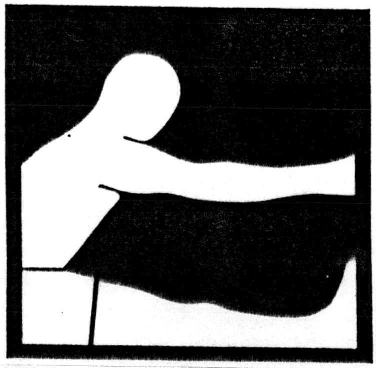
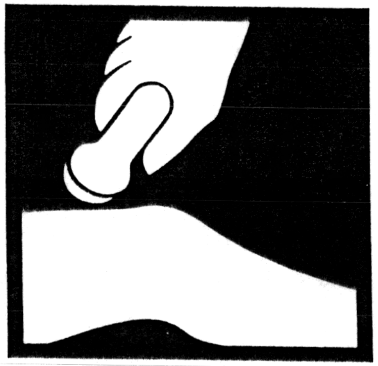
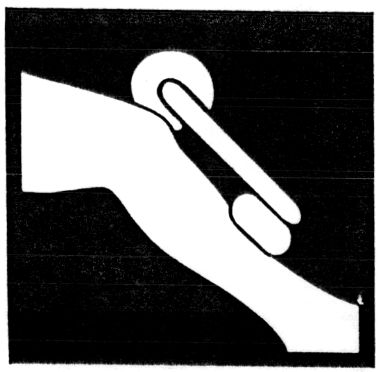
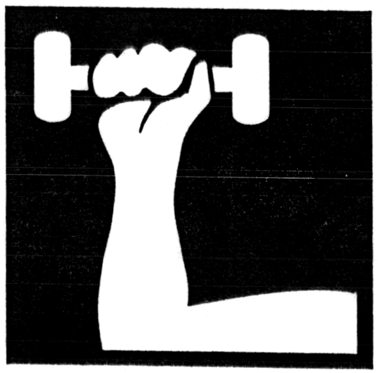
Journal of
SPORT
REHABILITATION





Closed Kinetic Chain
Rehabilitation





VOLUME 5 • NUMBER 1 • FEBRUARY 1996

Journal of Sport Rehabilitation, 1996, 5, 71-87

The Physiological Basis for Open and Closed Kinetic Chain Rehabilitation for the Upper Extremity

Scott M. Lephart and Timothy J. Henry

The confusion between the terms *open kinetic chain* and *closed kinetic chain* becomes even greater with application to the upper extremity. Upper extremity function is very difficult to define, due to the numerous shoulder positions and the great velocities with which the shoulder can move. Classifying exercises for rehabilitation of the upper extremity is very difficult due to the complexity of the joint. Many definitions and classification systems have been proposed; however, none of these entirely encompass rehabilitation of the upper extremity. Using previous classifications we have developed a Functional Classification System that is designed to serve as a template for upper extremity rehabilitation. This system has been designed to restore functional shoulder stability, which is dependent upon proper scapulothoracic and glenohumeral stability, and humeral control; all of these are in part mediated by neuromuscular mechanisms. The objective of our new Functional Classification System is to restore functional stability of the shoulder by reestablishing neuromuscular control for overhead activities.

The terms *open kinetic chain* and *closed kinetic chain* have recently provided a great deal of confusion for the sport rehabilitation clinician. Each term is defined in several different manners and can be interpreted in a variety of ways. This is particularly true when the terms apply to the upper extremity. These terms were first suggested by Steindler (41), who defined a kinetic chain as a "combination of several successively arranged joints constituting a complex motor unit." In the upper extremity, the scapulothoracic articulation and the acromioclavicular, sternoclavicular, and glenohumeral joints can be defined as a kinetic chain.

For the purpose of rehabilitation, open and closed chain exercises have been defined in an attempt to qualify joint forces and kinematics based on a condition of the distal extremity. Many have suggested that closed chain activities promote coactivation of stabilizing muscles, minimize shear forces, and stimulate

Scott M. Lephart is with the Neuromuscular Research Laboratory, Sports Medicine Program, University of Pittsburgh, Pittsburgh, PA 15261. Timothy J. Henry is a doctoral student in exercise physiology/athletic training, University of Pittsburgh.

proprioceptors of the involved joints (9, 16, 21, 23, 36). But relative to the upper extremity, these types of activities are seldom functionally specific. Therefore, the dilemma concerning open versus closed kinetic chain exercises for the upper extremity involves defining the condition of the exercises and determining their functional benefit.

Much of the confusion surrounding this issue can be attributed to the traditional definitions of these terms. There are numerous definitions for open chain and closed chain activity, yet none of these are quantitatively based. In addition, mechanics are not used to categorize the activities. Finally, and probably most importantly, there is questionable application of these traditional definitions to upper extremity activity.

Stability Versus Mobility

When considering upper extremity function it is imperative to consider the delicate balance between mobility and stability (6, 10, 12, 45). It has been documented that there are in excess of 16,000 shoulder positions and that the shoulder can move at a velocity up to 7,000°/s (13, 28, 29, 36). This type of movement and velocity requires an intricate integration between the static and dynamic structures of the shoulder in order to maintain functional stability (9, 19, 20, 35, 37, 40, 42). Such an integration requires a balance of muscular strength and endurance, flexibility, and neuromuscular control. Functional stability of the shoulder joint is the result of proper scapulothoracic stabilization, glenohumeral stabilization, and humeral control, all mediated by neuromuscular mechanisms. If any one of these factors is compromised, functional instability results and injury occurs (6, 9, 19, 20, 29, 35, 37, 40, 42).

The roles of the static and dynamic mechanisms have been very well documented (6, 7, 11, 13, 20, 35, 44–46). The static mechanism is provided by the joint capsule, labrum, and ligaments, structures that serve both a mechanical role and a sensory role. The dynamic mechanism is provided by the musculature; muscles acting on the shoulder provide both a stabilizing role and a functional role. Disruption of either mechanism can result in episodes of functional instability in the athlete. Thus, integration of these restraining and functional characteristics is imperative in order to maintain functional stability of the shoulder joint.

