Journal of Sport Rehabilitation, 1994, 3, 84-104

Functional Assessment and Rehabilitation of Shoulder Proprioception for Glenohumeral Instability

Paul A. Borsa, Scott M. Lephart, Mininder S. Kocher, and Susan P. Lephart

Following injury to the articular ligaments, disruption of mechanoreceptors results in partial deafferentation of the joint. This has been shown to inhibit normal neuromuscular joint stabilization, and it contributes to repetitive injuries and the progressive decline of the joint. Assessment of proprioception is valuable in identification of proprioceptive deficits and subsequent planning of the rehabilitation program. A shoulder rehabilitation program must address both the mechanical and sensory functions of articular structures by incorporating a proprioceptive training element within the normal protocol. The objective of proprioception rehabilitation is to enhance cognitive appreciation of the respective joint relative to position and movement, and to enhance muscular stabilization of the joint in the absence of structural restraints. If these objectives are properly addressed, the restoration of the proprioceptive mechanism will prevent further disability of the shoulder joint.

There is a delicate balance between mobility and stability in the shoulder. Static and dynamic stabilizers interact to provide stability to the glenohumeral joint (10, 29, 30, 47, 50, 57–59, 64, 68). This stability and mobility of the glenohumeral joint necessitate an intricate balance of muscular strength and endurance, flexibility, and neuromuscular control. Historically, much attention has been directed toward the restoration of muscular strength, muscular endurance, and joint flexibility following injury without consideration to the role of the neuromuscular mechanism. The neuromuscular mechanism that contributes to joint stability is mediated by articular mechanoreceptors and provides the individual with the sensations of kinesthesia and joint position sense (44, 46). The neurological feedback for the control of muscular actions serves to protect against excessive strain on passive joint restraints and is referred to as joint proprioception.

Paul A. Borsa and Susan P. Lephart are doctoral students in sports medicine/exercise physiology at the University of Pittsburgh. Scott M. Lephart is with the Department of Sports Medicine/Athletic Training and the Department of Orthopaedic Surgery, 104 Trees Hall, University of Pittsburgh, Pittsburgh, PA 15261. Mininder S. Kocher is with the Department of Orthopaedic Surgery, Harvard Medical School, Boston, MA 02115. Direct correspondence to Scott M. Lephart.

Functional instability of the glenohumeral joint affects normal joint kinematics and contributes to the vicious cycle of insidious microtrauma (39, 52–54, 56). Glenohumeral instability refers to excessive, symptomatic translation of the humeral head on the glenoid fossa, and reflects altered static and dynamic structures for stabilization (49, 66). The disruption of capsuloligamentous structures that results in excessive humeral head translation can also contribute to glenoid labral tears (1, 3, 4).

Ligaments play a major role in normal joint kinematics, providing mechanical restraint to abnormal joint motion when a stress is placed on the joint (66). The primary concern of the athletic trainer and orthopedic surgeon has been the mechanical restoration of these ligaments following injury, or postreconstructive surgery, in an attempt to reestablish the joint's static stability and kinematics. If normal joint kinematics are restored, recurrent injury will be minimized and progressive joint degeneration can be avoided (7, 8, 60).

Baxendale et al. and Kennedy, however, observed that in addition to performing their mechanical restraining function, articular ligaments provide important neurological feedback that directly mediates muscular reflex stabilization about the joint (9, 39). Following injury to the articular ligaments, disruption to articular mechanoreceptors results in partial deafferentation of the joint. This has been shown to inhibit normal neuromuscular joint stabilization, and it contributes to repetitive injuries and the progressive decline of the joint (42, 45).

Articular mechanoreceptors have morphohistologically been identified in both animal and human models in the ankle, knee, and shoulder, suggesting an anatomical basis for an active proprioceptive mechanism in all joints (2, 67). The proprioceptive mechanism is essential for proper joint function in sports, activities of daily living, and occupational tasks.

Proprioception is considered a specialized variation of the sensory modality of touch, which encompasses the dynamic and static sensations of joint motion (kinesthetic sensibility) and position (joint position sensibility), respectively. Conscious proprioception is essential for proper placement of the hand in upper extremity activities, while unconscious proprioception modulates muscle function (44, 61).

