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Shoulder Plyometrics

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Summary: Rehabilitation and training of the shoulder in throwing and overhead athletes has dramatically changed during the last decade. Athletes are returning to participation in overhead sports faster than ever. There are numerous reasons for this rapid return to athletic training or competition. These reasons include increased anatomic understanding of the shoulder complex, increased understanding of the biomechanics that occur at the shoulder complex in sports, and ability to integrate this new knowledge into performance enhancement. In addition, a better understanding of the scientific and clinical concepts of plyometrics has facilitated this improvement in performance. Although there are numerous studies regarding the application of plyometrics in the lower extremities, there are very few regarding the application of plyometrics to the upper extremities. This article describes the physiologic, biomechanical, and neurophysiological basis of upper extremity plyometrics with an emphasis on clinical application. **Key Words:** Amortization—Periodization—Rehabilitation—Sports—Upper extremity.

The rehabilitation program in throwing and overhead sports has dramatically changed in the past several years.[1–16] There is often pressure to return the athlete back to optimum function as quickly as possible after an injury or surgical procedure. Using the knee as the model, dramatic changes have occurred with knee rehabilitation because of the integrated approach of the surgical procedure followed by specificity rehabilitation. Athletes are returning back to competition after knee injuries and surgeries faster than anyone could have predicted 10 years ago. The ability of the clinician to return the athlete back more quickly and safely has been due to advances in rehabilitation, including the use of integrated open and closed kinetic chain rehabilitation programs, proprioceptive training, neuromuscular reactive training, and plyometrics. There are numerous studies[17–21] that document the efficacy of using plyometrics in increasing performance in the lower extremities.

However, what about the shoulder? A review of the sports medicine literature reveals that the advances in shoulder rehabilitation are approximately 10 to 15 years behind those of the knee. Recently, with the advent of newer surgical procedures (i.e., arthroscopic mini-capsular shifts rather than open Bankart procedures), it seems that some overhead athletes may be able to return to activity quicker than before. Yet unproven with long-term longitudinal studies, the use of thermal-assisted capsulorrhaphy has also made some claims about returning athletes back to activity sooner than other capsular tightening procedures. Therefore, as was true with the knee, it is time for accelerated rehabilitation concepts to also start being applied to select patients with shoulder conditions. A very integral part of that aggressive approach to rehabilitation is the use of plyometrics as a component of the entire rehabilitation program. Because of the large forces involved, plyometrics are most appropriately used in a periodization rehabilitation program toward the terminal phases of rehabilitation. However, as will be discussed later, there is limited scientific research supporting the use of plyometrics in enhancing shoulder performance. Because of the concepts of specificity of rehabilitation and specific adaptation to imposed demands, plyometrics should form a foundation for the

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overhead athlete in helping build a power foundation from which to refine the skills of the sport.

This raises the question: why use plyometrics in the rehabilitation or performance enhancement of the athlete involved in throwing and overhead sports? Almost all throwing or overhead sports use the plyometric concept as part of the functional movement pattern while executing the requirements of the sport.[1,16,22–25] The stretch-shortening cycle concept applies the principle of specificity of training to facilitate the maximum amount of muscular force in a minimal amount of time. A few examples will demonstrate the plyometric concept, which is a stretch-shortening type of muscle contraction. In the throwing athlete, when they go into the cocking and late cocking phases, they are causing a stretch to the internal rotator muscles of the shoulder complex. This stretching provides potential kinetic energy that is transferred to the shortening cycle and facilitates the resultant force production or performance pattern of the movement.[1,16,22–25]

The overhead pitching motion has been described as one of the most violent activities in human sports performance. The angular velocities for throwing a baseball can be anywhere from over 5,000° per second, as reported by Gainor et al.,[23] to greater than 9,000° per second. The average angular throwing velocity is approximately 7,000° per second, as reported by Newton and McEvoy.[25] Because of the tremendous angular velocities created with the overhead throwing motion, the stretch (elastic loading) cycle is necessary to generate the forces required in the throwing motion. With the shortened amortization phase, it permits the stretching to contribute to the maximal explosive shortening (concentric contraction). The follow-through of the throwing motion again causes an explosive eccentric decelerative movement to the core stabilizers, scapular stabilizers and the posterior shoulder structures. The volleyball player and tennis player use an abbreviated cocking motion to strike the ball, but are still creating the prestretch movement in preparation for the ball strike. Because this is often a reactive response instead of the pitching motion that is a proactive response, the stretching movement occurs more quickly. Interestingly, swimming is the overhead sport that probably requires the greatest numbers of repetitions in practice and in competition. Yet, swimming involves only a minimal number of plyometric movements or eccentric contractions of the shoulder muscles.

Recognizing the large angular velocities and forces required in the throwing motion and the subsequent demands being placed on the shoulder complex, illustrates the need for plyometric training in returning or preparing the athlete for participation. However, at present, it is beyond the scope of most exercise equipment or techniques that are presently available in the clinic to reproduce the demands placed on the shoulder with the overhead throwing motion.[1,3,26,27]

Every rehabilitation or conditioning program is designed to return the athlete back to his or her optimum function as quickly and as safely as possible. The rehabilitation and conditioning program accomplishes this with the use of exercises based on functional and sports specificity principles. Plyometric exercises play an important role in this process with the overhead athlete.

DEFINITION OF PLYOMETRICS

Plyometrics have been used for many decades in the Russian and Eastern European training of the track and field athletes.[17,21,28–38] Verhoshanski, a well-known track and field coach in Russia, used the concept that he referred to as shock training or jump training.[18,19] It is thought that this type of training is the reason that, in the 1950s and 1960s, the Russian and Eastern European athletes were so successful in international competitions. The actual term, plyometrics, was first coined by former Purdue University women's track coach Fred Wilt in 1975.[39] The word "plyometrics" is actually a derivation from the Greek word *plythein* or *plyo* which means to increase. The term "metric" derives from measure. Consequently the purpose of plyometrics may be thought of as "to increase the measurement." Typically the measurement is sports performance in testing or competition.[3,40,41]

Phases of Plyometrics: The Stretch-Shortening Cycle

Plyometrics[17,21,28–33,35–38] is resistance training that involves the quick stretching of muscle from an eccentric muscle action to a concentric muscle action.[34] This stretch-shortening cycle may be divided into the three following phases.

Eccentric prestretch phase

The eccentric prestretch phase has often been described as the preparatory, facilitatory, readiness, setting, preloading, potentiation, counter-force, or counter-movement phase. All these terms have been used to describe the first phase of the plyometric activity. The eccentric prestretch phase of a plyometric activity stimulates the muscle receptors and prepares the muscle for loading. This stimulation of muscle receptors is often referred to as the neurophysiological-biomechanical response. Several investigators[42–44] showed that an eccentric muscle action immediately preceding a concentric muscle action will increase the concentric force production. The prestretch phase is dependent on the three stretch factors, including the magnitude of the stretch, rate of stretch, and duration of the stretch.[42,45] Changing any of these factors will have a significant effect on the amount of energy that is stored by the eccentrically acting muscles.

Amortization phase

The amortization phase is also known as the electromechanical delay phase of plyometrics. This is the time delay between the eccentric prestretch of the muscle and the concentric shortening phase or from negative to positive work. The amortization phase is the time delay between overcoming the negative work of the eccentric prestretch to generating the force production and accelerating the muscle contraction and the elastic recoil in the direction of the plyometric movement pattern.[46] The shorter the amortization time the more effective and powerful is the plyometric movement because the stored energy is used efficiently in the transition. Also, the shorter the amortization phase, the greater the work output due to the maximal utilization of stored elastic energy.[42] If there is a delay in the amortization phase, the stored energy is wasted as heat, the stretch reflex is not activated and the resultant contraction is not as effective. Decreasing the amortization phase is one of the key goals of plyometric training.