The static structures play a major role in joint kinematics by providing mechanical restraint to abnormal joint motion (6, 43). This mechanical role has been the primary concern with regard to injury to these structures (6). Baxendale et al. (4) and Kennedy et al. (24) have observed that in addition to this mechanical role, these articular structures provide important neurological feedback that directly mediates muscular reflex stabilization about the joint (4, 6, 24). It has been shown that following injury to the articular ligaments, neuromuscular joint stabilization is inhibited. This is due to disruption of articular mechanoreceptors, resulting in partial deafferentation of the joint. The combination of a compromised mechanical function and inhibited neuromuscular stabilization capabilities results in functional instability, repetitive injury, and progressive decline of the joint (6, 25–27).

The normal role of the dynamic mechanism (muscle) during the overhead throwing motion is also twofold: stabilization and humeral control. Stabilization occurs through the integration of force couples that act upon the shoulder. A force couple involves two or more muscles contracting simultaneously around a particular joint in order to promote stability within that joint (21, 46). The dynamic force couples increase joint compression, which in turn provides for maximum congruency of the articulating surfaces. In the shoulder joint, this occurs as the head of the humerus is compressed into the glenoid fossa of the scapula. This mechanism is vital in maintaining functional stability of the shoulder joint due to the lack of bony support and complex kinematics that are inherent to this articulation. The serratus anterior and upper trapezius serve in unison to stabilize the scapula and provide a stable base for the glenohumeral articulation. The first force couple acting on the glenohumeral joint includes the deltoid, countered by the infraspinatous and teres minor (10, 25, 32, 34). The second force couple is the subscapularis, also countered by the infraspinatous and teres minor (10, 25, 32, 34, 46).

The second role of the dynamic mechanisms is humeral control. The dynamic mechanisms responsible for humeral control during overhead throwing can be classified as prime movers (accelerators) or decelerators. The prime movers, or accelerators, of the shoulder joint are the teres major, latissimus dorsi, pectoralis major, triceps brachii, and subscapularis. These muscles act concentrically to accelerate the humerus through a range of motion. The decelerators are the deltoid, infraspinatous, and teres minor. These muscles generally act eccentrically in order to decelerate the humerus (1, 13, 46).

Any condition that alters the synchronized balance between the dynamic and static mechanisms can result in shoulder dysfunction. Injury to the static structures results in mechanical instability. With prolonged mechanical instability, both the static and dynamic structures are predisposed to further injury. The excessive joint laxity associated with mechanical instability and the resulting microtrauma damage the neural receptors within the static and dynamic structures. These receptors are ultimately responsible for neuromuscular control of the joint (8, 16, 25–27). This combination of mechanical instability and decreased neuromuscular control of the joint leads to functional instability and repetitive injury (6, 24, 31–34). Restoration of the neuromuscular mechanisms responsible for functional stability is necessary in order to properly return an athlete with shoulder instability to his or her desired activity.

Classification of Open Versus Closed Chain Activity

Traditionally, rehabilitation programs have been designed using the concepts of open and closed kinetic chain exercises. Definitions of these terms have usually been based on the status of the distal segment, body weight, and external resistance (13, 17, 18). According to these criteria, an open kinetic chain would result if the distal segment is not fixed, body weight is not supported, or the external resistance is negligible (13, 17, 41). A closed kinetic chain occurs when the distal segment is fixed, body weight is supported by the extremity, or the external resistance is considerable. Steindler observed that open chain exercises exhibited speed that involved more free movement and less stabilization, while closed chain exercises required more stabilization and less acceleration (6, 41). According to this classification system, examples of open chain exercise would be throwing a baseball, hitting a tennis ball, or throwing a shot put. Closed chain exercises would include chin-ups, push-ups, or rowing. Steindler (41), among others, admits that classifying functional activities as either open or closed chain is sometimes difficult using these criteria, because some activities are a combination of the two.

Other researchers have defined open and closed chain activities in different manners. Gray (17) defined an open chain as a system in which the distal segment is free. He also stated that a closed chain is the result of either set of limbs supporting the body weight. Panariello (30) defined closed chain activity of the lower extremity as an activity in which the foot is in contact with the ground. Likewise, Panariello (30) described an open chain activity as one in which the foot is not in contact with the ground. Both researchers agreed that body weight must be supported for a closed kinetic chain to exist (13). These definitions can easily be applied to upper extremity activity.

Both closed and open chain activities are utilized in the rehabilitation setting, with each type of activity demonstrating different characteristics and advantages. The characteristics commonly associated with closed chain activity are large resistance and low acceleration, greater compressive forces, joint congruency, decreased shear, stimulation of proprioceptors, and enhanced dynamic stabilization (13, 17, 41). Each of these characteristics would appear to be the direct result of the body weight being supported and the resulting joint compression. On the other hand, the characteristics of open chain activity include large acceleration and low resistance forces, distraction and rotary forces, promotion of a stable base, joint mechanoreceptor deformation, concentric acceleration and eccentric deceleration, and assimilation of function (13, 17, 41). Each of these characteristics can be associated with the extremity in a non-weight-supported position. In traditional rehabilitation settings, both types of exercise are used in order to employ the desired characteristics.

As we mentioned previously, categorizing open and closed chain exercises is very difficult. It becomes very confusing trying to classify the status of the distal segment, resistance, supported body weight, and loading for a single exercise. Dillman et al. (13) attempted to clarify this with an alternative classification system, which is based on the mechanics of the particular exercise. The system considers two points: the boundary condition and the external load encountered at the distal segment. The boundary condition of the distal segment may be either fixed or movable, while the external load may or may not be present at the distal segment. According to the classification system, the conditions include a fixed boundary with an external load, a movable boundary with an external load, and a movable boundary with no external load. Utilizing this classification system, Dillman examined the muscle activity during each condition and found that muscle activation was similar regardless of the boundary once the external load became considerable.

