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Current Concepts

The Role of Proprioception in the Management and Rehabilitation of Athletic Injuries

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ABSTRACT

Rehabilitation continues to evolve with the increased emphasis on patient management and proprioceptive training. Proprioception can be defined as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). Numerous investigators have observed that afferent feedback to the brain and spinal pathways is mediated by skin, articular, and muscle mechanoreceptors. Examining the effects of ligamentous injury, surgical intervention, and proprioceptively mediated activities in the rehabilitation program provides an understanding of the complexity of this system responsible for motor control. It appears that this neuromuscular feedback mechanism becomes interrupted with injury and abnormalities, and approaches restoration after surgical intervention and rehabilitation. Rehabilitation programs should be designed to include a proprioceptive component that addresses the following three levels of motor control: spinal reflexes, cognitive programming, and brainstem activity. Such a program is highly recommended to promote dynamic joint and functional stability. Thus far, current knowledge regarding the basic science and clinical application of proprioception has led the profession of sports medicine one step closer to its ultimate goal of restoring function.

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The proper management of athletic-related injuries and orthopaedic lesions can be complex in the sports medicine setting. One of the most challenging aspects to the clinician is understanding the role of proprioceptively mediated neuromuscular control after joint injury and its restoration through rehabilitation. Proprioception contributes to the motor programming for neuromuscular control required for precision movements and also contributes to muscle reflex, providing dynamic joint stability. The coupling effect of ligamentous trauma resulting in mechanical instability and proprioceptive deficits contributes to functional instability, which could ultimately lead to further microtrauma and reinjury (Fig. 1). Achieving functional and sport-specific activities after musculoskeletal trauma and rehabilitation can be enhanced significantly if proprioception is addressed and instituted early in the treatment program.

In addition to the mechanical restraint provided by articular structures, it has been observed that ligaments provide neurologic feedback that directly mediates reflex muscular stabilization about the joint.[20] The inclusion of proprioception in the rehabilitation program should be based on the preceding finding and not on anecdotal evidence without an understanding of the neuromuscular mechanism. This understanding, coupled with a base of knowledge regarding the current research on proprioception, is necessary for sports medicine practitioners to optimize treatment programs for athletes.

THE ROLE OF PROPRIOCEPTION

Numerous investigators have provided definitions regarding the terminology of joint sensation, or proprioception and kinesthesia.[3,26] Most contemporary authorities define proprioception as a specialized variation of the sensory

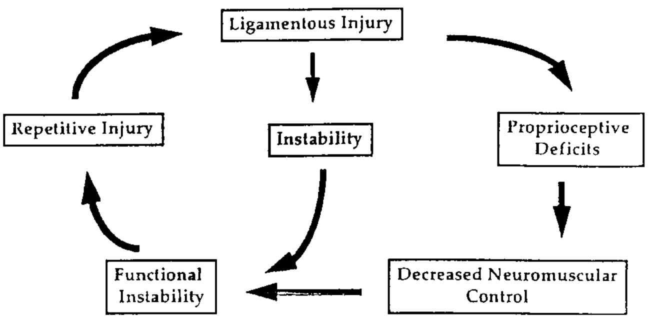

Figure 1. Functional stability paradigm depicting the progression of functional instability of the shoulder joint due to the interaction between mechanical instability and decreased neuromuscular control. (Reprinted with permission from Lephart and Henry.[23])

modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). The sensory receptors for proprioception that are found in the skin, muscles, and joints as well as in ligaments and tendons all provide input to the central nervous system (CNS) regarding tissue deformation.[15] Visual and vestibular centers also contribute afferent information to the CNS regarding body position and balance.[33]

Trauma to tissues that contain mechanoreceptors may result in partial deafferentation, which can lead to proprioceptive deficits. Susceptibility to reinjury, therefore, becomes a realistic possibility because of this decrease in proprioceptive feedback. However, studies have shown at least partial restoration of kinesthesia and joint position sense in surgically reconstructed shoulders and knees after rehabilitation.[24,25] Regaining neuromuscular control after injury or surgery is a necessary prerequisite for athletes wishing to return to competition.