Proprioception is mediated by peripheral receptors in articular, muscular, and cutaneous structures. Articular structures include nociceptive free-nerve endings and proprioceptive mechanoreceptors consisting of Pacinian corpuscles, Ruffini endings, and Golgi tendon organ–like endings (27). Mechanoreceptors are specialized neurons that transduce mechanical deformation into electrical signals concerning joint motion and position (23, 24). Ruffini endings and Golgi tendon organ–like endings are slow adapting and are important in signaling actual joint position or change in joint position. Pacinian corpuscles are rapidly adapting and function for the most part in sensing sudden motion or acceleration/deceleration-type motions (61). These three articular mechanoreceptors have recently been histologically identified in the glenoid labrum and glenohumeral ligaments, through gold chloride staining techniques, suggesting that shoulder capsuloligamentous structures possess the anatomical basis for perceiving joint position and motion (67). Stimulation of these receptors propagates the proprioceptive mechanism and results in proprioceptive sensibility and reflex musculature stabilization about the joint (9, 36, 63). Muscle spindle and Golgi tendon organ (GTO) receptors, which are slow adapting, are the receptors thought to subserve proprioceptive function in muscles. The muscle spindle receptors sense changes in muscle length, while the GTO receptors sense changes in muscle tension.

The joint capsule has traditionally been thought to be the site of the peripheral receptors responsible for joint proprioception (48, 61). More recent studies have shown that capsular receptors only respond at the extremes of the range of joint motion (25) or during other situations when strong stimuli are imparted on the joint capsule, such as distraction, compression, or deep pressure (13, 24, 26). Muscle receptors are thought by many to play a more important role in signaling joint position (14, 17, 20). Recent work suggests that muscle and joint receptors are probably complementary components of an intricate afferent system in which each receptor modifies the function of the other (9, 15, 22). Articular and muscle receptors have well-established cortical connections to substantiate a central role in the proprioceptive mechanism (31, 32, 61).

Assessment of proprioception is valuable for identifying proprioceptive deficits and subsequent planning of the rehabilitation program. A rehabilitation program that addresses the need for restoring normal joint stability and proprioception cannot be constructed until one has a total appreciation of both the mechanical and sensory functions of articular structures. Simply restoring mechanical restraints or strengthening the associated muscles neglects the coordinated neuromuscular-controlling mechanism required for joint stability, especially during the sudden changes in joint position common to functional activities. A lag time in the neuromuscular reaction time can result in recurrent joint subluxation and joint deterioration (19).

The link between proprioceptive deficits and joint pathology has been well established in populations of athletes, individuals presenting acute traumatic joint pathology, and people who have degenerative joint disease (7, 8, 42, 45, 60, 62). In each of these populations the lack of proper joint stability presents the potential for reinjury and progressive deterioration of articular structures. If these deficiencies in proprioception can be clinically diagnosed and rehabilitated, the restoration of the proprioceptive mechanism will prevent further disability.

The objective of proprioception rehabilitation is to enhance cognitive appreciation of the respective joint relative to position and motion, and to enhance muscular stabilization of the joint in the absence of structural restraints. We have studied all of the aforementioned populations and are confident that this type of rehabilitation can provide enhanced joint stability in individuals following capsuloligamentous injury.

Functional Assessment of Shoulder Proprioception

Characteristics of Proprioception

The assessment of proprioception is accomplished by measuring the characteristics that make up the proprioceptive mechanism. This includes kinesthetic sensibility (KS), which is the perception of joint motion, and joint position sensibility (JPS), which is the perception of joint position. Peripheral mechanoreceptors are the structures that initiate the proprioceptive mechanism when stimulated. Joint motion places articular structures under tension, and this tensile loading mechanically deforms the mechanoreceptors located within the structure. Mechanoreceptor deformation results in electrical stimulation of the central nervous system (CNS).

Assessment techniques attempt to activate receptor fields specific to joint motion and position. Patterns of stimulation for capsular receptors have been investigated by a few researchers over the past 2 decades (23-26). In capsuloligamentous structures the Ruffini endings and Golgi tendon organ–like endings are the receptors that are stimulated most during motion and changes in joint position (25, 26). In musculotendinous structures, the muscle spindle and GTO are stimulated in response to muscle length and tension. These receptors are slow adapting and are useful in monitoring joint position both statically and dynamically when the muscle is activated. Joint proprioception is assessed in order to establish patterns of proprioceptive sensibility in healthy and pathological joints. Altered patterns of sensibility have been identified in pathological conditions.