Considering all of the previous confusion and the different classification systems, it is difficult to determine what is really relevant to upper extremity rehabilitation. With regard to the shoulder complex, we feel that the following three areas need to be addressed in order to restore functional stability: scapulothoracic stabilization, glenohumeral stabilization, and humeral control. Stabilization of the scapula by dynamic mechanisms is necessary to provide a stable base of support for the glenohumeral joint. Glenohumeral stabilization is required for

maintaining the position of the humerus in the glenoid fossa of the scapula throughout movement and activity. Humeral control is necessary for shoulder function, as the accelerators and decelerators are required for performance of overhead activities. These three elements of functional shoulder stability must be integrated in order to perform complex functional activities.

Considering the requirements for shoulder functional stability and the concepts of open and closed chain exercise, we have defined a number of functional characteristics of activity. These characteristics are designed to provide a comprehensive basis for defining rehabilitation protocols, which we have called the Functional Classification System. The first characteristic is the direction of the force, which can be either axial or nonaxial. The second is the magnitude of the load; a load can be either a high load with a low velocity or a low load with a high velocity. The third characteristic is muscle action, which can be either cocontraction or acceleration and deceleration. The fourth characteristic is joint motion, which can be classified according to the direction of the load; either linear or rotary. Last, neuromuscular function may be the result of either voluntary activation or reactive muscle function. We believe that clinicians need to consider these characteristics when developing a rehabilitation protocol for the upper extremity, as they provide a more comprehensive assessment of functional shoulder demands than traditional definitions of open and closed kinetic chain.

As we mentioned previously, the classifications by Dillman et al. (13) considered only the boundary and the external load, with the external load classified only as an external load or as no load at all. It is very common when examining upper extremity function to encounter a load that is nonaxial, or rotary in nature. These types of loads differ from axial loads and are usually functionally specific. Therefore, our classification system is designed to be more functionally specific than previous systems.

The majority of the activities described by the Functional Classification System should be incorporated into the functional stages of the rehabilitation process. Traditional elements of rehabilitation such as range of motion, flexibility, and strength should be addressed before the functional stages of rehabilitation begin.

Our Functional Classification System considers boundary and load plus the direction in which the load is applied. The direction of the load can be either axial or rotary, or there can be no load at all. The modified conditions include fixed boundary, external axial load; movable boundary, external axial load; movable boundary, external rotary load; movable boundary, no load; and functionally specific exercises. We believe that this modified classification system considers the magnitude of load, the velocity of the motion, the neuromuscular reaction, and the muscle action associated with each condition. The majority of the conditions in our Functional Classification System are designed to be incorporated during the functional stages of rehabilitation.

The first condition in the Functional Classification System is a fixed boundary with an external axial load. In this case the load is classified as considerable with a slow velocity. The neuromuscular reaction can be either active or reactive, and the muscle action can be cocontraction, acceleration, or deceleration. The advantages associated with this type of exercise are cocontraction of the scapular and humeral force couples, promotion of dynamic stabilization, joint compression, facilitation of proprioceptors, minimal shear forces, and some functional specificity (6, 13, 17, 41). These characteristics mainly result from the external load being applied in an axial manner. This type of exercise is similar to a weight-supported maneuver in the previous classification system. Examples are axial loading of the shoulder in the tripod position on an unstable base and upper extremity activities on the slide board.

The second condition is a movable boundary with an external axial load. This is similar to the first condition, except that the boundary is free to move. Once again the load is considerable, but the velocity is variable. The muscles may function as accelerators, decelerators, or coactivators. One of the main benefits associated with this type of movement is coactivation of scapular and humeral force couples. This condition also promotes dynamic stabilization, joint compression, and activation of the prime movers. Last, minimal shear forces are reported during this type of activity (13, 17, 41). Examples of such exercises include protraction/retraction exercise using the closed chain attachment for the Biodex System 2 Isokinetic Dynamometer or a traditional bench press exercise.

The next condition is a movable boundary with an external rotary load. In this type of activity the load is variable and the velocity approaches functional speeds. The muscles involved may be the accelerators, the decelerators, or both as coactivators. These muscles may function either actively or reactively. The advantages associated with this type of exercise include promoting stability of the scapulothoracic and glenohumeral base, activation of the prime movers, functional joint kinematics, and functional motor patterns. Two commonly used examples of this type of exercise are isokinetic exercise in a functional diagonal pattern and exercise on a shoulder multiaxial machine.

The last condition in our Functional Classification System is a movable boundary with no external load. This type of activity involves a variable velocity, a negligible load, and either active or passive motion. The objective of this condition is to promote functional movement patterns or joint position sensibility. Functional movement patterns are utilized in order to reacquaint the athlete with movement patterns that he or she will encounter during sport activity. Joint position sensibility activities are utilized to enhance the athlete's ability to position the limb during activity. The musculature may act as accelerators, as decelerators, or passively. The benefits of this type of activity are sequential activation of muscles proximal to distal, low muscle activation without resistance, and functional specificity. This activity also promotes free movement of the distal segment. Functional motor patterns and muscle activation patterns can be employed that are very similar to those encountered during actual functional activity. The most common type of these exercises is joint position sensibility training. Joint position sensibility training includes both repositioning exercises and cognitive orientation to joint position and can be performed both actively and passively.

The four conditions in our Functional Classification System appear to include most of the activities commonly prescribed for rehabilitation of the upper extremity; the system is presented in Table 1. Each condition and the activities included within it mediate a specific aspect of the neuromuscular system in order to adequately restore functional stability to the injured shoulder. A rehabilitation protocol for the upper extremity may be designed more effectively using a classification system such as the one described here.