The neural input that is provided by the peripheral mechanoreceptors as well as the visual and vestibular receptors are all integrated by the CNS to generate a motor response. These responses generally fall under three levels of motor control: spinal reflexes, cognitive programming, and brainstem activity (Fig. 2). In a situation where a joint is placed under mechanical loading, reflex muscular stabilization is stimulated through the spinal reflexes.[17] Cognitive programming that involves the highest level of CNS function (motor cortex, basal ganglia, and the cerebellum) refers to voluntary movements that are repeated and stored as central commands. This awareness of body position and movement allows various skills to be performed without continuous reference to consciousness.[33] As defined earlier, proprioceptive feedback plays a major role in the conscious and unconscious awareness of a joint or limb in motion.

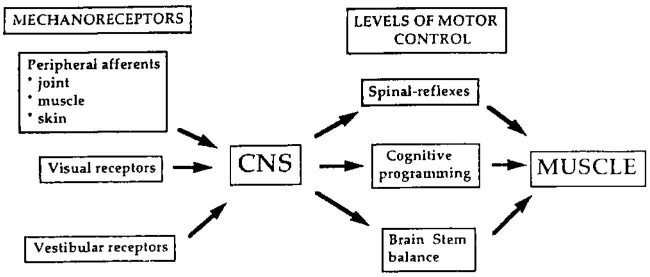

Figure 2. Neuromuscular control pathways. (Reprinted with permission from Lephart and Henry.[23])

PERIPHERAL AFFERENTS

The concept of proprioception is based on the fact that neural feedback to the CNS is mediated by cutaneous, muscle, and joint mechanoreceptors (Fig. 3). When examining the neural composition of joints, Hilton's law states that joints are innervated by articular branches of the nerves supplying the muscles that cross the joint.[19] In addition to proprioceptive mechanoreceptors, articular structures also include nociceptive free nerve endings.

Activation of joint mechanoreceptors is triggered by the deformation and loading of the soft tissues that compose the joint. This neural stimulation travels to the CNS for integration via cortical and reflex pathways. These mechanoreceptors demonstrate adaptive properties depending on a particular stimulus[15] (Table 1).

Quick-adapting joint mechanoreceptors, such as the Pacinian corpuscles, decrease their discharge rate to extinction within milliseconds of the onset of a continuous stimulus.[7] The Ruffini ending, Ruffini corpuscles, and the Golgi tendon-like organs that are referred to as the slow-adapting mechanoreceptors, continue their discharge in response to a continuous stimulus.[15] The properties of the

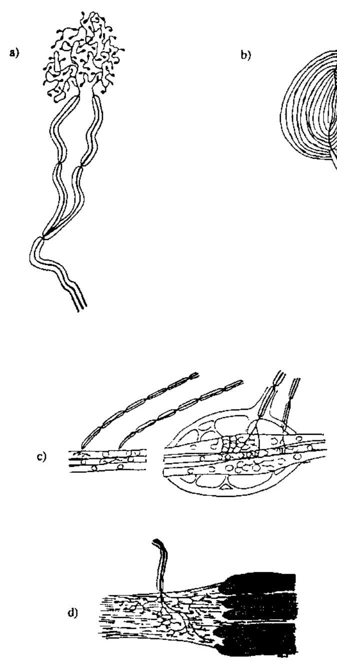

Figure 3. Schematic representation of proprioceptive mechanoreceptors: a) Ruffini ending, b) Pacinian corpuscle, c) muscle spindle receptors, and d) Golgi tendon organs. (Adapted from Willis and Grossman.[34])

TABLE 1
Articular Mechanoreceptors and Articular Nociceptors[a]

Receptor type	Location	Adaptation rate	Function
I, Ruffini endings	Joint capsule and ligaments	Slow	Joint pressure
II, Pacinian corpuscule	Joint capsule	Quick	High frequency vibration
IV (a), Unmyelinated free nerve endings	Ligaments (and related muscles)	Slow	Joint pain

[a] Modified from Freeman and Wyke.[11]

quick-adapting mechanoreceptors lead to the notion that they mediate the sensation of joint motion because they are very sensitive to changes in position. Muscular mechanoreceptors and Ruffini ending joint receptors are slow-adapting mechanoreceptors and are thought to mediate the sensation of joint position and changes in position because they are maximally stimulated at specific joint angles. One form of the slow-adapting receptors are the complex, fusiform muscle spindle receptors found within skeletal muscle. The muscle spindle receptor functions to measure muscle tension over a large range of extrafusal muscle length (Table 2). It has been suggested that muscle and joint mechanoreceptors are complementary to each other in providing afferent input in regard to limb position.[4]