Concentric shortening phase

The concentric shortening phase is often described as the performance, power, facilitated, or enhancement phase of plyometrics. All these terms describe the final phase of the plyometric movement and are descriptive of what actually happens in the plyometric activity. This third component of the stretch-shortening cycle is the biomechanical response that utilizes the elastic properties of the prestretched muscles.[47,48]

The eccentric prestretch, amortization, and concentric shortening phases are blended in plyometric training to enhance the muscles' performance.[42,45,48] It is the careful planning (periodization programs) and execution of the actual plyometric drills to be described later that is what makes these exercises so effective in performance enhancement.

SCIENTIFIC FOUNDATION FOR THE APPLICATION OF PLYOMETRICS

Physiologic Basis

The contractile component of the actin and myosin cross bridges within the sarcomere plays an important role in motor control and force development during plyometrics. The plyometric movement uses the prestretch of the Blix curve (muscle physiological length-tension curve) in order to enhance the ability of the muscle fibers to generate more tension and resultant force production.

This idea of biomechanically "priming" muscle is supported by the work of Elftman.[49] The Elftman proposal simply states that the force production of muscle is arranged in an orderly format. In other words, eccentric actions create more force than isometric contractions, and isometric contractions generate more force than concentric contractions.[49] Admittedly, the force-producing component is the concentric muscle contraction, but with the stretch-shortening cycle, the potential kinetic energy built up in the eccentric prestretch muscle action carries over to enhance the concentric power output.

As early as 1924, Fenn and Hill characterized eccentric exercise as requiring a lower metabolic cost with greater mechanical tension development. During eccentric actions, the muscle lengthens as it contracts and stretches the series elastic components (SEC) of the muscle. This elastic stretching contributes to the resulting muscle force production apparent in stretch-shortening plyometric activities.[50,51]

Basic muscle physiology demonstrates that muscle torque production in vivo will follow along with the basic physiologic findings of in-vitro testing. This concept of positioning has obvious clinical implications for rehabilitation and performance enhancement using plyometric exercises: 1) specificity replication of a muscles position in certain activities, 2) positioning to bias the muscle for its optimum force production, and 3) biasing the muscle in a shortened position to decrease its torque production when rehabilitating a musculo-tendinous unit strain in the early stages following an injury.[52]

Furthermore, it has been demonstrated that eccentric muscular actions exhibit less electromyographic (EMG) activity at comparable workloads than concentric muscle contractions. This neuromuscular efficiency is transferred to the power phase of the stretch-shorten cycle and creates an efficient plyometric movement.[47,52–55]

The eccentric phase of the plyometric movement is very efficient regarding oxygen utilization and therefore makes the stretch-shortening action very economical regarding energy requirements. During the eccentric prestretch, the chemical energy cost of ATP is minimal and efficient.[56]

Research regarding energy conversion and use during eccentric muscle actions parallels the physiologic concepts of muscle contractions. Analysis of muscle metabolites in an isolated muscle contracting while being stretched showed a greater concentration of adenosine triphosphates (ATP) and inorganic phosphate than muscle stimulated isometrically. ATP usage during eccentric work is reported to be 1/13 that used in positive work despite generating 70% greater muscle tension than concentric contractions.[53]

However, with eccentric exercises, there is always the concern of delayed onset muscle soreness (DOMS).[52,53,57,58] DOMS is the sensation of pain or discomfort in the skeletal muscles following unaccustomed eccentric exercises. Because plyometrics use the stretch-shorten cycle, often at a high intensity level, the development of DOMS in the early stages of training needs to be recognized in program development and progression. The important consideration to realize is that, when beginning an eccentric exercise program, all patients or athletes will experience DOMS. Therefore, alerting the patients or athletes to the onset and spontaneous resolution of DOMS in approximately 7 to 10 days is important for the patient's understanding of the additional soreness while participating in the early stages of a plyometric program.[52] Clarkson et al.[59] have described the repeated bout effect that indicates that as a result of the mutability of muscle that occurs after an initial exposure to eccentrics (plyometrics), there is a reduced micro-traumatic response with a concomitant decrease in the sensation of DOMS. This is an important consideration when developing and integrating plyometrics into the total rehabilitation or conditioning program.

Rapid voluntary contractions of skeletal musculature are achieved via selective recruitment of motor units. It is generally accepted that recruitment of muscle fibers follows an orderly pattern or sequence termed the size principle. In the muscle containing both slow-twitch and fast-twitch muscle fibers (the majority of skeletal muscles), the size principle implies that the initial recruitment for the performance of muscular work will involve the slow twitch motor units. As the contraction intensity increases, as with plyometric exercises, the fast twitch motor units are recruited.[60] Friden et al.[60] reported preferential recruitment and an increased number of fast twitch muscle fibers following an eight week training program of eccentric ergometry. Friden et al. concluded that eccentric training caused a preferential recruitment of type IIb fast-twitch muscle fibers and suggested that this was due to the higher muscular tension generated with eccentric contractions.[60] Fast twitch muscle fibers respond better to a high-speed small amplitude prestretch, whereas slow twitch muscle fibers respond differently. Therefore, specificity of rehabilitation is important.

Research delineating fiber recruitment and physiological adaptations to plyometrics is not currently available. It is well understood that plyometrics are effective in the lower extremities to enhance performance.[17,21,34,36] Owing to the role of the fast twitch muscle fibers in maximal muscle performance, it is clearly evident that the possible enhancement of fast-twitch motor unit recruitment would be beneficial in performance training and rehabilitation. Further research is required to clearly delineate and define these physiologic principles in the plyometric spectrum.

Mechanical Basis

When we consider the function of muscles in many sporting activities, they act as eccentric decelerators and shock absorbers primarily due to the elastic properties within the muscles. These elastic properties that form the mechanical basis of the muscle mechanics can be contributed to three structural components within the muscle. These three structural components are the contractile components (CC), the series elastic components (SEC), and the parallel elastic (PEC) components.[43,45,61]

All three of these components interact with one another to produce force output. Generally, the contractile component is most often the focus when the physiological function of muscle is tested and trained. However, the SEC and the PEC are also vital components of muscle function when the muscle is lengthened and subsequently are instrumental in augmenting the force output. Consequently, the mechanical behavior of the SECs is a major contributor in the plyometric action. The mechanism for this increased concentric force is the ability of the muscle to utilize the force produced by the elastic component (referred to as elastic tissue loading). During this prestretch, the SEC is stretched and as the muscle is lengthened, potential kinetic energy is stored in the SEC. This stored energy can be used for force production as the muscle returns to its normal length. During this shortening phase, the potential energy in the SEC is released and adds to the work performed by the muscles. This is referred to the rebound force response. The SEC acts like a spring, obeying Hooke's Law that states that the energy release will be greater with higher forces. This effect of plyometric exercises is attributed to the elastic recoil of the elastic (PEC, SEC) tissues.[44,62,63]

Stretch-shortening exercises uses the elastic and reactive properties of a muscle to generate maximal force production. In normal muscle function, the muscle is stretched before it contracts concentrically. This eccentric-concentric coupling, also referred to as the stretch-shortening cycle, employs the stimulation of the body's proprioceptors to facilitate an increase in muscle recruitment over a minimal amount of time.[37,64]

During a concentric contraction of muscle the only functioning component is the CC with the muscle fiber filaments sliding past one another. However, during an eccentric action in the prestretch phase the SEC and PEC store potential kinetic energy much the same way a rubber band stores energy when it is stretched. Consequently the load is transferred to the elastic components of the muscle and stored as elastic energy, which creates the potential energy. Then during the concentric phase the SEC recoils and contributes to the overall force (kinetic energy) that is generated. During this recoil response, the elastic elements can then deliver the stored kinetic energy to increase the energy capabilities as it is recovered and used for the concentric contraction. The muscle's ability to use this potential energy is affected by the time, magnitude, and velocity of the stretch. The SEC accounts for 70% to 75% of the force increases of muscle thereby making the plyometric training very efficient.[53]

The availability of the muscles to use the stored elastic energy in the connective tissue components (i.e., SEC, PEC) is dependent on the variables of time, magnitude of the stretch, velocity of the stretch, and the muscle fiber type. Increased force generation during the concentric muscle contraction is most effective when the eccentric prestretch has a short amortization phase, has a short range of motion (ROM), occurs quickly at a high velocity and intensity to facilitate the muscle contraction of the fast twitch muscle fibers.