Table 1 Summary of Functional Classification System, Including Name of Classification, Characteristics of Each Classification, and Examples of Exercises

Classification	Characteristics	Examples
Fixed boundary: external, axial load	Considerable load, slow velocity NM reaction: active or reactive MM action: coactivation, acceleration, deceleration Coactivation of force couples Joint compression Minimal shear forces Promotion of dynamic stability	Axial loading in tripod position Slide board Unstable platform
Movable boundary: external, axial load	Considerable load, variable velocity MM action: coactivation, acceleration, deceleration Coactivation of force couples Promotion of dynamic stability Activation of prime movers Minimal shear forces	Closed chain protraction/retraction on an isokinetic dynamometer Traditional bench press Rhythmic stabilization activities
Movable boundary: external, rotary load	Variable load, functional speeds NM reaction: active or reactive MM action: coactivation, acceleration, deceleration Stability of scapular and glenohumeral base Activation of prime movers Functional joint kinematics Functional motor patterns	Isokinetics in functional diagonal patterns Multiaxial machine Resistive tubing exercise Proprioceptive neuromuscular facilitation exercise
Movable boundary: no load	Negligible load, variable velocity NM reaction: active or passive MM action: acceleration, deceleration, or perceptual Activation of muscles proximal to distal Low muscle activation without resistance Functional significance	Joint sensibility training: active and passive

NM = neuromuscular; MM = muscular

Reestablishing Neuromuscular Control

As we mentioned previously, the ultimate goal of a rehabilitation program for the shoulder is to restore functional stability. We have described the necessary characteristics for functional stability, which include scapulothoracic stability, glenohumeral stabilization, and humeral control. The restraining and activating roles of the shoulder complex musculature are mediated by neural mechanisms and therefore result in functional stability when the neuromuscular mechanisms function properly.

Neuromuscular control is initiated by the proprioceptors, which play a very important role in maintaining functional stability of the shoulder joint. Proprioception both mediates function of the shoulder and protects the joint. For example, proprioception aides in placement of the hand during activities of daily living as well as positioning of the shoulder in athletic activities that involve overhead motion. Proprioception also serves as a protector through dynamic stabilization of the humeral head resulting in glenohumeral stabilization (6, 26, 39).

The role of proprioception in athletic performance has been very well documented (6, 25–27). Proprioception may be especially important for the shoulder joint, a joint complex with very little inherent stability. Due to the positioning of the shoulder joint during sports and the velocities that are imparted on it, neuromuscular control and proprioception are vital to functional performance of the shoulder joint (6, 23, 26).

The role of proprioception in maintaining functional stability of the shoulder is illustrated in Figure 1 (6, 25, 27). This paradigm suggests a cyclical pattern beginning with injury to the static structures, the ligaments or joint capsule. With injury to the capsuloligamentous structures, the resultant instability is twofold. First, there is a mechanical instability that is commonly associated with injury to these structures. This type of mechanical instability has been very well documented throughout the literature (9, 19–21, 29, 35, 43–45). However, research has shown that mechanical instability alone does not result in episodes of functional instability

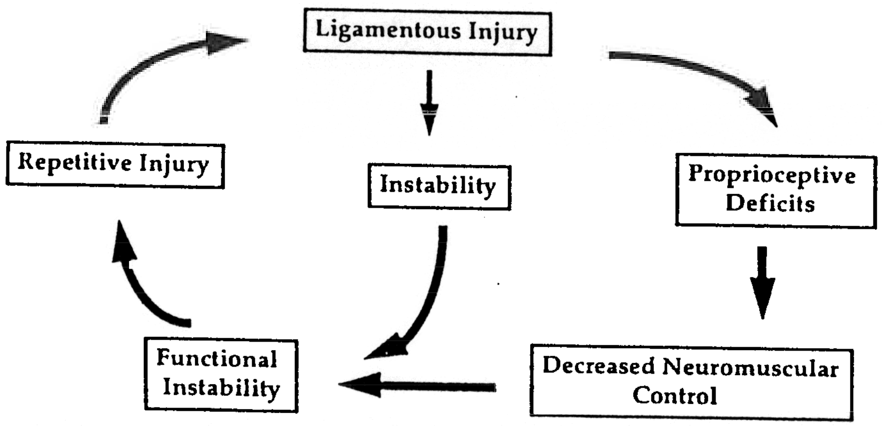


Figure 1 — Functional stability paradigm: The paradigm depicts the progression of functional instability of the shoulder joint due to the interaction between mechanical instability and decreased neuromuscular control.

in all cases. Thus, functional instability is the result of a coupling between mechanical instability and partial deafferentation of the mechanoreceptors responsible for mediating proprioception, a coupling that occurs with capsuloligamentous trauma. The presence of mechanoreceptors in the capsuloligamentous structures has been confirmed in the literature, and these receptors are damaged with injury to the capsuloligamentous tissue. The result of the deafferentation is a reduced afferent neural signal, described as a proprioceptive deficit. The decreased proprioceptive signal inhibits normal motor response and diminishes neuromuscular stabilization of the joint. The combination of decreased neuromuscular control and mechanical instability results in functional instability of the shoulder joint and contributes to an insidious pattern of repetitive injury.

Our laboratory and others have confirmed proprioceptive deficits following injury (2, 3, 6, 14, 15, 26, 38). Proprioception is measured by assessing the cortical pathway, the reflex pathway, and the combined peripheral, vestibular, and visual pathways. The cortical pathway is responsible for joint position sensibility and perception of joint motion. This pathway is assessed by measuring threshold to detection of passive joint motion and reproduction of passive positioning. The reflex pathway provides dynamic muscular stabilization and synchronized muscle activation. The reflex pathway is assessed by electromyographical analysis of muscle firing patterns. The combination of peripheral, vestibular, and visual pathways provides joint afference responsible for maintaining posture and balance. These combined pathways are assessed through balance and sway measurements (6).

Once we have identified mechanical instability and proprioceptive deficits, we need to correct them in order to prevent episodes of functional instability and repetitive injury. Mechanical instability may be corrected through surgery, but proprioceptive deficits must be addressed through rehabilitation (6). This is necessary in order to break the insidious cycle of events leading to functional instability and repetitive injury.

Principles of Neuromuscular Rehabilitation

Our Functional Classification System was designed to serve as a guide for restoring proprioceptive deficits and reestablishing neuromuscular control. Our classification was designed specifically to integrate all subsystems of movement and all levels of motor control. The subsystems that should be included are the peripheral somatosensory, the visual, and the vestibular (6, 22, 25, 27, 39). The three levels of motor control to be included are the spinal reflex, cognitive programming, and the brain stem (6, 22, 25, 39). These levels are summarized in Figure 2. The Functional Classification System will enable the sport clinician to incorporate each subsystem and level of motor control into a simple, easy-to-follow rehabilitation program. The concept of functional specificity is included in our Functional Classification System to allow the injured athlete to return to the desired sport activity (6, 22, 25).