This relationship between muscle and joint mechanoreceptors has been supported by the identification of the neural components necessary for the sensation of motion (rapidly adapting receptors, e.g., Pacinian corpuscles), joint position and acceleration (slow-adapting receptors, e.g., Ruffini endings and Ruffini corpuscles), and pain (free nerve endings) within ligamentous, cartilaginous, and muscular structures of the joints.

The spindle receptors found within the muscle are composed of a small bundle of modified muscle fibers called intrafusal fibers, to which the endings of several sensory nerves are attached. The extrafusal fibers that form the bulk of the muscle are responsible for generating force and are innervated by the alpha-motor neurons whereas the intrafusal fibers are innervated by the gamma-motor neurons. In the case of muscle contraction, alpha-gamma coactivation is believed to be the mechanism through which muscle length and tension are monitored.[27] Activation of gamma-motor neurons allow the readjustment of spindle sensitivity in the case where extrafusal fibers are shortened. This allows the spindles to be functional at all times during a contraction. When a muscle is loaded beyond an anticipated level, intrafusal fiber shortening occurs to a greater degree than extrafusal shortening. Stretching of the spindles in the central region causes a burst of excitatory postsynaptic potentials from spindle afferents. These signals summate with the alpha-motor neurons from descending pathways, thereby increasing force production.[27]

TABLE 2
Muscular Mechanoreceptors[a]

Receptor type	Location	Adaptation rate	Function
III, Golgi tendon organ	Tendons	Slow	Reflex
Muscle spindle	Muscle	Slow	Reflex (stretch reflex)

[a] Modified from Freeman and Wyke.[11]

With respect to changes in muscle and tendon tension, the Golgi tendon organs function as a protective mechanism. The Golgi tendon organs are located within the tendons of muscles and are recruited when muscle contraction pulls on the tendon, which straightens the collagen bundles and distorts the receptor endings of the afferent neurons.[27] This distortion increases the discharge rate of action potentials of these receptors that travel and synapse on spinal interneurons that project to motor neurons. Increased activity of the Golgi tendon organ afferents result in the inhibition of the motor neurons innervating the muscles that were stretched while exciting the motor nerves of the antagonistic muscles.

Studies have demonstrated the detrimental effect on reflex joint stabilization as a result of joint injury.[30,31] The contribution of musculotendinous receptors over joint receptors to the proprioceptive reflex remains a controversial issue in the literature. The ability to quantify proprioceptive deficits is a vital component to the evaluation of joint injury that may attempt to answer a number of clinical research questions.

CLINICAL QUESTIONS

Clinical application of proprioception research findings must be achieved at various levels of care for the management of orthopaedic lesions. A thorough understanding of proprioception assessment techniques will aid the clinician and orthopaedic surgeon to apply what is currently known concerning the nontraumatized joint to muscular, ligamentous, and cartilaginous injury. Establishing the effects of musculoskeletal trauma on joint position sensibility and neuromuscular control assists the need for critical decision-making regarding the appropriateness of various forms of treatment. From this point, it is known that surgical intervention plays an important role in the restoration of mechanical joint stability but its effects on proprioception pathways require further clarification. Finally, rehabilitation activities incorporating principles that stimulate the different levels of motor control to facilitate the return to function should be examined not only for its theoretical basis but also for its practical applicability.

The assessment of neuromuscular control includes the measurement of cortical, spinal reflex, and brainstem pathways. The evaluation of this complex neuromuscular system as different components allows a more detailed explanation of afferent control mechanisms. As defined previously, kinesthesia and joint position sense are components of proprioception. Functionally, kinesthesia is assessed by measuring threshold to detection of passive motion while joint position sense is assessed by measuring reproduction of passive positioning and reproduction of active positioning. When tested at a slow angular velocity (0.5 to 2 deg/sec), threshold to detection of passive motion as well as the reproduction of passive positioning is thought to selectively stimulate Ruffini or Golgi-type mechanoreceptors. Because the test is performed passively, it is believed to maximally stimulate joint receptors, thereby relying on the cortical pathway in the neuromuscular control system. After ligament lesions, passive joint sensibility testing is often chosen to assess afferent activity because muscle activity is negated. Stimulation of both joint and muscle receptors is done by the reproduction of active positioning, which provides a more functional assessment of the afferent pathways.