Proprioception of the Knee and Ankle

The first proprioception studies in the human model were of the ankle joint. Freeman et al. (16) in their study on unstable ankles revealed significant proprioceptive deficits following capsuloligamentous injury and subsequently developed effective rehabilitation training methods to remediate this condition. Glencross and Thorton (18) concluded that normal functioning of joints during skilled actions is likely to be inadequate as a result of the distortion of proprioceptive signals after injury to the ankle joint and that rehabilitation is as much relearning these movements as it is physical recovery. Konradsen and Raven (40) studied muscle activity, joint motion, and alteration of body center of pressure in unstable ankles to sudden inversion and demonstrated prolonged peroneal reaction time. They suggested that a partial deafferentation of the ankle occurs due to the disruption of the joint receptors within the torn tissue.

Studies of knee joint proprioception by Barrack et al. (6, 60) and Lephart et al. (44) revealed the effects of disruption of the anterior cruciate ligament with resultant deficits in proprioception. Additionally, joint laxity resulting from capsular stretching and consequent injury to mechanoreceptors was also postulated as a cause of reduced position sense in ballet dancers (5). Proprioception has been found to be diminished in osteoarthritic (OA) knees (7, 60), and it is believed to be the cause of the wide-based gait in individuals with this condition. The diminished proprioception in OA knees has been suggested to be the result of capsular laxity, destruction of proprioceptive receptors, and attendant muscular atrophy as a result of the disease process. On the other hand athletic training and bracing appear to improve proprioception in the knee (8, 44, 60).

Assessment of Shoulder Joint Proprioception

Functionally, proprioception is assessed by measuring the components of proprioceptive sensibility. KS is measured by establishing the threshold to detection of passive motion (TTDPM), and JPS is assessed by reproduction of passive positioning (RPP), which is the ability to accurately reproduce a set arc of angular rotation. The methods of assessing KS and JPS in our laboratory are similar in principle to those used in other studies (6, 8, 42, 44, 60, 62). A proprioceptive testing device (PTD) (Figure 1) is used to assess shoulder proprioception. The PTD rotates the shoulder into internal and external rotation through the axis of the joint. A rotational transducer is interfaced with a digital microprocessor counter providing the angular displacement values. The subjects are tested in the supine position, as in the previous studies by Hall and McCloskey (28) and Smith and Brunolli (62). The arm of the tested shoulder is positioned at 90° of elbow flexion and 90° of shoulder abduction. The subject's forearm is placed in a pneumatic compression sleeve to reduce cutaneous input, and the pneumatic sleeve is attached to the drive shaft of the PTD.

TTDPM for internal and external rotation is used to assess kinesthetic sensibility. The PTD rotates the limb passively at a slow, constant angular velocity (0.5°/s) from preset reference angles. The subjects use an on/off switch to disengage the device when motion is detected. The angular displacement is recorded by the digital microprocessor counter in degrees.

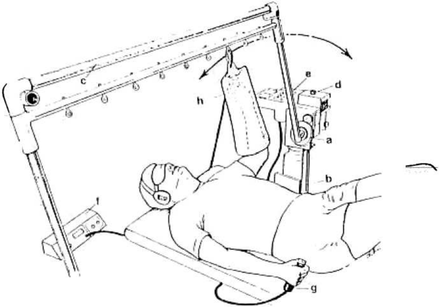


Figure 1 — The University of Pittsburgh's Proprioception Testing Device: (a) rotational transducer, (b) motor, (c) moving arm, (d) stationary arm, (e) control panel, (f) digital microprocessor counter, (g) hand-held disengage (on/off) switch, (h) pneumatic compression sleeve, (i) pneumatic compression unit. The clinician assesses proprioception by measuring the angular displacement until the subject senses motion in the shoulder joint, and also by observing the subject's ability to reposition selected angles. *Note.* From *The Shoulder: A Balance of Mobility and Stability* (p. 611) by F.A. Matsen, F.H. Fu, and R.J. Hawkins, 1993, Rosemont, IL: American Academy of Orthopaedic Surgeons. Reprinted by permission.

Joint position sensibility is assessed by reproduction of passive and active positioning (RPP and RAP). All positioning is done in the passive mode, and reproduction is done both passively and actively in order to evaluate all neural mechanisms involved with proprioception.