An example of an activity within the fixed boundary, external axial load category would be an exercise in a tripod position on an unstable platform (Figure 3). Another common exercise that would fit this category is upper extremity activity on the Biodex stability system, also in the tripod position. Each of these

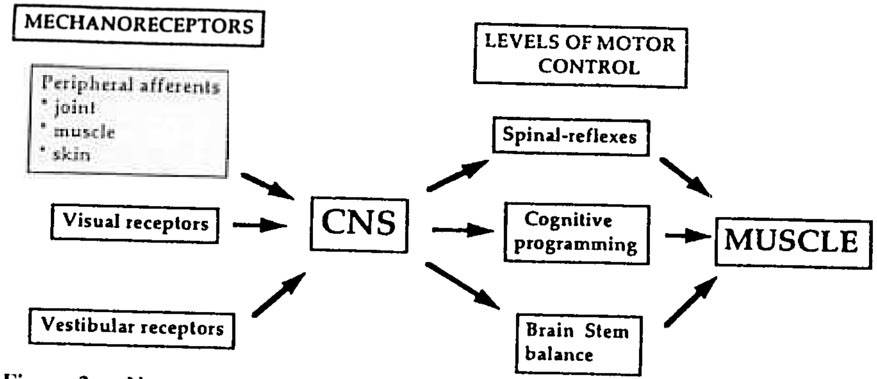


Figure 2 — Neuromuscular control pathways.

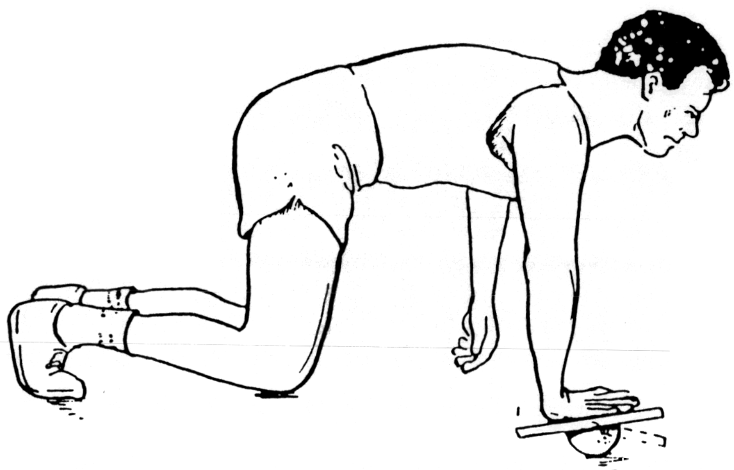


Figure 3 — Fixed boundary, external axial load: exercise on an unstable platform enabling axial loading of the joint.

activities provides axial loading of the shoulder complex with the hand fixed. Such activities are often referred to as dynamic or rhythmic stabilization exercises (10, 46); they work mainly at the spinal reflex level and combine all subsystems of movement.

The second category, movable boundary with an external axial load, is best represented by a traditional bench press activity or exercise on the Biodex isokinetic dynamometer with the closed chain attachment (Figure 4). Another common example would be exercise in a push-up or modified push-up position on a slide board (Figure 5). These activities provide for axial loading but also activate prime movers in order to move the boundary. These activities are similar to those in the first category and work in much the same manner, but they also incorporate the movement. These exercises may also be classified as dynamic or rhythmic stabilization exercises, and they also work at the spinal reflex level

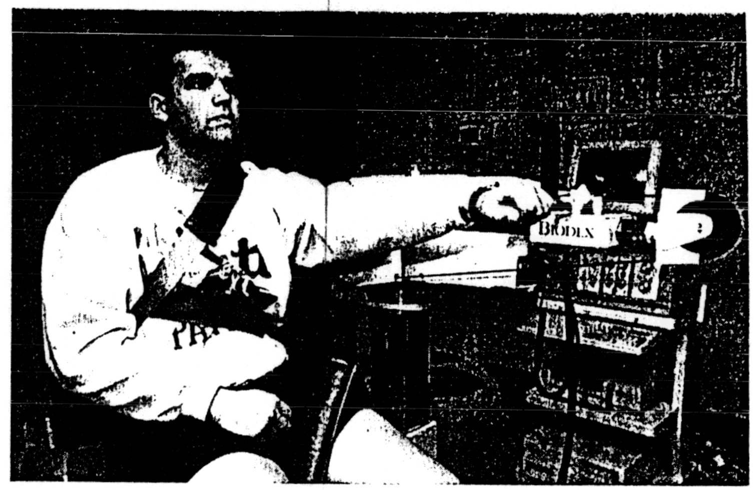


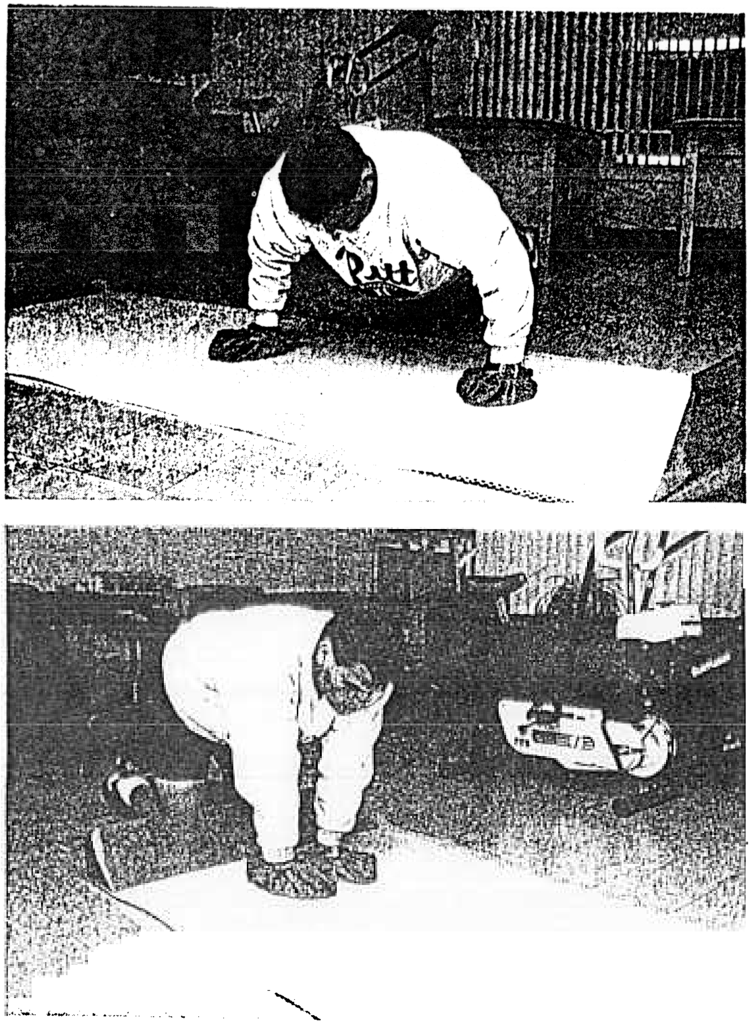
Figure 4 — Movable boundary, external axial load: isokinetic exercise on the Biodex System 2 Dynamometer with the closed chain attachment.