The evaluation of reflex capabilities is often assessed by measuring the latency of muscular activation to involuntary perturbation via electromyographic interpretation. The ability to quantify the sequencing of muscle firing can provide a valuable tool for the assessment of asynchronous neuromuscular activation patterns that may predispose an articulation to overuse trauma.

Functional assessment of the combined peripheral, vestibular, and visual contributions to neuromuscular control is best accomplished through the use of balance and postural sway measurements for the lower extremity. The availability of stabilometric methods and instrumentation can provide a relatively accurate index for these measures.

To reiterate this understanding of the proprioception mechanism, the clinician must apply the available knowledge to try to delineate the effects of orthopaedic injury, surgical reconstruction, and rehabilitation on the various afferent pathways. Specifically, clinical research aimed at determining the effects of injury, surgery, and rehabilitation on joint position sensibility, neuromuscular control as well as balance and postural sway can provide a solid foundation for the development of a testing model for the knee, ankle, and shoulder that attempt to address these issues.

KNEE PROPRIOCEPTION

Numerous studies have been performed that examined the role of proprioception in the knee joint. It has been found that damage to articular structures, such as the ACL and meniscus, in addition to osteoarthritic changes disrupts articular structures containing mechanoreceptors. The disruption in the cortical pathway, therefore, results in an alteration in joint position sense and kinesthesia. Barrack et al.[1] and Skinner et al.[28] observed decreased kinesthesia with increasing age and ACL disruption. Joint position sensibility decrements have also been documented as a result of osteoarthritic changes in the knee.[2]

Deficits in the neuromuscular reflex pathway may have a detrimental effect on this motor control system's role as a protective mechanism in acute knee injury. The initiation of the reflex arc stimulated by mechanoreceptors and muscle spindle receptors occurs at a faster rate than signals induced by nociceptors (70 to 100 m/sec versus 1 m/sec).[15] This suggests that proprioception may play a more significant role than pain impulses in preventing injury in the acute setting. However, the incidence of reinjury and the cause of chronic injuries may be attributed, to a greater extent, to proprioceptive deficits. These deficits may be induced by partial deafferentation as a result of initial knee injury and may also contribute to chronic joint disease through a decrease in joint afferents. This phenomenon has been observed by Beard et al.[5] in subjects with arthroscopically confirmed ACL deficiency. A significant deficit in reflex activation of the hamstring muscles after a 100 N anterior shear force in a single-legged closed kinetic chain position was identified, as compared with the contralateral uninjured limb.[5] Furthermore, Solomonow et al.[30] found that a direct stress applied to the ACL resulted in reflex hamstring activity, thereby contributing to the maintenance of joint integrity.

Although Barrack et al.[1] demonstrated a proprioceptive deficit after ACL disruption, it appears that kinesthetic awareness may be partially restored after ACL reconstruction. Kinesthesia has been reported to be restored after surgery as detected by the threshold to the detection of passive motion in the midrange of motion (45°).[1] However, a longer threshold to the detection of passive motion was observed in the ACL reconstructed knee compared with the contralateral uninvolved knee when tested at 15° of flexion. Lephart et al.[24] found similar results in patients after either arthroscopically assisted patellar-tendon autograft or allograft ACL reconstruction. This evidence suggests that kinesthesia may have returned in the midrange of motion after ACL reconstruction and appears to be more sensitive in the near-terminal range of motion.

The importance of incorporating a proprioceptive element in any comprehensive rehabilitation program is justified based on the results of these studies. Proprioceptive deficits may predispose an athlete to reinjury through decrements in the neuromuscular pathways resulting in the inhibition of complete rehabilitation.