Neurophysiological Basis

The propriceptors of the body include the muscle spindle, the Golgi tendon organ (GTO), and the mechanoreceptors of joint capsules and ligaments. Stimulation of these receptors can cause facilitation, inhibition, and modulation of both agonist and antagonistic muscles.[37,64,65]

Another possible theory that illustrates how plyometric training may improve muscular performance involves neuromuscular coordination. This theory states that speed of muscular performance may be limited by neuromuscular coordination. To put it simply, the arm may be strong enough, but it will only move within a set speed because of the neural limitations imposed on it. It is believed that explosive plyometric training may improve neural efficiency. If this is true, plyometric training increases neuromuscular performance by increasing the set speed in which the muscles may act. The use of the prestretch enables an individual to better coordinate the activities of the active muscle groups and its synergists. Even without a morphologic adaptation of the active muscle this neural adaptation can increase performance by producing greater net force. Ultimately this mechanism results in the enhancement of the neurologic system to become more automatic.

The proprioceptive stretch reflexes are other components that contribute to an increase in force production. The muscle spindles and GTOs are the primary mechanoreceptors responsible for the myotatic stretch reflex. Each of these structures causes a modulating effect in different ways.[65]

The muscle spindles are the stretch receptors located in the muscle fibers. The muscle spindle functions mainly as a stretch receptor and is primarily sensitive to changes in velocity. The muscle spindle is provoked by a quick stretch, which reflexively produces a quick contraction of the agonistic and synergistic extrafusal fibers. This cycle occurs in 0.3–0.5 ms and is mediated at the spinal cord level in the form of a monosynaptic reflex arc, such as the knee jerk.[54] Thus, when the muscle spindle is stretched, there is an increase in afferent nerve firing. This facilitation creates an efferent motor response that is sent back to the muscles from the spinal cord causing a muscle contraction. The muscle contraction causes a decrease in the muscle length and removes the initial stimulus by decreasing the stretch applied to the muscle spindle. The strength of the signal that is sent to the spinal cord from the muscle spindle is dependent on the rate of the applied stretch. The faster the rate of the stretch, the stronger the neurologic signal sent from the muscle spindle. As a result, the greater the efferent muscle contraction (the shortening cycle of the plyometric movement).[65]

The other mechanoreceptor that plays a significant role in the plyometric stretch-shorten cycle is the GTO. The GTO, which is sensitive to tension, is located at the junction between the tendon and muscle both at the origin and insertion. The unit is arranged in series with the extrafusal muscle fibers and, therefore, becomes activated with stretch. Unlike the muscle spindle, the GTO has an inhibitory effect on the muscle. Upon activation, impulses are sent to the spinal cord, causing an inhibition of the alpha motor neurons of the contracting muscle and its synergists and, thereby, limiting the force produced. It has been postulated that the GTO is the protective mechanism against over-contraction or stretch of the muscle. Because the GTO use at least one interneuron in its synaptic cycle, inhibition requires more time than monosynaptic interneuron excitation.[37,38] Therefore, the function of the GTOs is to act as protective devices preventing over-contraction or tension within the muscle.[65]

During concentric muscle contraction, the muscle spindle output is reduced because the muscle fibers are either shortening or attempting to shorten. During eccentric actions, the muscle stretch reflex generates more tension in the lengthening muscle. When the muscle tension increases to a high or potentially harmful level, the GTO fires, thereby generating a neural pattern that reduces the excitation of the muscle. Consequently, the GTO receptors may be a protective mechanism, but in correctly performed plyometric exercises, their influences are overshadowed by the reflex arc pathway incorporated with excitation of Type la nerve fibers.[37,38]

Therefore, the purpose of plyometric training is to increase the excitability of the neurologic receptors for improved reactivity of the neuromuscular system. Some authors have described this type of sports performance training as reactive neuromuscular training.

SCIENTIFIC RESEARCH SUPPORTING UPPER EXTREMITY PLYOMETRICS

As previously mentioned in the introduction, numerous studies[17,21,34,36] have established the effectiveness of plyometric exercises in improving power and performance in the lower extremities. However, a Medline database search of the application of plyometrics in the upper extremities provides limited results. Many clinicians and practitioners assume that the upper extremities will respond in a similar fashion to plyometrics as did the lower extremities. However, the external force applied during the eccentric preload phase would have to be much smaller due to the smaller mass of the upper extremities and the high potential for iatrogenically causing an injury to the shoulder complex from overloading the structures in an unaccustomed position. The only upper extremity plyometric study published in an *Index Medicus* journal was by Heiderschiet et al.[66] This study compared the effects of isokinetic and plyometric training on the shoulder internal rotators. For the purpose of this discussion, only the plyometric results of the study will be presented and discussed. The subjects consisted of 78 sedentary, untrained college age women. Exclusion criteria consisted of either current participation in an upper extremity weight training program, current participation in college sports, or a history of shoulder pathology. Each subject underwent pretesting consisting of an isokinetic power test, kinesthetic awareness testing, and a Underkoefler softball distance throw. These tests were used to measure internal rotator strength, shoulder kinesthesia, and upper extremity functional performance, respectively.

The plyometric training group ($n = 27$) trained on the Plyoback system (Functionally Integrated Technologies, California). The women stood 5 feet from the center of the trampoline and threw weighted balls using a one-handed overhead throw of the dominant arm. The subjects were required to maintain an upper arm position of at least 45 degrees with 5 to 10 degrees of horizontal flexion and the forearm in a position perpendicular to the transverse plane. All subjects trained with a 3-lb ball for 3 sets of 10 throws for the first 2 weeks and then 4 sets of 10 throws for the next 2 weeks. A 4-lb ball was then thrown for 3 sets of 10 throws for weeks 5 and 6. Four sets of 10 throws using the same ball were performed in the final 2 weeks. The subjects were instructed to give a maximal volitional effort with each throw.

The results of the post-test (same format as the pretest) of the plyometric group showed no statistically significant differences in isokinetic power, kinesthesia awareness, or the Underkoefler softball throw for distance. The investigators believed they obtained these results because the training program was based on previous lower extremity training studies. The parameters (i.e., optimal number or repetitions, sets, ideal rest periods, progression, etc.) for upper extremity plyometrics have yet to be determined. The investigators also noted that it was difficult to control proper technique in training and believe that substitutions could have resulted in ineffective training of the target muscles. Finally, they believe that these results were because the untrained subjects concentrated on technique rather than giving maximal effort on each throw. The investigators recommended that trained throwers serve as potential subjects in future studies. A follow-up study[67] replicated the study using experienced overhead athletes. The purpose of the study was to determine the effects of plyometric training on the shoulder internal rotators. College age (18–28 years) men ($n = 34$) with at least 1 year of experience in a competitive overheard sport were randomly assigned to the control or plyometric training group. Pre-, interim-, and post-testing measurements included kinesthetic measurements of shoulder internal rotation and external rotation, active and passive shoulder external rotation ROM, concentric isokinetic power of the shoulder rotators, and a softball throw for distance. The plyometric group trained 2 times per week for 2- to 4-week sessions with 1 week in between the first and second sessions. A dependent *t*-test was performed on the plyometric group's two interim tests. A repeated measure analysis of variance was performed on the pre-/post-test data. Post hoc tests were then performed on the significant variables. The plyometric group demonstrated no significant change between the interim tests one and two. The analysis of the plyometric group's pre- post-test data showed significant ($P < 0.05$) increases in passive external rotation, concentric isokinetic power at 180° per second ($P < 0.004$) and 300° per second ($P < 0.029$), and the softball throw for distance ($P < 0.001$). The control group demonstrated no significant changes in any of the four dependent variables. Some of the conclusions of the study were that there were no significant detraining effects demonstrated by the plyometric group as a result of 1 week off between sessions 1 and 2. Plyometric training of the shoulder improved passive external rotation ROM, internal rotation isokinetic power, and functional performance as shown by a greater distance achieved with the softball throw.