as well as the cognitive level (10, 46). These types of exercises combine all subsystems of movement.

The third category, movable boundary with an external rotary load, incorporates some functional movement and motor patterns. The load during the movement is variable and the velocity approaches normal functional speeds. Exercises in this category include proprioceptive neuromuscular facilitation (PNF) patterns, Theraband exercise, isokinetic exercise in a functional diagonal pattern, or exercise on a shoulder multiaxial machine (Figure 6). Plyometric exercise for the upper extremity may also be included in this category (Figure 7). Each of these exercises works in functional patterns that are specific to the upper extremity, particularly for overhead movements. Finally, sport-specific activities such as throwing and swinging that an athlete encounters every day can be included in this category. Each of these activities can be performed with varying loads and at varying speeds. Activities in this category emphasize both the spinal and cognitive levels of motor control. This category is designed to provide activities that include overhead motion and to ultimately return the athlete to the desired sport activity. Activities within this category concentrate mainly on the combination of peripheral somatosensory and visual subsystems of movement.

The last category in our Functional Classification System is movable boundary with no load. These activities include joint position sensibility exercises and can be included very early in the rehabilitation program. Position sensibility involves glenohumeral repositioning both with and without visual input. These exercises can be performed both actively and passively with a goniometer or on an isokinetic dynamometer (Figure 8). This category works at the brain stem level of motor control as well as the cognitive level. The subsystems included are the peripheral somatosensory and the vestibular. The visual may be included in some activities but is not always emphasized in this category.

It is imperative that activities from each classification in our system be a



b

Figure 5 — Movable boundary, external axial load: (a) exercise on a slide board in push-up position, (b) exercise on a slide board in quadruped position.

included in the upper extremity rehabilitation program in order to fully return the athlete to preinjury level. These categories incorporate all subsystems of movement and all levels of motor control. Most importantly, functional specificity is emphasized throughout each of our classifications, allowing the athlete to resume functional activity as quickly and safely as possible.

Summary

Functional stability of the shoulder joint depends on proper scapulothoracic stabilization, glenohumeral stabilization, and humeral motion, as well as the

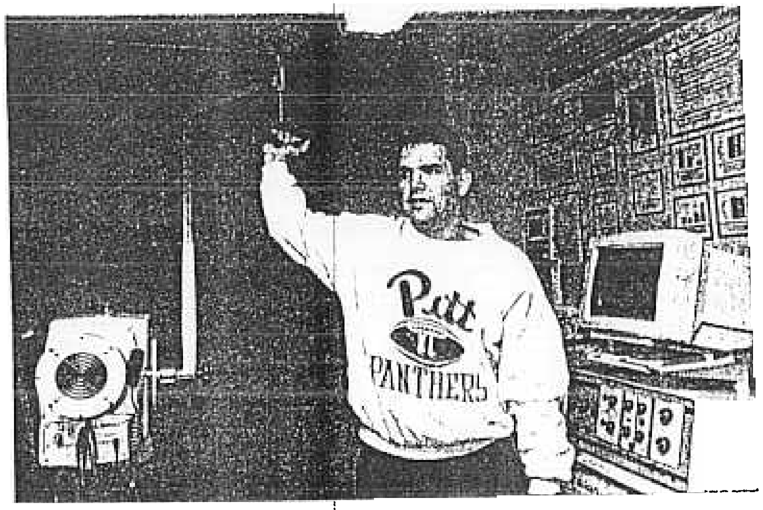


Figure 6 — Movable boundary, external rotary load: isokinetic exercise on the Biodex System 2 Dynamometer in a functional diagonal pattern.

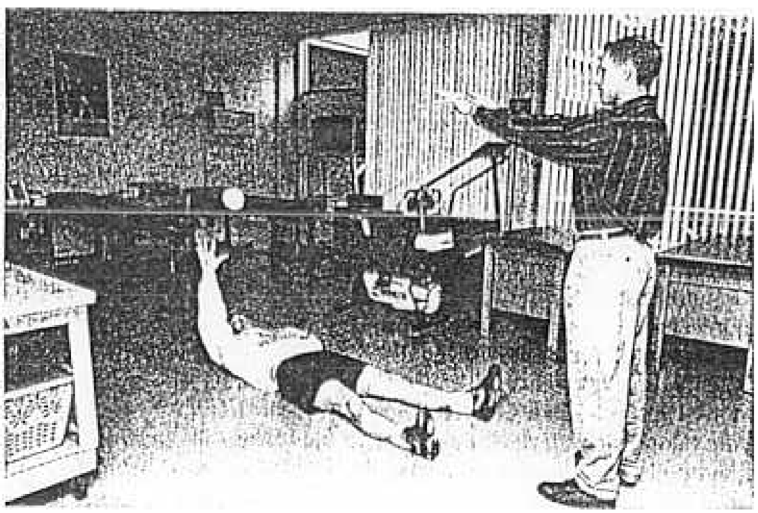
integration of these through neuromuscular control. Functional stability and neuromuscular control are provided by both the static and dynamic mechanisms. With injury to the ligamentous structures, the musculature, or both, episodes of functional instability result. Surgical intervention may restore the mechanical restraints to the shoulder, but rehabilitation is needed to restore the dynamic mechanism and neuromuscular control of the unstable shoulder.