ANKLE PROPRIOCEPTION

Chronic ankle instability as a result of partial deafferentation of articular mechanoreceptors with joint injury was first postulated by Freeman et al.[10] They observed that a decrease in the ability to maintain a one-legged stance occurred in the sprained ankle versus the contralateral uninjured ankle.[10] The effect of unilateral ankle sprains on cortical pathway measures of proprioception have been investigated by Garn and Newton,[12] who measured the ability of a subject to properly sense a passive movement or no movement state in the sagittal plane. Deficits in the ability to actively replicate passive ankle and foot positioning in this plane was reported by Glencross and Thornton[13] while testing the sprained ankle versus the contralateral uninjured ankle. Gross[16] recently reported that an increased probability of reinjury occurs as a result of a decrease in sensory input from joint receptors, leading to abnormal body positioning and diminished postural reflex responses. It was also found by Konradsen and Ravn[21] that chronic ankle instability resulted in a prolonged peroneal reaction time in response to a sudden inversion stress when compared with age-matched controls. Partial deafferentation resulting in diminished reflex joint stabilization may contribute to these findings.

The development of high technologic systems to assess the effects of musculoskeletal injury on balance has occurred in an attempt to quantify both static and dynamic components of proprioception.[18] The method of evaluation is based on the notion that damage to joint proprioceptors after injury to the lateral ligamentous complex of the ankle diminishes afferent feedback from the injured joint, thereby resulting in increases in postural sway.[10] To date, however, documented evidence exists concerning the alterations in postural sway after ankle injury using subjective evaluation (i.e., Romberg test). No increases in postural sway were observed by Tropp and Odenrick[32] when comparing a group of soccer players with previous ankle sprains to a control group of uninjured soccer players. Furthermore, no differences in postural sway were found between the involved and uninvolved ankles in a group of soccer players with a history of unilateral, recurrent ankle sprains.[32] However, significant increases in postural sway were observed by Cornwall and Murrell[8] when comparing patients with acute ankle sprains with uninjured controls as long as 2 years after their injuries.

The effects of surgical reconstruction for functional ankle instability on proprioception pathways as measured through joint position sensibility or balance and postural sway assessments have not yet been thoroughly investigated. Empirical evidence exists suggesting that proprioceptive training techniques after acute and chronic ankle injuries are highly effective. In addition, ankle wrapping and bracing have also been suggested to have a proprioceptive benefit. However, this notion remains untested and, therefore, unproven.

SHOULDER PROPRIOCEPTION

Placement of the hand is a necessary task during activities of daily living in addition to sport-specific patterns. Joint position sensibility has not only played a role in the maintenance of dynamic shoulder stability but has also been shown to demonstrate alterations after injury. Smith and Brunolli[29] have observed deficits in shoulder kinesthesia and joint position sense in male subjects with unilateral, traumatic, recurrent anterior shoulder instabilities. In a similar group of patients, Lephart and coworkers[25] also demonstrated proprioceptive deficits in the pathologic shoulder as compared with the contralateral normal shoulder.

In addition to alterations in the cortical pathway, Glousmann and coworkers[14] observed changes in the electromyographic pattern in baseball pitchers demonstrating shoulder instability. Reduction in neuromuscular activation of the pectoralis major, subscapularis, and latissimus dorsi muscles was found to contribute to anterior instability through a decrease in the normal internal rotation force required for this motion.[14] Compensatory increases in biceps and supraspinatis muscle activity were also discovered in an attempt to restore anterior stability. This loss in the normal synchronization of neuromuscular firing patterns in the unstable shoulder has, therefore, been attributed to altered joint kinematics resulting in repetitive microtrauma.[14]

Surgical intervention has been shown to partially restore joint proprioception through the repair of traumatized tissue. Partial restoration of kinesthesia has been observed in patients undergoing capsulolabral reconstruction.[25] This observation of enhanced proprioception centers around the procedural techniques used that promoted modification of joint sensation. Because this procedure modifies soft tissue dissection, there was a minimal loss of intact mechanoreceptors and a promotion of repopulation. In addition, the use of the capsular shift in these shoulder instability cases, which tightens the capsule, "retensions" the soft tissue and most likely facilitated proprioception function. It may be through this procedure of retensioning that mechanoreceptor-containing shoulder capsuloligamentous structures transmit afferent information at a more functional level regarding joint position sensibility.