RPP for internal and external rotation is measured from reference angles. The subjects are blindfolded in order to eliminate visual cuing. From each reference angle the experimenter will move the shoulder to an angle 10° from the reference angle in either direction. The angle will be presented for 10 s for mental processing. After 10 s the shoulder will be moved by the experimenter back to the reference angle. Next, the subject is instructed to manipulate the on/off switch in order to reproduce the presented angle. The subject will press the switch to engage the motor, and press the switch a second time to disengage the motor when the presented angle is most accurately matched. The angular displacement is recorded by the microprocessor counter as error in degrees from the presented angle.

Reproduction of active positioning will follow the same protocol as RPP, except reproductions will be done actively using muscular contractions of the internal and external rotation muscle groups, thus eliciting input from the musculotendinous receptors.

Shoulder Proprioception Studies

The knee and ankle proprioception studies provide a basis for similar mechanisms in the shoulder, yet to date few studies have been reported that measure proprioception of the shoulder joint. Hall and McCloskey measured proprioception in the normal shoulder (28), and Smith and Brunolli (62) measured proprioception in a small group of subjects with recurrent anterior dislocation. Most recently Lephart et al. (42, 45) studied shoulder joint proprioception in normal, unstable, and postreconstructed individuals.

The paradigm that we have been testing suggests that symptoms of instability in the shoulder are commonly attributed to the loss of static and dynamic mechanical restraint provided by intact capsuloligamentous and muscular structures. With injury to these structures, partial deafferentation occurs with resultant proprioceptive deficits. This, in turn, leads to reinjury and further functional instability.

In a population of college-age individuals without any history of shoulder injury, we found minimal variation in proprioception between subjects and no difference between dominant and nondominant shoulders (41). We then assessed proprioception in subjects with unilateral, traumatic, recurrent, anterior glenohumeral instability (42). When compared to the contralateral uninvolved shoulder, the unstable shoulder demonstrated significant deficits in kinesthetic sensibility in all test conditions, and deficits in joint position sensibility were demonstrated in extreme external rotation. The uninvolved shoulders demonstrated proprioceptive measurements similar to the previously studied normative population. We then studied patients with chronic, unilateral, traumatic, recurrent shoulder instability who underwent capsulolabral reconstructive surgery. We found no significant kinesthetic or position sense deficits between the surgical shoulder and the uninvolved shoulder in these subjects. These studies suggest three things: (a) Arm dominance is not a factor in the proprioceptive mechanism; (b) functional instability produces a diminished sense of proprioception, especially in the functional position of abduction and external rotation, and finally (c) surgery combined with rehabilitation may restore some, if not all, of the proprioceptive sensibility and may ultimately improve function and prevent the recurrence of symptoms. These findings demonstrate that capsulolabral reconstruction for shoulder instability restores both the mechanical and sensory mechanisms of joint restraint, which are both integral for function of the upper extremity.

Areas in need of future research include elucidating the relationship between the afferent pathway deficits we have demonstrated and the efferent effect, and further examining the relationship between proprioception and shoulder function. This can be done through investigation of the effect of rehabilitation and neuromuscular training on proprioception, and assessment of proprioceptive deficits in other pathological conditions.

Shoulder Proprioception Rehabilitation

Two management options available for shoulder instability are capsulolabral reconstructive surgery followed by rehabilitation, or the conservative approach emphasizing rehabilitation. The objective of both management options is to restore functional stability, and rehabilitation provides the basis for this restoration.

Surgical management for shoulder instability restores structural mechanisms, while attempting to minimize restrictions in range of motion and morbidity following surgery. Both reattachment of a Bankart lesion and a capsular shift procedure have shown promise in meeting this criterion of restoring structural mechanisms. The capsular shift procedure obliterates the capsular "pouch" by incising the capsule and advancing it superiorly. Surgical intervention to address a Bankart lesion is designed for reattachment of the glenoid labrum to the anterior glenoid. Dependent on the athlete's pathology, a combination of these procedures may be performed in order to repair and reinforce the glenoid labrum while also adjusting for capsular laxity.

The rehabilitation programs for individuals with shoulder instabilities vary depending upon the specific pathology and procedures performed. Therefore, the activities outlined in this paper will be global in nature and will address functional objectives without regard to management options. The functional progression will be demonstrated with the ultimate goal to reestablish functional stability while preventing the recurrence of the symptom of instability.