THEORETICAL TRAINING BENEFITS OF PLYOMETRIC EXERCISES FOR THE SHOULDER COMPLEX

The potential and theoretical training benefits of plyometric exercises for the shoulder complex include, but are not limited to the following.

Research does support that the faster a muscle is loaded eccentrically, the greater the force produced,[68] therefore, the plyometric stretch-shortening cycle should facilitate performance

By desensitizing the muscle spindle, plyometric exercises allow muscles to generate greater force by having the musculoskeletal system tolerate increased workloads without the GTO firing

Plyometrics increase neuromuscular coordination by training the nervous system and making movements more automatic during activity (training effect). This is known as reinforcing a motor pattern and creates automation of activity. This improves neural efficiency and increases neuromuscular performance. The increase of performance often occurs without a concomitant increase in morphologic changes within the muscle. This training effect of the neural system predominates in the first 6 to 8 weeks of any training program,[69] and after several weeks, hypertrophic changes of the muscles begin to occur.

CLINICAL GUIDELINES WHEN BEGINNING A PLYOMETRIC PROGRAM

As a plyometric-training program is initiated, both the athlete and the clinician need to be aware of several guidelines described in the literature involving this type of training.[17,21,28–38] Some of these guidelines are described below, even though the exact parameters for plyometric training are not known. However, minimal improvement and increased risk for injury may result if the clinician does not consider these guidelines.

Because of the stresses imposed with plyometric training, there are several safety considerations in program designs. The age of the patient is an important consideration because of the intensity of plyometrics on the musculoskeletal system. There are no absolute guide-

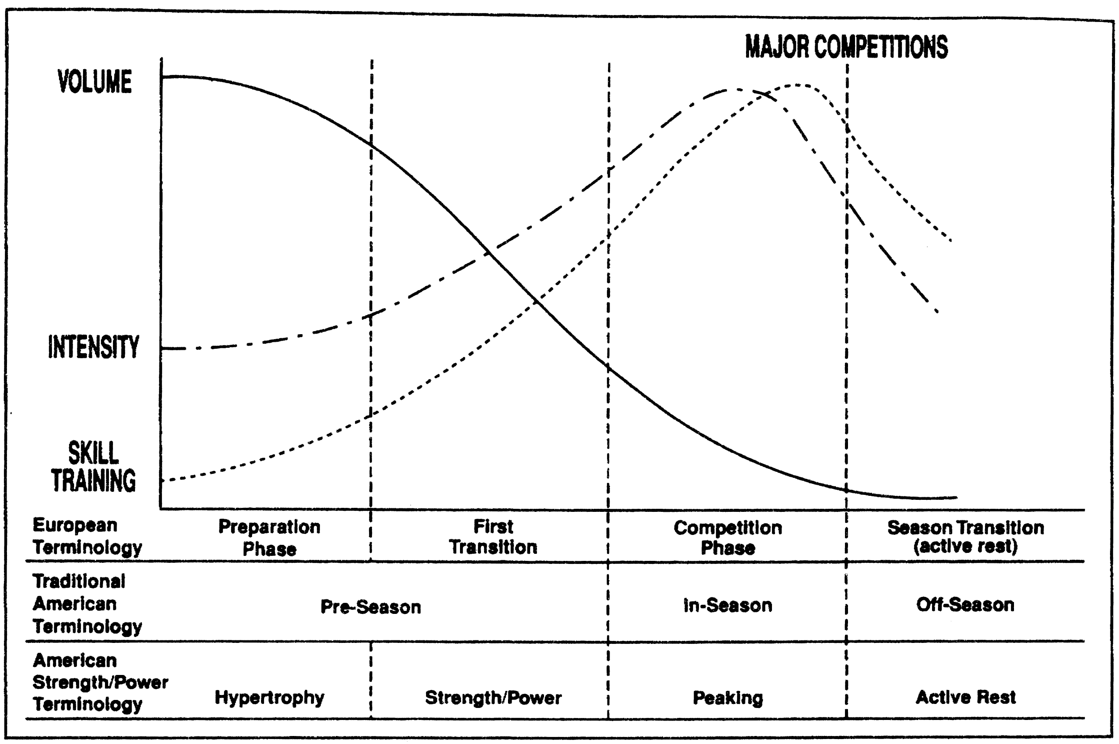

FIG. 1. Training phases of periodization. (Reprinted with permission from Fleck SJ, Kreamer WJ. *Periodization Breakthrough.* New York: Advanced Research Press, 1996.)

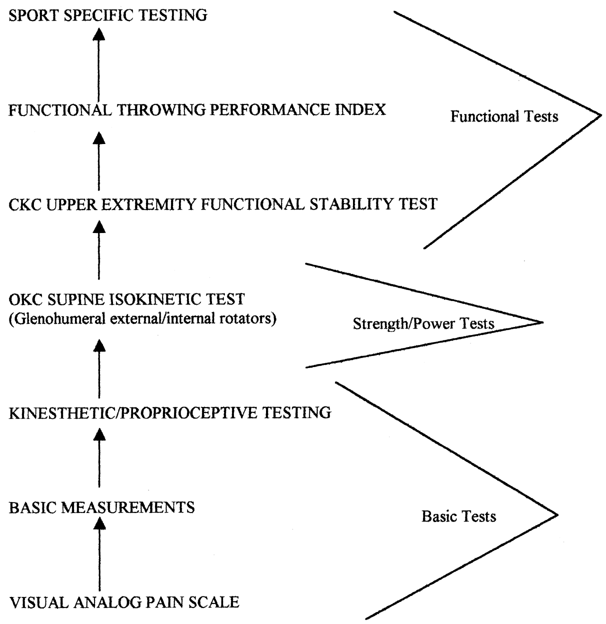

FIG. 2. Functional testing algorithm (FTA) for the upper extremity. CKC, closed kinetic chain; OKC, open kinetic chain.

lines provided in the literature, but precautions for the younger athletes with the use of plyometric training in the upper extremities are warranted. The injury history of the athlete or the type of injury being rehabilitated must be taken into consideration to prevent exacerbating an existing or prior deficit. An adequate systemic and local tissue warm-up should also be preformed prior to the initiation of plyometric training. The purpose of the warm-up is to prevent injuries and prepare the neuromusculoskeletal system for the demands of the training. The experience of the athlete and the foundation strength is also critical in the program development of the athlete, whether in rehabilitation or training. The athlete's experience in resistive training programs must be factored into the program to develop any customized programs. The strength ratio of the athlete is important regarding his/her foundation to begin a plyometric program. Some guidelines have been provided in the literature,[36] such as squatting two times one's body weight. Most of these guidelines are empirically based from the Russian and Eastern European literature and really do not correlate with clinical applications. There are even fewer specific guidelines provided for the upper extremities. Therefore, the clinician should make the plyometric training specific to the individual goals of each athlete. Each specific movement pattern involved in the activity needs to be trained in isolation, allowing the sports activity to be dissected into smaller components and trained with isolated movement patterns. Only then can smaller components be integrated back together into a total coordinated movement pattern. If a muscle cannot function normally in an isolated pattern, then it cannot function normally in an integrated pattern. For best results, the training program should be individualized as much as possible to the athlete and his or her sport. Plyometric training should always be preceded by and coincide with other forms of resistance and flexibility training until an adequate base (foundation) of strength and flexibility has been established. Plyometric exercises need to be integrated into the totality of the rehabilitation or conditioning program. This needs to be done via the periodization model.