Regaining dynamic neuromuscular control of the unstable or postoperative shoulder is of primary importance for the return of an athlete to functional activity. Rehabilitation exercises should focus on the importance of incorporating joint position sensibility and reflexive-type contractions into the therapy program. The inclusion of reflexive-mediated activities is based on the recent findings of Guanche and coworkers[17] who have observed three different articular branches of the axillary nerve innervating the shoulder capsule that provide a primary reflex arc to the biceps, supraspinatis, infraspinatis, deltoid, and subscapularis muscles in the feline model. This reflexive contraction has been attributed to providing a dynamic muscular restraint to the intact shoulder capsule.[17] Because the shoulder model in this study was that of a weightbearing joint, the closed kinetic chain principle is needed in upper extremity rehabilitation.

REHABILITATION

The objectives of proprioceptive rehabilitation are to retrain altered afferent pathways to enhance the sensation of joint movement. Proprioceptively mediated neuromuscular control of joints takes into account three distinct levels of motor activation within the CNS. Reflexes at the spinal level mediate movement patterns that are received from higher levels of the nervous system. This action provides for reflex joint stabilization during conditions of abnormal stress about the articulation and has significant implications for rehabilitation.[20] The use of exercises that facilitate dynamic joint stabilization may result in the improvement of this neuromuscular mechanism.

The second level of motor control, located within the brainstem, receives input from joint mechanoreceptors, vestibular centers, and visual input from the eyes to maintain posture and balance of the body. Reactive neuromuscular activities that allow this pathway to process input from the aforementioned forms of afferent stimuli can be used to enhance brainstem function.

The highest level of CNS function (motor cortex, basal ganglia, and cerebellum) provides cognitive awareness of body position and movement in which motor commands are initiated for voluntary movements. Use of the cortical pathway allows movements that are repeated and stored as central commands to be performed without continuous reference to consciousness. Kinesthetic and proprioception training are such types of activity that can enhance this function.

Incorporating the three levels of motor control into activities to address proprioceptive deficiencies should be initiated early during the rehabilitation process.[23] Encouraging maximum afferent discharge to the respective CNS level must be the goal in stimulating joint and muscle receptors.[33] To stimulate reflex joint stabilization, which emanates from the spinal cord, activities should focus on sudden alterations in joint positioning that necessitate reflex neuromuscular control. Enhancing motor function at the brainstem level can be achieved by performing balance and postural activities, both with and without visual input. Maximally stimulating the conversion of conscious to unconscious motor programming can be achieved by performing joint positioning activities, especially at joint end ranges.[33] Simple tasks such as balance training and joint repositioning should begin early in the rehabilitation program and should become increasingly more difficult as the patient progresses. Regaining joint sense awareness to initiate muscular reflex stabilization to prevent reinjury should be the primary objective once the final stage of rehabilitation is reached.

Some contemporary authors believe that adaptations that occur during rehabilitation are related to (mediated by) feed-forward processing and are less a function of enhanced afferent pathways.[22] This theory suggests that fast movements are controlled by advance information known about the task, while concurrent proprioceptive feedback is relatively less important. Feedback is used primarily at the cortical level to determine the success or failure of that movement and to a lesser extent at the subcortical level for directing the movement. With repetition, the cerebral cortex can determine the most effective motor pattern for a given task, based on the proprioceptive information of previous attempts.[22] Biofeedback training appears to use the feed-forward learning process.[9] However, there is still controversy regarding the contribution of afferent feedback in feed-forward processing.

Following is an example of a shoulder rehabilitation protocol that has been designed using the principles outlined in this paper for reestablishing proprioception and neuromuscular control.

Reestablishing Proprioception and Neuromuscular Control in the Shoulder

Proprioception training of the upper extremity has been incorporated into the rehabilitation program to a lesser extent than that of the lower extremity. Because the primary sport-specific activity of the upper extremity is the throwing motion, refined joint positioning and repositioning of the shoulder is vital. Therefore, mechanoreceptor activity plays an important role in both performance and dynamic shoulder stabilization. To maximally restore proprioception and neuromuscular control, it is recommended that the following progression of activities be conducted to allow the return of an athlete to functional levels: 1) joint position sense and kinesthesia, 2) dynamic joint stabilization, 3) reactive neuromuscular control, and 4) functionally specific activities. Such a progression allows the rehabilitation program to address the integration of spinal reflex, cognitive, and brainstem pathways to focus on scapular stabilization, glenohumeral stabilization, humeral motion, and neuromuscular control.[23]