Reestablishment of neuromuscular control is best accomplished through a combination of both open and closed kinetic chain activities. Both open and closed chain activities possess characteristics that are important in restoring neuromuscular control to an injured extremity. In this paper we have described our Functional Classification System, which classifies activities according to these functional characteristics rather than the traditional definitions of open and closed chain exercise. In this new classification system, closed chain activities provide for large resistance/low acceleration, great compressive forces, joint congruency, low shear, stimulation of proprioceptors, and enhanced dynamic stabilization. Open chain activities provide for large acceleration/low resistance, distraction and rotary forces, promotion of a stable scapulothoracic base, joint mechanoreceptor deformation, concentric acceleration, eccentric deceleration, and assimilation of function.

Considering the complexity of the upper extremity and of any associated rehabilitation program, we believe that a few characteristics are important for classifying and designing rehabilitation activities. These include direction of the force, magnitude of load, muscle action, joint motion, and neuromuscular function. These general characteristics provide the basis of our Functional Classification System and should be considered when choosing activities for an upper extremity rehabilitation program.

Ultimately, integration of the functional characteristics that provide for neuromuscular control and proper stabilization of the scapulothoracic and gleno-

a



b

Figure 7 — Movable boundary, external rotary load: (a) plyometric exercise for the shoulder joint with Plyoball and pitchback, (b) plyometric exercise for the shoulder joint with Plyoball and partner.

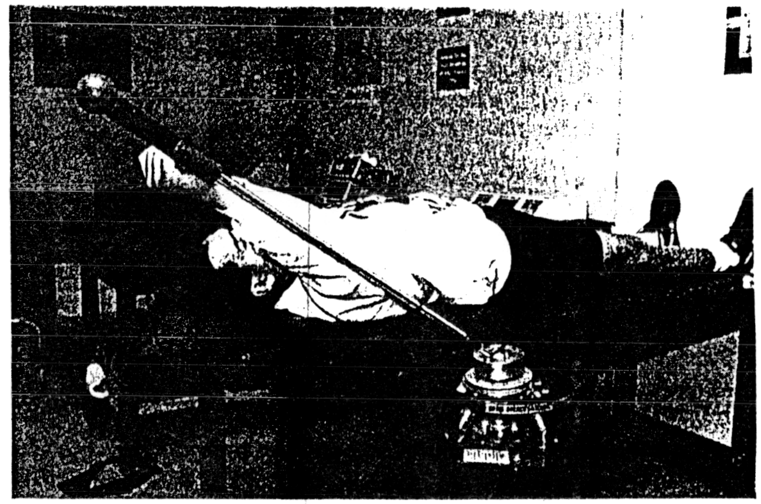


Figure 8 — Movable boundary, no load: active and passive repositioning exercises for the upper extremity.

humeral joints, as well as humeral control, will provide functional stability in the shoulder joint. Without integration of these areas and proper neuromuscular control, episodes of functional instability may occur and functional performance will suffer. Rehabilitation of the shoulder complex based upon the classification system proposed here should return the athlete to a high level of activity.

References

1. Andrews, J.R., and R.H. Gidamal. Shoulder arthroscopy in the throwing athlete: Perspectives and prognosis. *Arthroscopy* 6:656-661, 1987.
2. Barrack, R.L., H.B. Skinner, M.E. Brunnet, and S.L. Buckley. Proprioception in the anterior cruciate deficient knee. *Am. J. Sports Med.* 17:1-6, 1989.
3. Barrack, R.L., H.B. Skinner, S.D. Cook, and R.J. Haddad. Effect of articular disease and total knee arthroplasty on knee joint-positioning sense. *J. Neurophysiol.* 50(3):684-687, 1983.
4. Baxendale, R.A., W.R. Ferrell, and L. Wood. Responses of quadriceps motor units to mechanical stimulation of knee joint receptors in decerebrate cat. *Brain Res.* 453:150-156, 1988.
5. Blazina, M.E., and J.S. Satzman. Recurrent anterior subluxation of the shoulder in athletes. A distinct entity. *J. Bone Joint Surg.* 51A:1037, 1969.
6. Borsa, P.A., S.M. Lephart, M.S. Kocher, and S.P. Lephart. Functional assessment and rehabilitation of shoulder proprioception for glenohumeral instability. *J. Sport Rehabil.* 3:84-104, 1994.
7. Bowen, M.K., X.H. Derg, J.J.P. Warner, and R.F. Warren. The effect of joint compression on stability of the glenohumeral joint. *Trans. Orthop. Res. Soc.* 17:289, 1992.
8. Bradley, J.P., and J.E. Tibone. Electromyographic analysis of muscle action about the shoulder. *Clin. Sports Med.* 10:789-805, 1991.