Periodization Program

The concept of periodization is a form of training that has been used in the conditioning of athletes since the 1950s.[37,70,71] Periodized training, in essence, is a training plan that changes the workouts at regular intervals of time. Periodization is the gradual cycling of specificity, volume, intensity, duration, and frequency to achieve peak levels of sport specific physiological abilities for the most important competitions.[37,70,71] Periodization of training is a sequential, systematic and progressive method of training, which divides the rehabilitation program or training cycle in various periods of specialized training with set goals for that period. The traditional concept of periodization training usually manipulates the variables of volume, intensity and skill training.[37,70,71]

TABLE 1. *Guidelines for patient progression using the upper extremity functional testing algorithm*

Level	Test	Guideline
Subjective	analog pain scale (0–10)	<3
Basic measurements	anthropometry	<10% bilateral difference
	goniometry	<10% bilateral difference
	kinesthetic testing[85]	male <3° ± 2°; female <4° ± 3°
Strength and power	OKC[30]	≤25% bilateral difference to advance to CKC stability test
		≤15% bilateral difference to advance to throwing performance index
Functional tests	CKC stability test[85]	male 18.5 touches; female 20.5 touches
	functional throwing performance index[85]	male 33–60%; female 17–41%

CKC, closed kinetic chain; OKC, open kinetic chain.

This provides the clinician with the opportunity to focus the training to meet the demands of the athlete. Reasons for using periodized rehabilitation or training include the prevention of a plateau response from occurring during the rehabilitation or training program by providing manipulation of the different variables and continual stimulation of the patient or athlete. The continual stimulation is accomplished by establishing micro-cycles during the course of the rehabilitation or training program. The systematic change in rehabilitation or training generates measurable progress that can facilitate the rehabilitation or performance enhancement. The same concept is actually applied daily by phasing or focusing the rehabilitation program based on the needs of the patient. The concepts of cycles as described in periodization programs are similar to what is actually performed in physical therapy by establishing long term patient goals (macro-cycles), intermediate patient goals, (meso-cycles), and short term patient goals (micro-cycles). The purpose of discussing periodization is to emphasize that plyometrics would be integrated into a rehabilitation or training program in micro-cycles in the terminal phases of the rehabilitation program or integrated throughout a strength and conditioning program. The contents of the periodization program regarding the strength, power, endurance, speed, and technical aspects, etc. need to be considered and integrated in the development of any plyometric program. Understanding the periodization model as the template of the progressively changing program is an intricate part of plyometric training. The periodization training model takes into consideration the specific demands of the athlete's sport from a technical standpoint and how to best integrate plyometric training to enhance performance. Furthermore, the periodization model considers the time of the year (preseason, in-season, postseason) and the need to peak for certain events. Manipulating the variables previously discussed in the periodization model allows for customizing the needs of the athlete at different times throughout their training cycles (Fig. 1).

TABLE 2. *Parameters that can be manipulated in designing training progressions for plyometric programs*

- Repetitions
- Sets
- Intensity (sub-maximal or maximal, although maximal intensity plyometrics are most effective)
- Volume
- Length or duration of training
- Rest intervals (recovery)
- Weight of plyoball
- Resistance implement (plyoballs, body weight, etc.)
- Position of patient (standing kneeling, sitting, supine)
- Body parts involved in the activity
- Effects of fatigue

TABLE 3. *Example of a progression for a plyometric training program*

- Warm-ups
  - general systemic
  - specific joint
- Lower extremity plyometrics
- Trunk (core) stability plyometric
  - trunk flexion/extension
  - trunk lateral flexions
  - trunk rotations
  - trunk PNF functional patterns
- Total pattern plyometrics
  - sport specific simulations
- Shoulder complex plyometrics
  - combined GH and ST joint
- Isolated plyometrics of the primary joint
  - i.e. isolated GH joint

GH, glenohumeral; PNF, proprioceptive neuromuscular facilitation; ST, scapulothoracic.

Functional Testing Algorithm

To help the clinician decide if the patient or athlete is ready for plyometric training, serial dynamic testing of the athlete on a regular basis will provide important details regarding the athlete's progression and readiness for plyometric training. Serial testing also provides motivational feedback and should continue after the plyometric exercises have been initiated. One method of testing used in the clinic is a functional testing algorithm (FTA).[5,6,8,26,40,72,73] An example of the FTA is shown in Figure 2 and the criteria used to progress the patient through the FTA are described in Table 1.

The FTA is based on a series of successively more difficult tests that progress the patient objectively and safely back to return to their functional activities. The FTA consists of basic measurements,[74,75] strength and power measurements[3–5,72,73,76–80] and functional performance testing.[3,40,41] As the patient passes each level of the testing hierarchy, the tests get more difficult as the patient's condition improves. This is an example of the periodization concept applied to rehabilitation based on the test results. The patient should meet the minimal test criteria in the strength and power-testing phase of the FTA before plyometrics should be introduced into the rehabilitation or training program (Tables 2–9).

Contraindications for Upper Extremity Plyometrics

Some of the contraindications to upper extremity plyometrics include pain, inflammation, acute or sub-acute

TABLE 4. *Plyometric throwing motions specific to the overhead athlete*

- Total body
- Two-arms (i.e., chest toss)
- One-arm (i.e., reverse throw)
- Specificity for sports performance

TABLE 5. *Examples of plyometric exercises used for rehabilitation and/or training the shoulder complex in the overhead athlete (Many of these are demonstrated in the figures throughout the article)*

- Two-hand chest pass (Fig. 5)
- Two-hand overhead soccer throw (Fig. 6)
- Two-hand rotations overhead (Fig. 2)
- Two-hand rotations underhand
- Two-hand overhead step and throw
- Eccentric decelerations (Fig. 4A)
- Eccentric decelerations followed by trunk rotation concentric tosses (Fig. 4B)
- Proprioceptive neuromuscular facilitation (PNF) patterns (Fig. 9)
- One-hand side arm throw (Fig. 14)
- 90°/90* baseball throw (Figs. 15, 16)
- Reverse throw for plyometric eccentric decelerations (Fig. 17)

* 90° of shoulder abduction, 90° of shoulder external rotation

sprains, acute or sub-acute strains, joint instability, and soft tissue limitations based on postoperative conditions. However, probably the most significant contraindication to plyometrics is when the athlete does not have the foundation strength or training base upon which a plyometric program can be built. Plyometric exercises are intended to be an advanced speed strengthening or power program for the competitive athlete to enhance athletic performance. It is controversial and the research is limited as to whether plyometrics should be used with orthopedic patients and recreational athletes. The clinician also needs to be aware and to make the athlete aware of any secondary reaction to plyometric exercises, such as pain, inflammation, swelling, postexercise soreness, or DOMS. Also, ankle, chest, and wrist weights are not recommended for plyometrics. This is because use of these weights defeats the principle that the faster a muscle is forced to lengthen the greater the tension it will exert.

The plyometric program should use the principles of progression and overload. This can be accomplished by manipulating the volume (total work performed in one exercise session) or the intensity. These variables will be discussed in greater detail in the next section. The quality of the work is more important with plyometrics than the quantity of the work. Additionally, the intensity of the work should stay at a maximal level. Remember that the rate of the muscle stretch is more important than the length of the stretch. Finally, when proper technique in the performance of the plyometric activity can no longer be demonstrated, the exercise should be stopped. The greater the intensity of the workout with plyometrics, the greater the recovery time required.

Clinical Guidelines From the Literature

In a review of the literature regarding the use of plyometrics in the upper extremity for the throwing and overhead athlete, there is one thing that is quite clear: there is no consensus on the specific criteria, parameters, guidelines, or principles of progression that should be used.[17,27,37,38] Additionally, most of the recommendations are empirically based with minimal scientific research supporting the optimum techniques or guidelines to be used.

