soccer players (14).

Proprioception in Low-Back Pain

Several neurophysiologic studies suggest a close relationship between back pain and various aspects of proprioception, and mechanoreceptors have been identified in the back. Yamashita et al (15) found that facet joints in rabbits contained two types of mechanosensitive afferent units, one believed to serve as a nociceptor and one as a proprioceptor.
Research suggests that patients who have low-back pain may have impairments in certain aspects of proprioception that can persist when proprioception is not specifically addressed. Nies and Sinnott (16) found that subjects who had low-back pain demonstrated significantly greater postural sway and were less likely to be able to balance in challenging positions than subjects who had no back pain. Based on such information, empiric programs have been developed on the premise that patients who have low-back pain experience an alteration in afferent feedback that may lead to poor control of posture and movement (17).
Some research (18) (including K.N. and E.R.L., unpublished data) suggests that, compared with postural sway, position sense may not be the most sensitive measure of proprioception in the low back, since pain may provide a feedback stimulus and actually enhance performance on tests such as replication of back position. Thus, reliable methods for measuring other aspects of proprioception and impairment of the afferent system need to be identified.

Specific Exercises

Despite the absence of definitive knowledge of discrete aspects of the proprioceptive system, rehabilitation programs can be designed to challenge, enhance, and improve this system. In addition, uninjured athletes may benefit from incorporating proprioceptive exercise into their training program. Healthy throwing athletes, for example, have been shown to have impaired ability to detect passive motion in their throwing shoulders (19).

Prophylactic programs designed to comprehensively address proprioceptive aspects of the joint may protect against injury (14). Specific proprioceptive training can help to fine-tune the afferent-efferent arcs. Exercises should include repetitive, consciously mediated movement sequences performed slowly and deliberately as well as sudden, externally applied perturbations of joint position to initiate reflex, "subconscious" muscle contraction (20). It may be impossible to single out specific mechanoreceptors to train, but certain activities can enhance mechanoreceptor activation and therefore affect the central nervous system pathway. To improve the proprioceptive system in dynamic joint stability, it must be challenged. In injury, "pain free" does not mean "cured," and unless the proprioceptive deficit is addressed, complete rehabilitation has not been accomplished. In addition, correction of a damaged static restraint (eg, surgical correction of mechanically disrupted tissue) may not maximize the afferent neuromuscular input needed to enhance dynamic joint stability. A recent study (21) has shown that ACL reconstruction did not improve the threshold of perception of passive knee motion. Mechanically stable joints are not necessarily functionally stable, especially in less constrained systems like the shoulder.

Balance training. One major category of proprioceptive exercise is balance training. These exercises help to train the proprioceptive system in a mostly static activity. In the lower extremities, activities can include one-legged standing balance exercises, progressive use of wobble board exercises (figure 1), and tandem exercises in which a postural challenge can be applied to the individual by the therapist or exercise partner (eg, challenges to stability while standing on one leg).

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Figure 1. Patients can balance on one foot on a wobble board to enhance dynamic ankle stability for training or ankle sprain rehabilitation.

Kinetic chain exercises. Closed-kinetic-chain exercises (those in which movement at one joint produces predictable movement at other joints, usually involving axial forces) challenge the dynamic and reflexive aspects of proprioception in the legs and feet. The lower extremities function in a closed-chain manner during sports and daily life activities, so these exercises will facilitate the proper neuromuscular engrams. Examples include the leg press, squat, circle running, figure eights, single-leg hops, vertical jumps, lateral bounds, one-legged long jumps, and carioca (crossover walking).

In the upper extremities, therapist application of graded, multidirectional manual resistance can provide proprioceptive feedback in a closed-chain fashion. Open-chain manual resistance exercises with rhythmic stabilization (rapid change in direction of applied pressure) are also considered proprioceptively enriched. In either case, resistance can be modified, depending on pain, as the patient progresses (figure 2).

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Figure 2. A physical therapist provides resistance in all planes of movement for upper-extremity strengthening. These maneuvers activate mechanoreceptors in multiple planes, stimulating proprioceptive pathways, and are especially helpful in treating rotator cuff tendinitis.

Focus on the back. Dynamic lumbar muscle stabilization (figure 3) has become the most popular method of proprioceptive retraining for the low back (22). This involves coordinated strengthening of the abdominal, back, and trunk muscles in functional movement planes. The lower back is often considered the "weak link" in the movement chain. Dynamic lumbar stabilization exercises are designed to progressively challenge this segment to promote successive adaptation, with an emphasis on balanced load distribution via a neutral pelvis, optimal skeletal alignment, and balanced strength.