Position sensibility activities are designed to restore joint position sense and kinesthesia (Fig. 4). These exercises stimulate cognitive level processing through the use of such an exercise as glenohumeral repositioning both with and without visual input and proprioceptive neuromuscular facilitation patterns performed with manual resistance.[23]

Dynamic stabilization activities are designed to stimulate muscular coactivation. In the shoulder, such activities include axial loading of the glenohumeral joint promote coactivation of the glenohumeral and scapulothoracic force couples (Fig. 5).[6] The use of such activities as upper extremity balance training results in muscular coactivation.

Ultimately, the integration of both spinal and cognitive levels can be accomplished by the use of neuromuscular control exercises such as plyometrics. Shoulder plyometric exercises stimulate reflexive activity through the facilitation of the myotatic reflex via the release of stored elastic energy.[23] Such activities stimulate reflex joint stabilization, which are critical to the overhead athlete (Fig. 6).

Once joint sensibility and dynamic muscle joint stabilization are restored, progression to functionally specific activities can be accomplished. Functionally specific activ-

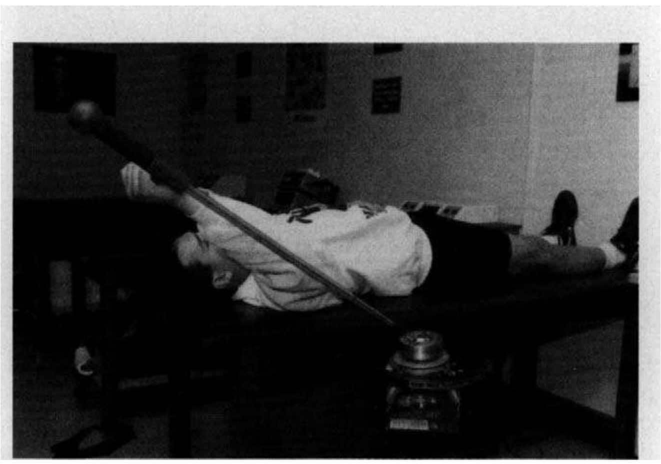

Figure 4. Joint position sense and kinesthetic exercise: Shoulder kinesthetic training through functional arcs of abduction and external rotation. (Reprinted with permission from Lephart and Henry.[23])

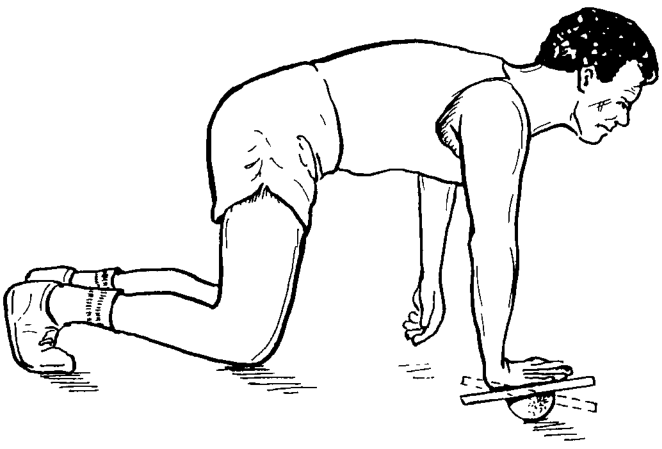

Figure 5. Dynamic joint stabilization exercise: Exercise performed with a wobble board to stimulate coactivation of shoulder muscle force couples. (Reprinted with permission from Lephart and Henry.[23])