For example, according to Chu,[17,31,32] the typical plyometric exercise program using a medicine ball should

TABLE 6. *Examples of progression of plyometric exercises for core stability and the upper extremity*

Beginner	Intermediate	Advanced
Wall dribbling		
Half-twists		
Full twists		
Medicine ball throws	Medicine ball throws (Increase weight, frequency, intensity)	Medicine ball throws (Increase weight, frequency, intensity)
Surgical tubing exercises	Surgical tubing exercises with isometric holds and perturbation training superimposed on the position wit the Shoulder Horn for support	Surgical tubing exercises with isometric holds and perturbation training superimposed on the position without the Shoulder Horn for support
Rhythmic stabilization (perturbation training)	Rhythmic stabilization (perturbation training)	Rhythmic stabilization (perturbation training)
Clap wall pushups	Clap pushups in quadruped	Clap pushups in full pushup position
		Plyometric rebounders off of two plyoballs
		Plyometric bounders off of one plyoball
	Eccentric drop pushups	Eccentric drop/rebound pushups
		One-arm pushups
		Other Advanced Exercises
		• One-arm wall pushups
		• Pylometric boxes
		• Surgical tubing and PNF patterns
		• Impulse IET exercise

IET, Impulse Inertial Exercise Trainer (Engineering Marketing Associates, Newnan, GA); PNF, proprioceptive neuromuscular facilitation. Note, many of the examples are not specific to the overhead athlete.

TABLE 7. *Range of motion progression following an injury or surgery and the application of plyometric exercises*

- Limited range of motion (short-arc exercises) using a bolster
- Limited range of motion using table as support
- Full range of motion with patients arm off the side of the table

follow the concept of periodization with training occurring in the following order: Preseason general body conditioning, beginning of season sport-specific conditioning, and in-season sport specific maintenance. Wilk et al.[37,38] disagrees and recommends that plyometrics be used only in the first and second preparation phases of training according to the periodization model.

DESIGNING AN UPPER EXTREMITY PLYOMETRIC PROGRAM

Training Variables to Consider

Resistive overload: applied loads and distances

In plyometric exercises, resistive overload usually takes the form of a rapid change of direction of a limb or the entire body. The amount of total work in repetitions, sets, etc. and/or the ROM the athlete moves through both contribute to the total resistive overload amount.

Spatial overload: range of motion

Movements can have the effects of overload from the standpoint of ROM. The ROM is usually performed in an exaggerated movement pattern. The concept is to employ the stretch reflex within a specific ROM. As previously described, the reflex mechanisms help facilitate the movement pattern to enhance force production.

Temporal overload: timing

Temporal overload can be accomplished by concentrating on executing the movement as rapidly and intensely as possible. The temporal overload, or keeping the amortization time as short as possible, is one of the keys to performing plyometric exercises. A shorter amortization time and electro-mechanical delay allows for effective force transmission from the eccentric prestretch to the concentric power performance phase of the plyometric movement.

TABLE 8. *Example of progressions of plyometrics*

- Closed kinetic chain exercises
- Open kinetic chain exercises—multiple joints
- Open kinetic chain exercises—isolated joint activity with assistance (Shoulder Horn) (see Fig. 10)
- Open kinetic chain exercises—isolated joint activity without assistance

TABLE 9. *Perturbation training guidelines*

Beginning guidelines	Advanced guidelines
Sub-maximal intensity	Maximal intensity
Slow movement pattern	Fast movement pattern
Know movement pattern (allows subject to preset muscles)	Random pattern (challenges subject to respond to imposed demands)
Position of stability (protected/restricted ROM)	Position of less stability (higher—risk position)

ROM, range of motion.

Intensity

Intensity is the actual percentage of effort required by the athlete to perform the activity. In plyometrics, the type of exercise performed controls intensity. Many plyometric exercises are rather intense and consequently must be considered when designing conditioning or rehabilitation programs.

Volume

Volume is the total work performed in a single work session or cycle (periodization). In the case of plyometric training, volume is often measured by counting the number of repetitions of the specific activity (number of throws, jumps, etc.).

Frequency

Frequency is the number of exercises sessions that take place during the training or rehabilitation cycle.

Recovery

Recovery is important to prevent injuries, overtraining and determining the primary emphasis of the plyometric program. Because of the intense demands on the body with plyometric training, longer periods between sets may be appropriate. There is limited research on the optimum recovery times, but usually 48 to 72 hours between exercise bouts with plyometrics is probably appropriate

Specificity

Specificity in a plyometric program should be designed on a per sport and per athlete basis to enhance the specific goals of the program and to replicate sport specific activities.

VARIOUS UPPER EXTREMITY PLYOMETRIC EXERCISES FOR REHABILITATION AND CONDITIONING

Although this article focuses on plyometrics for the shoulder in overhead athletes, oftentimes the forces

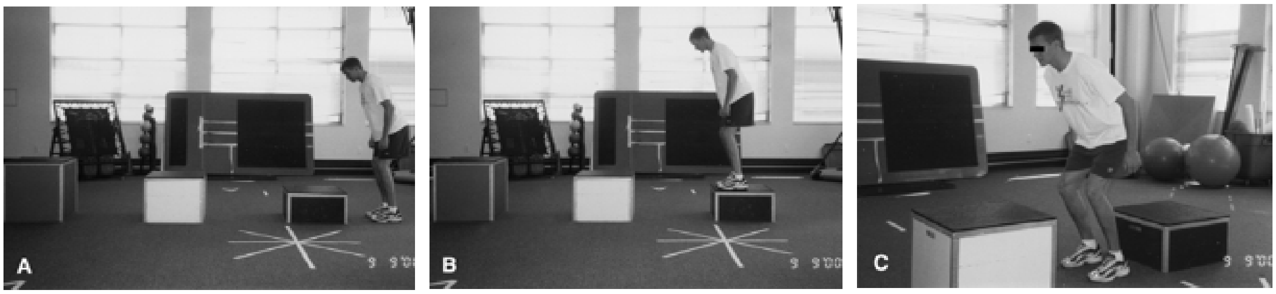

FIG. 3 Lower extremity plyometrics. Plyometric box jumps are shown demonstrating movement from concentric shortening power phase (**A**) to eccentric deceleration prestretch phase (**B**) that prepares the athlete for the next plyometric jump (**C**).

FIG. 4. Core exercises. **A**: Two-hand side throw with trunk rotation. **B**: Two-hand plyometric sit-ups.