Figure: © 1997. Terry Boles

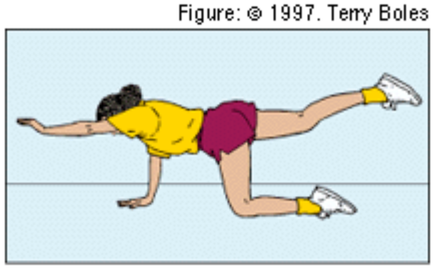

Figure 3. In this dynamic lumbar stabilization exercise, often used in the later stages of rehabilitation for low-back pain, the patient starts on all fours with knees bent 90°. He or she then extends the left arm and right leg simultaneously and holds for 10 seconds. The patient repeats with the right arm and left leg, five to six times on each side. This exercise trains coordinated co-contraction of abdominal and back muscles to enhance 'core' stability.

Shoulder care. Proprioceptive challenge can be applied to the shoulder using techniques such as quadruped stabilization on a balance board (figure 4), which can stimulate proper stabilization of the scapula in a closed-kinetic-chain position. This technique can encourage proper scapulothoracic and glenohumeral motion. This can be effective early in rehabilitation after an injury such as a rotator cuff tendinitis, because co-contraction (coordinated contraction of agonist and antagonist muscle groups) provides stability to the joint and is better tolerated than open-chain upper-extremity exercise. Wall push-ups are also useful and can be proprioceptively enhanced by having a physical therapist or resistance band provide resistance to the patient's back.

Figure: © 1997. Terry Boles

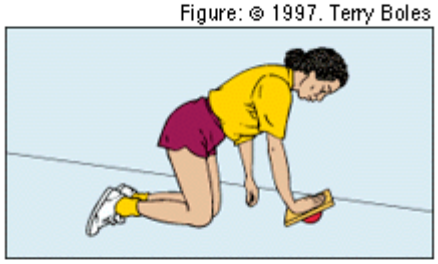

Figure 4. With rotator cuff tendinitis or another shoulder injury, patients can perform dynamic shoulder stabilization in the all-fours position but with one hand on a wobble board and the other hand held off the floor. The shoulder girdle is challenged as the patient tries to keep the edge of the wobble board from touching the floor. The patient can repeat with the other arm.

Sport-specific maneuvers. Sports specificity should also be incorporated. Sport-specific exercises will serve to "hard wire" the proprioceptive pathways and solidify a neuromuscular engram specific to these activities. Rehabilitation is incomplete until maneuvers specific to the sport and the athlete's position in the sport can be performed maximally and without pain or loss of function. These skills should be tested before the patient returns to competition. Starting sport-specific maneuvers with weighted resistance (eg, swinging a weighted tennis racket or baseball bat), could produce suboptimal neuromuscular engram patterning because the force of gravity hinders horizontal movement. Rather, the patient should first build a core program of symmetrical strength and stability in the upper and lower extremities. He or she then progresses to skill-specific practice (figure 5). For example, a football halfback can practice timed runs in tires or a rope maze; a baseball player can practice fielding and base running; a basketball player can practice lay-ups, perimeter shooting, and defensive slide drills.

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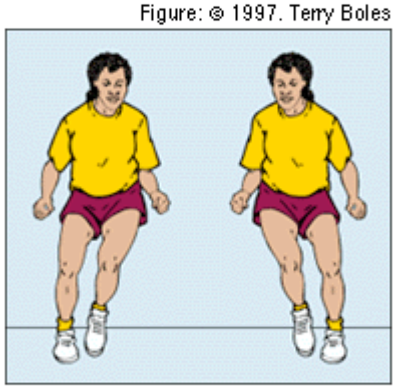

Figure 5. An example of sport-specific proprioception training is the lateral single-leg jump for downhill skiers. The patient assumes a skiing stance with legs shoulder-width apart, knees slightly bent, torso upright, and hands held in front. He or she then jumps laterally from one leg to the other as quickly as possible while keeping good skiing form. This exercise is useful both for training and in rehabilitating knee and ankle injuries.

Outcome analysis. Often with these exercises, we can measure only the results of proprioception--ie, dynamic stability--but from these measures we can infer how interventions affect the proprioceptive system. For example, one study (23) simulated ankle sprains on normal individuals with a platform that has a hinged trapdoor that produces sudden lateral ankle inversion of 20°. It revealed that after 8 weeks of using a wobble board, a "remodulation" of the ankle group muscles occurred to provide maximum dynamic ankle stability: Muscles that would create a greater inversion moment were slowed, which indirectly improved the efficiency of the peroneus longus to decelerate the foot during unexpected ankle inversion.

Research Needs

Focusing on aspects of neuromuscular function, such as dynamic joint stability, can help us study and design interventions that help to maximize neuromuscular function in sports and daily life. Given the significant data that point to the integral role of proprioception, further research on dynamic joint stability is necessary. In addition, because proprioceptive deficits exist after an injury--even in mechanically stable joints--research is needed to elucidate how these deficits can be remedied to improve function and prevent reinjury.

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Proprioception: General Concepts

Proprioception is one of the somatic senses--nervous system functions that collect sensory information from the body but are not one of the special senses of sight, hearing, taste, touch, smell, or vestibular equilibrium. Classically, three somatic senses are described: pain, thermoreceptivity, and mechanoreceptivity, the latter of which includes tactile and position sense. Proprioception relates primarily to the position sense of mechanoreceptive sensation (see "The Role of Mechanoreceptors," below).