Humeral Rotators and Scapular Stabilizers

Overhead-throwing individuals must possess a delicate neuromuscular balance between flexibility and stability in order to permit mobility necessary for their sport. Loss of normal coordinated neuromuscular firing occurs as a result of capsuloligamentous trauma and proprioceptive deficits (19, 43) (Figure 2). The unstable condition places increased physiologic demands on the dynamic stabilizers in order to compensate for the loss of static stability posttrauma, yet with damage to mechanoreceptors the musculature becomes inefficient. The dynamic stabilizers consist of the muscles that act to mobilize and stabilize the glenohumeral joint (12, 21, 35).

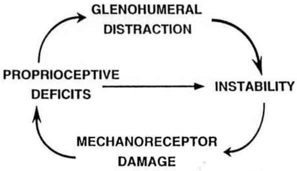


Figure 2 — Shoulder mechanoreceptor feedback mechanism: The paradigm depicts the progression of functional instability of the shoulder joint from insidious microtrauma.

The first group of dynamic stabilizers are the rotator cuff muscles, which fixate the humeral head in the glenoid fossa while providing controlled motion (38). These muscles must exert force over extended periods of time, thus requiring strength, power, and endurance. Endurance training is vital because it affords fatigue resistance and continued dynamic stabilization for the glenohumeral joint. Once the muscles fatigue, a higher risk of subluxation occurs due to the loss of dynamic compensation for stabilization.

The second group of dynamic stabilizers are the scapular stabilizers, which consist of the serratus anterior, rhomboid major/minor, and trapezius. This group must function, along with the rotator cuff, to stabilize and rotate the scapula during activity.

The demands for stability in the unstable individual override the demands for mobility, therefore requiring synchronous muscle firing and muscular endurance during continuous motion. The "stable base" of the scapula permits smooth, controlled motion of the humerus by the rotator cuff while also providing joint stability (38). The larger, more superficial muscles also acting on the shoulder (pectoralis major, biceps brachii, latissimus dorsi, deltoid, triceps) provide synergy to enhance both the strength and power of the overhead-throwing motion.

Strength and Endurance Considerations

The primary rehabilitation objective in the athlete with instability is to provide sufficient muscular strength and endurance for dynamic stability of the glenohumeral joint (11, 33, 55). In order to obtain this objective, the rehabilitation activities must maximally recruit the muscles responsible for humeral and scapular rotation and stabilization. Recent electromyographic studies have provided clinicians with a better understanding of shoulder instability and a basis for the selection of appropriate exercises (12, 19, 35, 66). Townsend et al. (65) identified six strengthening exercises that maximally stimulate the humeral and scapular rotators and stabilizers (Figures 3 and 4). These exercises provide the core of early strengthening for the shoulder. Additionally, specific eccentric exercises

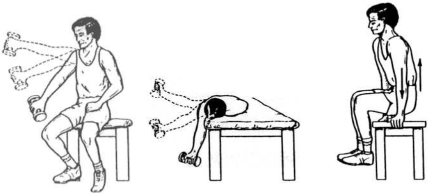


Figure 3 — Glenohumeral rotators/stabilizers: (a) scaption with internal rotation, (b) horizontal abduction with external rotation, (c) press-ups. *Note.* Adapted from "Electromyographic Analysis of the Glenohumeral Muscles During a Baseball Rehabilitation Program" by H. Townsend, F.W. Jobe, M. Pink, and J. Perry, 1991, *American Journal of Sports Medicine*, 19, pp. 265-269. Adapted by permission.

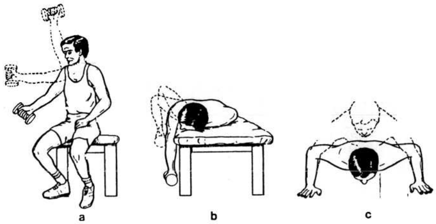


Figure 4 — Scapular rotators/stabilizers: (a) scaption with external rotation, (b) rowing, (c) push-ups. *Note.* Adapted from "Electromyographic Analysis of the Glenohumeral Muscles During a Baseball Rehabilitation Program" by H. Townsend, F.W. Jobe, M. Pink, and J. Perry, 1991, *American Journal of Sports Medicine*, 19, pp. 265-269. Adapted by permission.

should be performed to strengthen the musculature of the shoulder. Eccentric loading of the rotator cuff places high stress on the musculature and may reduce injury by permitting higher levels of dynamic stability. Fatigue-resistance exercise should also be used to maintain the long-term dynamic stabilizing capabilities of the cuff.