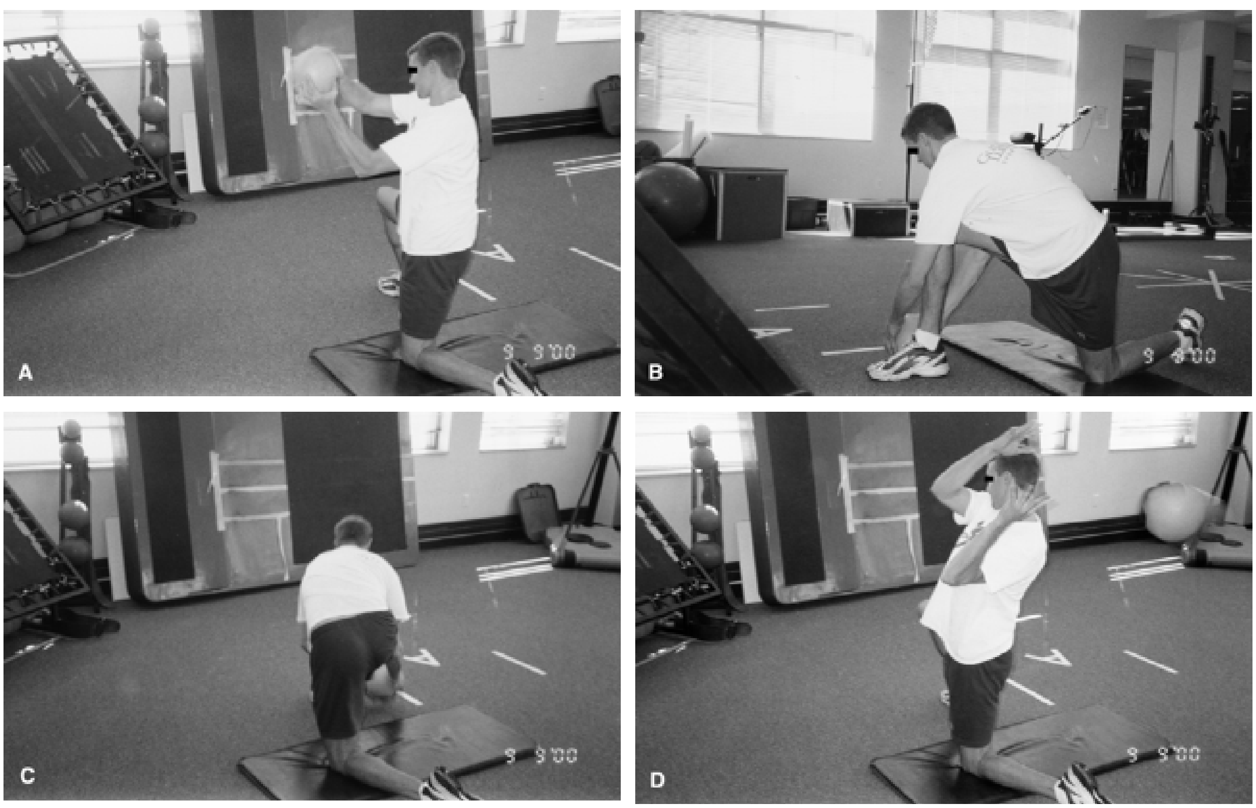

FIG. 5. Core exercises. **A-B**: Two-hand eccentric deceleration trunk rotations (also causes an eccentric deceleration pre stretch to the scapulothoracic and posterior glenohumeral muscles). **C-D**: Two-hand concentric shortening power phase.

FIG. 6. Total body. **A**: Two-hand chest pass. **B**: Two-hand overhead soccer throw. **C**: One-arm total throwing motion simulation.

generated by the shoulder are actually produced by the summation of forces originating from the legs.[6,7,9,14] Developing the explosive power through plyometrics for the lower extremities and trunk are an important component to also facilitating the performance in the upper extremities. Consequently an example of commonly used lower extremity plyometric box jumps are illustrated in Figures 3A–C.

Figures 4, 5 illustrate various plyometric exercises that can be incorporated to enhance core power training. Figure 5 is a two-hand side throw with trunk rotation which utilizes core stability training along with transferring the energy through the kinetic chain to the shoulders and upper extremities.

Core stability training can be developed with plyometric sit-ups in the sagittal plane as well as adding transverse plane rotations with the sit-up maneuvers as demonstrated in Figure 4B.

The plyometric movement employs the stretch-shortening cycle as the total motion. In Figures 5A–B, an excellent eccentric prestretch to the core, scapulothoracic and glenohumeral muscles occurs with the movement demonstrated in 7a, followed by the concentric shortening phase of the same muscles in 7b.

To integrate total body patterns into the plyometric drills involves exercise initiation from a safe starting position such as the two-hand chest drills in Figure 6A. This is a safe position because it does not stress the anterior capsule in the overhead athlete that oftentimes has excessive laxity. In addition, keeping the arms below shoulder level does not aggravate any conditions affecting the rotator cuff. Consequently this is one of the safer exercises to begin using to develop the plyometric movement without exacerbating any signs or symptoms with a patient during the rehabilitation process.

A progression for the overhead athlete is to progress the plyometric movement into the overhead position using the soccer throw as in Figure 6B.

To use the summation of forces of the total body kinetic chain, the next progression would be to one-arm total throwing motion simulations. By using the total motion pattern it minimizes isolated stresses to the glenohumeral joint and at the same time allows for replication of sport specific overhead skills as demonstrated in Figure 6C.

An excellent plyometric training drill that can be performed safely as the progression goes from two-arm to one-arm movement patterns is the side internal rotation plyometric throws in Figure 7A-B.

Proprioceptive neuromuscular facilitation (PNF) patterns[81–83] have been used manually for years in the rehabilitation process and more recently into the condition-

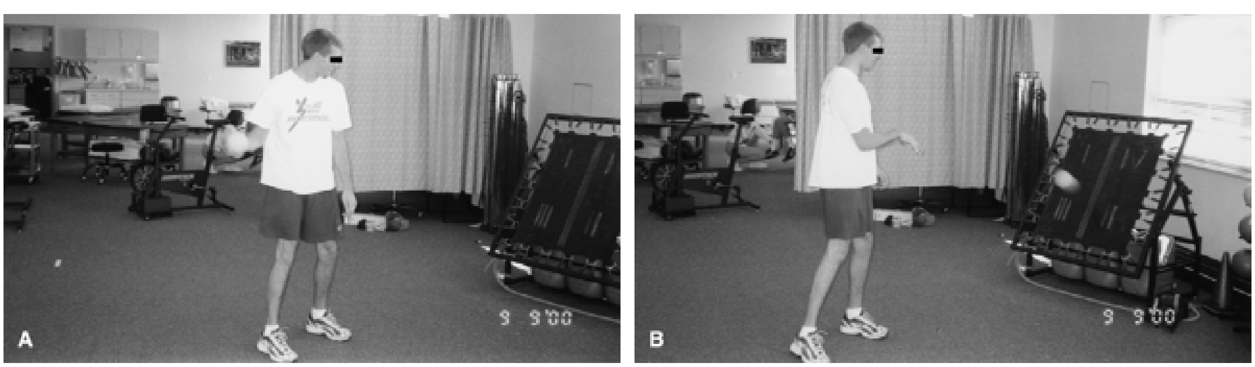

FIG. 7. Isolated glenohumeral plyometrics. **A-B**: Side internal rotation plyometric throws.

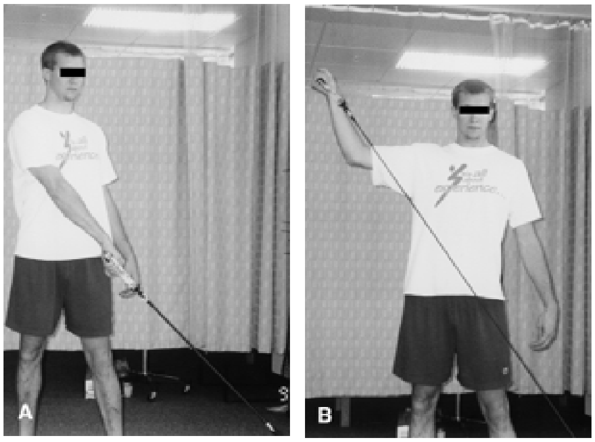

FIG. 8. Shoulder complex. **A-B**: Proprioceptive neuromuscular facilitation (PNF) patterns using Thera-Band (The Hygenic Corporation, Akron, OH, U.S.A.).

ing phases. PNF has used many of the concepts of plyometrics from the beginning such as the quick prestretch to facilitate the muscle recruitment. In conditioning for the overhead athlete, PNF patterns use the principles of plyometrics along with the functional specificity of replicating the various movement patterns incorporated in sports. Figures 8A,B demonstrate the use of Thera-Band (The Hygenic Corporation, Akron, OH, U.S.A.) in a D-2 pattern incorporating the plyometric concepts.

In the progression of rehabilitation, the concept of whole-part-whole is appropriate.[3,9,40] Therefore, variations of total body activities have been demonstrated with the aforementioned plyometric activities, and now the progression is to focus on isolated components parts to optimize their rehabilitation before integrating them back into the total functional pattern. Having the athlete perform one-arm throwing simulations without using the legs and the trunk permits focused rehabilitation. Figure 9 is an example of this type of activity.