Proprioception encompasses two aspects of position sense: static and dynamic. Static sense provides us with conscious orientation of one body part to another. Dynamic sense gives the neuromuscular system feedback about the rate and direction of movement.

Thus, proprioception can be thought of as a complex neuromuscular process that involves both afferent input and efferent signals and allows the body to maintain stability and orientation during both static and dynamic activities. In general, it is the process by which the body can vary muscle contraction in immediate response to incoming information regarding external forces (1).

There also are two levels of proprioception: conscious (voluntary) and unconscious (reflex initiated). While conscious proprioception enables proper joint function in sports, activities, and occupational tasks, unconscious proprioception modulates muscle function and initiates reflexive stabilization of joints by way of the muscle receptors (2).

Using the knee as an example, the afferent-efferent pathway can be described as a neuromuscular servomechanism that modulates hamstring and quadriceps activity. The central nervous system processes afferent proprioceptive input by comparing actual with intended movement. The discrepancy between the two can then trigger efferent output to correct the error.

Brand (3) has questioned the traditional view of ligaments as merely mechanical restraints and speculates that the neurosensory importance of the ligaments may, in fact, approach that of their mechanical effect. Because voluntary movements initiated at the cerebral cortex may be too slow to prevent injury, it is speculated that short-loop or spinal reflexes may be capable of a more timely response. Triggering these protective spinal reflexes during an "at risk" maneuver may play an even greater role in joint stability than the voluntary response.

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The Role of Mechanoreceptors

Mechanoreceptors initiate the afferent loop of proprioceptive feedback to the brain. They are specialized end-organs (neurosensory cells) that convert a physical stimulus into a neurologic signal that can be deciphered by the central nervous system (CNS) to modulate joint position and movement (1). Mechanoreceptors have important roles in joint position sense as well as in controlling muscle tone and generating reflex response (2).

Each of the four mechanoreceptor types responds to different stimuli and gives specific afferent information that modifies neuromuscular function. For further delineation of the functions of each type of mechanoreceptor, Wyke (3) provides an excellent review.

There is no clear consensus about the location of the key afferent receptors that trigger dynamic joint stability. Currently, the important receptors are thought to be cutaneous, joint capsule, muscle, and ligamentous. Grouped in broader classes, the articular and muscle receptors are considered the two important mechanoreceptor classes in joint stability; they contribute to joint position sense. Articular receptors are located within the joint capsule, ligaments, and intra-articular structures such as the meniscus. Muscle receptors are found in the muscle spindle and the Golgi tendon organ and are important for both proprioception and motor control of the muscles (1).

The action of mechanoreceptors can be better understood by looking at ligamentous mechanoreceptors, which are found in connective tissue running parallel to the ligament fibers. All receptors need a stimulus to change their membrane potential, which then causes an action potential to travel to the CNS. It is speculated that longitudinal tension on a ligament results in compression of the connective tissue and stimulates the mechanoreceptors (2).

Mechanoreceptors can also be stimulated by muscle-length change, including the rate of change in tension and length. The mechanical deformation of a receptor stretches the membrane and opens the ion channel. This allows positively charged ions (Na+) into the cell, which creates a net depolarizing effect that generates a nerve receptor potential. Mechanoreceptors detect deformation of the receptor itself or of cells adjacent to the receptor (4).

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Dynamic Joint Stability

Dynamic joint stability can be defined as the ability of appropriately activated muscles to stabilize a joint. Proprioception is a key component of dynamic joint stability, because afferent input indirectly produces and modulates the efferent response that allows the neuromuscular system to maintain a balance of stability and mobility. In essence, dynamic joint stability is the "product" of the proprioceptive system.

Much of the research regarding proprioception as it relates to dynamic joint stability has focused on the knee. Palmer (1) theorized that ligaments supply the central nervous system with input that makes neuromuscular control of the knee possible.

Cohen and Cohen (2) espoused the idea of an "arthrokinetic reflex" and suggested that the origin of important afferent input was the knee capsule. They also postulated that maintaining quadriceps/hamstring tension balance was necessary for joint stability.

Solomonow et al (3) postulated that anterior cruciate ligament (ACL) injury in humans interrupts the ACL-muscle reflex arc, triggering a second, slower pathway that originates from remaining muscle, capsule, and periarticular soft-tissue mechanoreceptors. This second pathway produces abnormal muscle activation patterns of the hamstrings and quadriceps, reducing dynamic knee stability.

Although a precise diagram of the afferent neural circuitry of dynamic joint control is not yet developed, the neuromuscular system has been shown to be capable of altering the strains imposed on the knee. For example, quadriceps contraction, which is driven by afferent information, has been shown to reduce the strain produced in the medial collateral ligament when a valgus force is applied (4). In addition, the stiffness of the medial knee can be increased up to 48% with contraction of the quadriceps and hamstrings (5).

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