The exercises previously mentioned address the humeral and scapular rotators/stabilizers. These exercises provide a muscle strength and endurance base necessary for the more functional exercises initiated in the later stages of the rehabilitation program.

Proprioception and Neuromuscular Training

The perception of shoulder joint motion and position is essential for placement of the hand in upper extremity function. In addition, proprioception plays an important role in dynamic joint stability and the modulation of muscle function. The role of the shoulder musculature extends beyond absolute strength and the capacity to resist fatigue. The complexity of shoulder motion, especially during overhead-throwing activities, necessitates synergy and synchrony of muscular firing patterns, permitting proper joint stabilization and activation of requisite muscles (35, 43).

The incorporation of a proprioceptive exercise training element within the rehabilitation program for functional instability is critical for restoring the synergy and synchrony of muscular firing patterns necessary for functional activity. Rehabilitation programs for shoulder instability and post–capsulolabral reconstruction have begun to incorporate neuromuscular training exercises that are thought to facilitate the restoration of proprioception. Proprioceptive sensibility following capsulolabral reconstruction and rehabilitation has been found to revert to normal levels, as demonstrated by Lephart et al. (45). Ligamentous re-tensioning coupled with rehabilitation is suggested to restore proprioceptive sensibility to near-normal levels in this population (45). Restoration is facilitated through enhancing mechanoreceptor sensitivity, increasing the number of mechanoreceptors stimulated, or enhancing compensatory sensations from secondary receptor fields.

There are two primary considerations relative to rehabilitation of the proprioceptive mechanism. Reflex muscular stabilization and conscious appreciation of joint motion and position are both mediated by the proprioceptive mechanism and need to be addressed during the reestablishment of the afferent and efferent pathways.

Developing a rehabilitation program that incorporates proprioceptively mediated muscular control of joints necessitates an appreciation for the CNS's influence on motor activities. Joint afferents contribute to CNS function at three distinct levels:

1. At the spinal level, reflexes subserve movement patterns that are received from higher levels of the nervous system. This provides reflex splinting during conditions of abnormal stress about the joint and has significant implications for rehabilitation. The muscle spindles play a major role in the control of muscular movement by adjusting activity in the lower motor neurons. Partial deafferentation of joint afferent receptors has also been suggested to alter the musculature's ability to provide co-contraction joint stabilization by antagonistic and synergistic muscles, thus resulting in the potential for reinjury (19, 42).

2. The second level of motor control is at the brain stem, where joint afference is relayed to maintain posture and balance of the body. The input to the brain stem about this information emanates from the joint proprioceptors, from the vestibular centers in the ears, and from the eyes. This level of proprioceptive input is not as significant in the upper extremity as it is in the lower extremity

3. The final aspect of motor control includes the highest level of CNS function (motor cortex, basal ganglia, and cerebellum) and is mediated by cognitive awareness of body position and movement. These higher centers initiate and program motor commands for voluntary movements. Movements that are repeated can be stored as central commands and can be performed without continuous reference to consciousness.

Development of a Proprioception and Neuromuscular Rehabilitation Program

With these three levels of motor control in mind, mediated in part by joint and muscle afferents, one can begin to develop rehabilitation activities to address proprioceptive deficiencies of the shoulder. The objectives must be to stimulate the joint and muscle receptors in order to encourage maximum afferent discharge to the respective CNS level.

There is considerable controversy regarding upper extremity proprioception rehabilitation relative to open versus closed kinematic chain exercises. We feel that both modes of training are of value to maximally stimulate glenohumeral mechanoreceptors, and thus we prefer to concentrate on functional positioning during exercise rather than isolating open or closed activities. Ideally an overhead-throwing individual should induce neural adaptations in the position of vulnerability (i.e., shoulder abduction/external rotation) since the role of proprioception training is to encourage dynamic stabilization during overhead-throwing motion. Specific care needs to be taken in the unstable shoulder to avoid subluxation. Conversely, a gymnast or football player should rehabilitate in the anatomical position that resulted in the pathoetiology of the instability.