9. Cain, P.R., et al. Anterior stability of the glenohumeral joint: A dynamic model. *Am. J. Sports Med.* 15:144-148, 1987.
10. Davies, G.J., and S. Dickoff-Hoffman. Neuromuscular testing and rehabilitation of the shoulder complex. *J. Orthop. Sports Phys. Ther.* 18:449-458, 1993.
11. Dempster, W.T. Mechanisms of shoulder movement. *Arch. Phys. Med. Rehab.* 46:49-70, 1965.
12. Dickoff-Hoffman, S. Functional subluxation of the glenohumeral joint in a college pitcher. *Isok. Exerc. Sci.* 3:162-165, 1991.
13. Dillman, C.J., T.A. Murray, and R.A. Hintermeister. Biomechanical differences of open and closed chain exercise with respect to the shoulder. *J. Sport Rehabil.* 3:228-238, 1994.
14. Freeman, M.A.R., M.R.E. Dean, and W.F. Hoffman. The etiology and prevention of functional instability of the foot. *J. Bone Joint Surg.* 47B:678-685, 1965.
15. Glencross, D., and E. Thorton. Position sense following joint injury. *J. Sports Med.* 21:23-27, 1981.
16. Glousmann, R., F.W. Jobe, J.E. Tibone, D. Moynes, D. Antonelli, and J. Perry. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. *J. Bone Joint Surg.* 70A:220-226, 1988.
17. Gray, G.W. *Chain Reaction: Successful Strategies for Closed Chain Testing and Rehabilitation.* Adrain, MI: Wynn Marketing, 1989.
18. Gray, G., J. Peterson, and C. Bryant. Closed chain sense. *Fitness Management* 31-33, April 1992.
19. Harryman, D.T., J.A. Sidles, J.M. Clark, K.J. McQuade, T.D. Gibb, and F.A. Matsen. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J. Bone Joint Surg.* 72:1334-1343, 1990.
20. Hawkins, R.J., J.P. Schutte, G.H. Huckell, et al. The assessment of glenohumeral translation using manual and fluoroscopic techniques. *Orthop. Trans.* 12:727-728, 1988.
21. Inman, V.T., J.R. Saunders, and J.C. Abbott. Observations on the function of the shoulder joint. *J. Bone Joint Surg.* 26:1-30, 1944.
22. Irrgang, J., S.L. Whitney, and C.D. Harner. Nonoperative treatment of rotator cuff injuries in throwing athletes. *J. Sport Rehabil.* 1:197-222, 1992.
23. Jobe, F.W., J.E. Tibone, J. Perry, and D.R. Moynes. An EMG analysis of the shoulder in pitching and throwing: A preliminary report. *Am. J. Sports Med.* 11:3-5, 1983.
24. Kennedy, J.C., I.J. Alexander, and K.C. Hayes. Nerve supply of the human knee and its functional importance. *Am. J. Sports Med.* 10:329-335, 1982.
25. Lephart, S.M., and M.S. Kocher. The role of exercise in the prevention of shoulder disorders. In *The Shoulder: A Balance of Mobility and Stability*, F.A. Matsen, F.H. Fu, and R.J. Hawkins (Eds.). Rosemont, IL: American Academy of Orthopaedic Surgeons, 1993, pp. 597-620.
26. Lephart, S.M., M.S. Kocher, F.H. Fu, P.A. Borsa, and C.D. Harner. Proprioception following ACL reconstruction. *J. Sport Rehabil.* 1:188-196, 1992.
27. Lephart, S.M., J.P. Warner, P.A. Borsa, and F.H. Fu. Proprioception of the shoulder in normal, unstable, and post-surgical injuries. *J. Shoulder Elbow Surg.* 3:371-381, 1994.
28. McLaughlin, H.L. Recurrent anterior dislocation of the shoulder. Morbid anatomy. *Am. J. Surg.* 99:628-632, 1960.
29. O'Brien, S.J., M.C. Neves, S.P. Arnoczky, et al. The anatomy and histology of the inferior glenohumeral complex of the shoulder. *Am. J. Sport Med.* 18:449, 1990.

30. Panariello, R.A. The closed kinetic chain in strength training. *Natl. Strength & Cond. Assoc. J.* 13(1):29-33, 1991.
31. Rockwood, C.A., Jr. Part II: Subluxation and dislocation about the shoulder. In *Fractures in Adults*, C.A. Rockwood, Jr., and D.P. Green (Eds.). Philadelphia: Lippincott, 1984, p. 772.
32. Rowe, C.R., and H.T. Sakellarides. Factors related to recurrence of anterior dislocation of the shoulder. *Clin. Orthop.* 20:40-48, 1961.
33. Rowe, C.R., and B. Zarins. Recurrent transient subluxation of the shoulder. *J. Bone Joint Surg.* 63A:863-872, 1981.
34. Saha, A.K. *Theory of Shoulder Mechanisms. Descriptive and Applied.* Springfield, IL: Charles C Thomas, 1961.
35. Schwartz, R.E., S.J. O'Brien, R.F. Warren, and P.A. Torzilli. Capsular restraints to anterior-posterior shoulder stability. *Orthop. Trans.* 8:1-89, 1974.
36. Silliman, J.F., and R.J. Hawkins. Current concepts and recent advances in the athlete's shoulder. *Clin. Sports Med.* 10:693-705, 1991.
37. Simonet, W.T., and R.H. Cofield. Prognosis of anterior shoulder dislocation. *Am. J. Sports Med.* 12:19-24, 1984.
38. Skinner, H.B., and R.L. Barrack. Joint position sense in the normal and pathologic knee joint. *J. Electromyogr. Kinesiol.* 1:180-190, 1991.
39. Skoglund, C.T. Joint receptors and kinesthesis. In *Handbook of Sensory Physiology*, A. Iggo (Ed.). Berlin: Springer-Verlag, 1973, pp. 111-135.
40. Smith, R.L., and J. Brunolli. Shoulder kinesthesia after anterior glenohumeral dislocation. *Phys. Ther.* 69:106-112, 1989.
41. Steindler, A. *Kinesiology of the Human Body.* Springfield, IL: Charles C Thomas, 1955, pp. 63, 436-445, 556-569.
42. Townley, C.O. The capsular mechanisms in recurrent dislocation of the shoulder. *J. Bone Joint Surg.* 32A:370-380, 1950.
43. Turkel, J., M.W. Panio, J.L. Marshall, and F.G. Girgis. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. *J. Bone Joint Surg.* 63A:1028-1217, 1981.
44. Warner, J.P., et al. Static capsuloligamentous restraints to superior-inferior translation of the glenohumeral joint. *Am. J. Sports Med.* 20:675-685, 1992.
45. Warren, R.F., I.V. Kornblatt, and R. Marchand. Static factors affecting posterior shoulder stability. *Orthop Trans.* 8:1-89, 1984.
46. Wilk, K.E., and C. Arrigo. Current concepts in the rehabilitation of the athletic shoulder. *J. Orthop. Sports Phys. Ther.* 18(1):365-378, 1993.