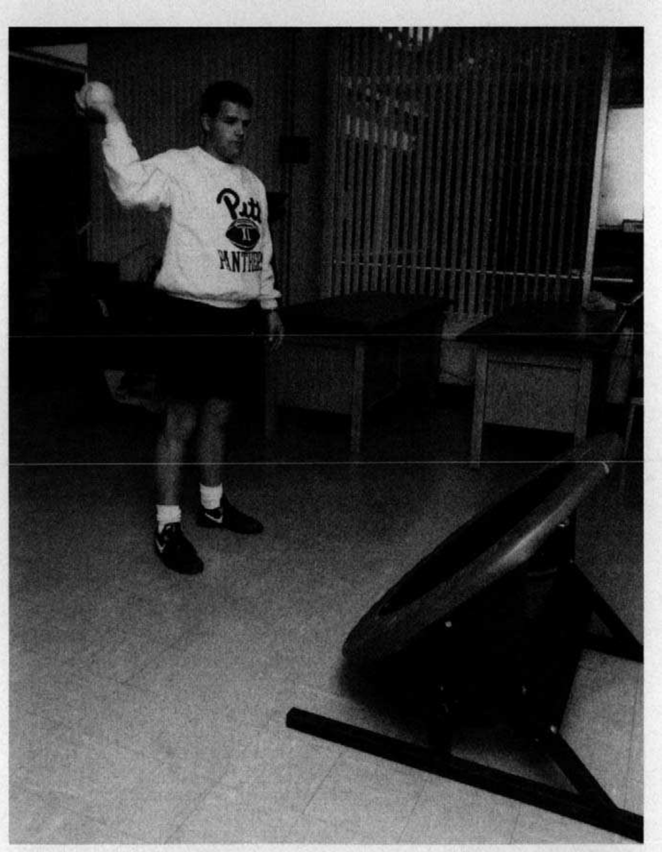

Figure 6. Reactive neuromuscular exercises: Shoulder plyometric exercise performed in the open kinematic chain position for stimulating reflex muscle activation necessary for dynamic joint stabilization. (Reprinted with permission from Lephart and Henry.[23])

ities are designed to restore functional motor patterns necessary for successful performance of the overhead athlete (Fig. 7).

The integration of these levels is a necessary component of the rehabilitation program to provide proper neuromuscular control and functional stability of the joint. Completion of the progressive neuromuscular control rehabilitation program minimizes the risk of reinjury and promotes a greater chance of successful return to competition.[23]

With respect to the lower extremity, mechanoreceptors located within the joints are most functionally stimulated when the extremity is positioned in a closed-kinetic chain orientation and perpendicular axial loading of the joint is permitted. These exercises should be performed at various positions throughout the full range of motion because of the difference in the afferent response that has been observed at different joint positions.

FUTURE DIRECTIONS

The numerous investigations cited in this review have attempted to present an understanding and a rationale behind the use of proprioception exercises in rehabilitation. However, this pool of knowledge has opened the door to many more questions concerning proprioceptively mediated neuromuscular control. Evidence regarding the effects of rehabilitation on proprioception has yet to be verified. In addition, the effects of tissue regeneration on neuromuscular pathways is an area that also needs to be investigated. The establishment of this relationship between proprioceptive deficits and motor control attempts to incorporate basic science and clinical findings into a practical rehabilitation exercise prescription. Finally, prospectively evaluating the effects of ligamentous injury, surgical reconstruction, and rehabilitation will help to justify the means through which articular lesions are managed. The research presented thus far puts the clinician one step closer to optimizing clinical decision-making

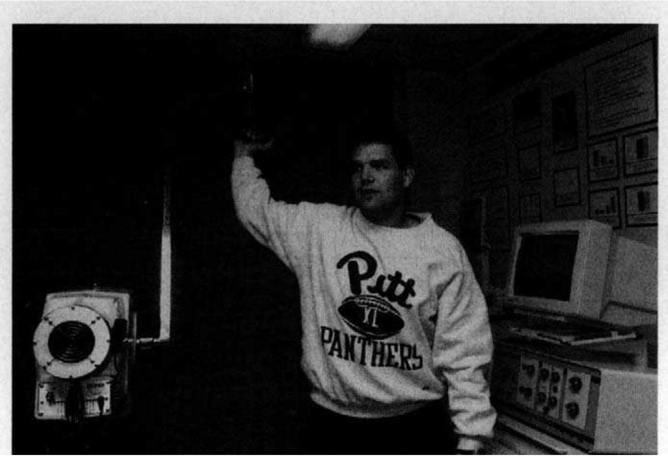

Figure 7. Functionally specific exercise: Isokinetic dynamometry for the overhead throwing athlete using functional motor patterns. (Reprinted with permission from Lephart and Henry.[23])

of the rehabilitation protocol. This process of understanding leads to the ultimate goal of restored function.

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