At the spinal level, activities that encourage reflex joint stabilization should be addressed. Such activities include sudden alterations in joint positioning that necessitate reflex muscular stabilization (43). Examples include rhythmic stabilization exercises that encourage co-contraction and neuromuscular coordination of the rotator cuff and scapular musculature (33). These exercises can be performed in an open kinematic chain using manual assistance, or in a closed kinematic chain position using an unstable base (Figure 5). This exercise stimulates both articular and muscular mechanoreceptors for reflex stabilization. The reflex stabilization exercises provide a mechanism for developing dynamic joint stability. The activities can be performed in the functional position of each joint. An axial force should be applied to the joint for maximal stimulation of the mechanoreceptors. The unstable platform should produce a series of patterns resulting in sudden changes in joint position during the exercise. As joint position changes, dynamic stabilization must occur for the athlete to control the balance of the platform. The platform can be designed using an air bladder or series of bearings that permit multiaxial directional movement (Figure 6).

Proprioception training also needs to consider cognitive appreciation of joint position. Such activities are initiated at the cognitive level and include programming motor commands for voluntary movements. Movements that are repeated will maximally stimulate the conversion of conscious to unconscious motor programming, which is then stored as central commands and can be performed without continuous reference to consciousness. We suggest both passive and active joint repositioning to accomplish this appreciation of joint position

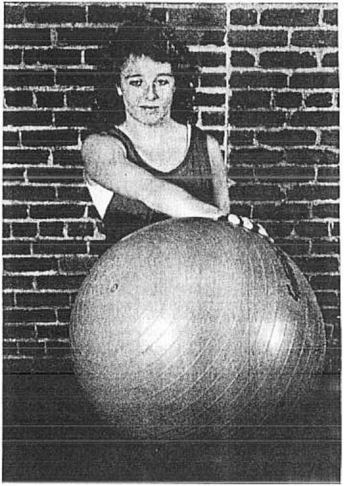


Figure 5 — Rhythmic stabilization using an unstable base encourages co-contracti of the rotator cuff for dynamic stabilization of the joint. *Note.* From "Nonoperati Treatment of Rotator Cuff Injuries in Throwing Athletes" by J.J. Irrgang, S. Whitney, and C.D. Harner, 1992, *Journal of Sport Rehabilitation*, 1, p. 214.

(43). The exercises should be performed in the functional position and especial near end-ranges of motion in each joint. Resistance can also be applied in t active mode to provide additional mechanoreceptor stimulation. These exercis can be performed if the clinician simply instructs the patient to reposition give ranges of angular motion without visual input. When the exercises are performe passively, clinician assistance or devices similar in design to the PTD or isokinet testing/training device can be used (Figure 7). Passive repositioning will max mally stimulate articular mechanoreceptors, while active repositioning relies input from both articular and muscle receptors. This training is designed

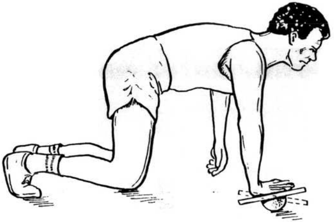


Figure 6 — Proprioception training using an unstable platform in the closed kinetic chain enables axial loading of the joint with maximal stimulation of articular mechanoreceptors.

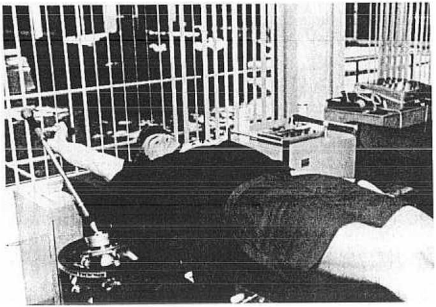


Figure 7 — Active and passive repositioning exercises are used for the conscious appreciation of joint position.

Figure 8 — Resistive tubing exercises are also incorporated to strengthen the shoulde in a functional position using PNF patterns. (a) Diagonal Pattern 1: flexion, abduction external rotation.

enhance neuromuscular controlling mechanisms relative to glenohumeral repositioning during shoulder rotation.

Proprioceptive neuromuscular facilitation (PNF) techniques are designe to enhance response of the neuromuscular mechanisms by stimulating stretc receptors located in the muscle/tendon units (34). The techniques use a combination of spiral and diagonal patterns of movement that demand both neuromuscula coordination and strength. The techniques induce a reflex neural inhibition whe a muscle is stretched, thus overriding the normal reflex contraction that is initiate when the muscle is stretched (34, 51). This reflex relaxation permits a muscl

Figure 8 **(b) Diagonal Pattern 2: extension, adduction, internal rotation.**

to stretch through relaxation before the extensibility limits are exceeded and damage to the muscle fiber ensues (37, 51). The stretch-shortening cycle or myotatic reflex is also used with this method, similar to plyometric training. For specific shoulder PNF techniques we suggest reviewing the descriptions by Kabat (37) (Figure 8, a and b).

Plyometrics is another method that retrains the proprioceptive/neuromuscular mechanisms. Plyometrics utilizes a quick, powerful movement that involves a prestretch or eccentric load of the muscle, followed by a shortening, concentric muscular contraction. This applies the stretch-shortening muscular cycle or myotatic reflex (36).

The concept of specificity of training suggests that plyometric exercises

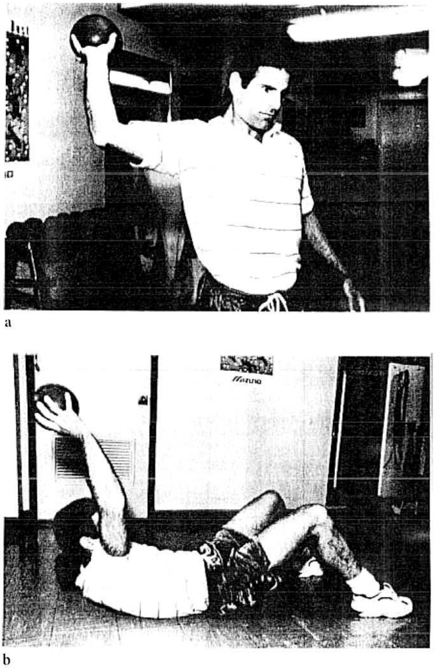
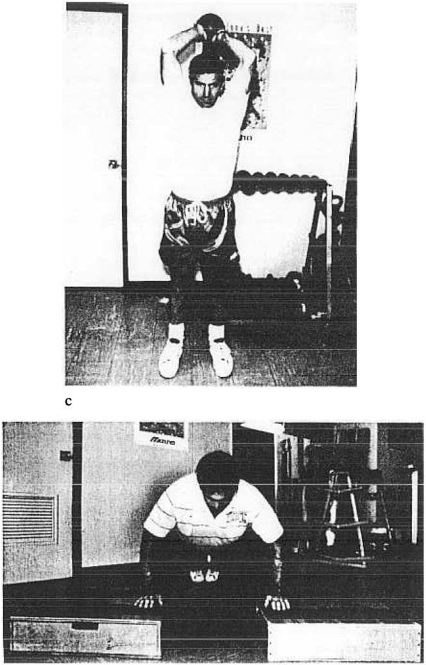


Figure 9 **Plyometric exercise: (a) throwing motions, (b) trunk motions.**



c

d

Figure 9 Plyometric exercise: (c) ball/wall drills, (d) push-up boxes.

should be implemented into the advanced stages of the overhead athlete's rehabilitation program. These exercises have been divided into three segments including throwing motions, trunk motions, and ball/wall drills (Figure 9, a–d). It should be emphasized that proper warm-up should precede plyometric training.

Summary

In addition to performing their mechanical restraining function, articular ligaments provide important neurological feedback that directly mediates muscular reflex stabilization about the joint. Following injury to the articular structures, disruption of mechanoreceptors results in partial deafferentation of the joint. This diminished proprioception has been shown to result in altered joint kinematics, and it contributes to repetitive injuries and the progressive decline of the joint. Assessment of proprioceptive sensibility is valuable for identification of proprioceptive deficits and subsequent planning of the rehabilitation program. The link between proprioceptive deficits and shoulder joint function has been well established in populations of athletes, individuals presenting acute traumatic joint pathology, and people who have degenerative joint disease. Rehabilitation must therefore focus on restoring the proprioceptive mechanism by enhancing cognitive appreciation of the respective joint relative to position and movement, and providing muscular stabilization of the joint in the absence of structural restraints.

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