During the progression of rehabilitation oftentimes necessitates the isolation of a muscle to optimize its function. If a muscle does not function normally in an isolated pattern, then it cannot function normally in a functional pattern. Consequently, performing isolated plyometric drills designed specifically for the glenohumeral joint are often appropriate components of a total rehabilitation or training program. Figure 10 demonstrate examples of isolated glenohumeral plyometric training. One of the more perplexing decisions to be made when rehabilitating the overhead athlete is when to progress them from resistive or plyometric activities that have been performed below the shoulder level up to the 90°/90° position. There has been no research to demonstrate when the athlete achieves a certain percentage of muscle strength based on objective dynamometer testing at the neutral position that he/she can safely progress to the overhead position. Consequently, it becomes an empirically based clinical experience decision. Over the years, probably all clinicians have recommended that a patient progress to the overhead position in their training just to have them develop a reactive tendonitis, synovitis, etc. which sets the rehabilitation program back. When progressing to the 90°/90° functional overhead position, many times the patient develops symptoms in the supraspinatus area, mimicking a tendonitis or impingement syndrome response. Part of the reason for this is probably because the supraspinatus is being asked to function in a shortened position on the muscle-tendon length-tension curve and it has limited capacity for shortening and developing muscle force. As a result of being in the shortened position, the supraspinatus has to work harder to try to dynamically control the glenohumeral joint. This overuse creates an inflammatory reaction to microtrauma. To attempt to minimize this iatrogenically produced microtrauma, we use a Shoulder Horn (Power Systems, Knoxville, TN, U.S.A.) as part of the progression from exercising at the side to the 90°/90° overhead position. The

FIG. 9. Shoulder complex. **A**: One-arm throwing motion simulation (cocking position). **B**: Acceleration phase. **C**: Follow-through phase.

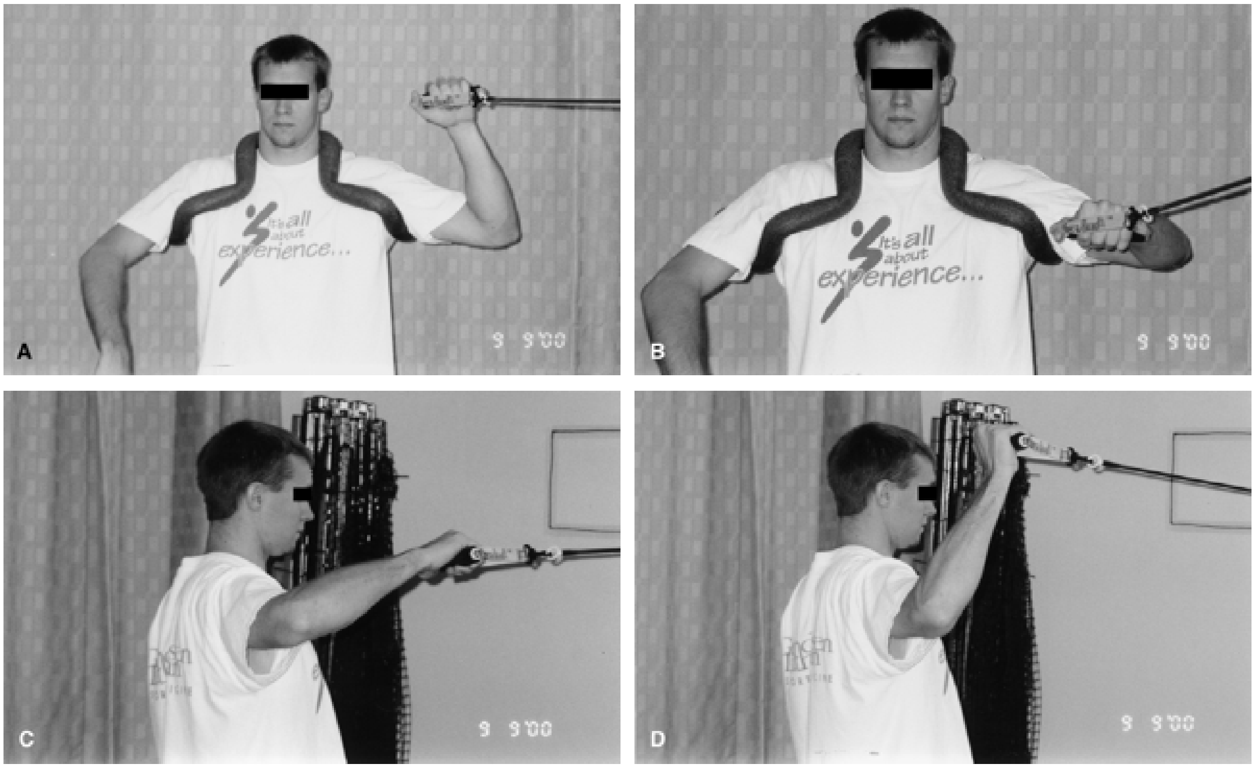

FIG. 10. Isolated glenohumeral plyometrics. Thera-Band external (**A**) and internal (**B**) rotation with the Shoulder Horn (Power Systems, Knoxville, TN, U.S.A.). Thera-Band internal (**C**) and external (**D**) rotation without the Shoulder Horn.

Shoulder Horn provides mechanical support and stability to the supraspinatus and glenohumeral joint and relieves some of the pressure from the muscle-tendon unit. Our empirical clinical experiences during the last several years with the use of the Shoulder Horn has minimized the reactive tendonitis we saw before. Moreover, the Shoulder Horn has allowed us to progress our patients faster with fewer setbacks. Figure 10A,B demonstrated Thera-Band training of the glenohumeral joint for isolated internal and external rotation with the Shoulder Horn.Figure 10C,D illustrate the progression of the same exercises without the additional support of the Shoulder Horn.

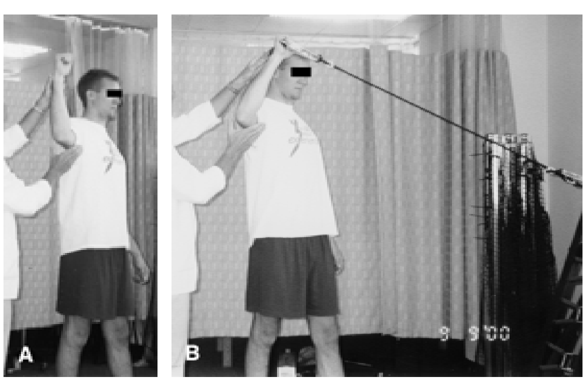

FIG. 11. Isolated glenohumeral plyometrics. **A**: Perturbation training. **B**: Thera-Band resistance for glenohumeral external rotation with superimposed perturbation training.

Figure 11A demonstrates examples of rhythmic stabilization or perturbation training that is often performed at different parts of the ROM of the shoulder joint. The purpose of the perturbation training is to enhance the proprioceptive/kinesthetic abilities of the receptors around the joint. This in turn should translate into more effective neuromuscular reactive training.[3,9,38,40]

FIG. 12. Isolated glenohumeral plyometrics: 90°/90° throwing plyometric drill.

FIG. 13. Isolated glenohumeral plyometrics: retro-throwing drill. **A**: Eccentric prestretch position. **B**: Concentric acceleration phase. **C**: Release. **D**: Follow through.

When working with many patients in overhead sports, there is a laxity in the anterior inferior capsule. As a result, the rehabilitation program using resistive training, PNF, reactive neuromuscular training and plyometrics is designed to create dynamically stability of the joint to compensate for the non-contractile laxity.[3,84] We utilize the concept of contra-coup neuromuscular training.[84] Therefore, creating a posterior dominant shoulder by increasing the unilateral ratio of muscular power of the posterior muscles is one of the goals of the rehabilitation program with this patient.[3,84] In the normal unilateral ratios of the glenohumeral internal rotators to external rotators is approximately 3:2 through the velocity spectrum. Our operational definition of the posterior dominant shoulder is to increase the posterior muscles relative to the anterior muscles by approximately 10% thereby changing the unilateral ratio to 4:3. In Figure 11B, the patient needs to perform the contraction of the posterior shoulder muscles (posterior dominant shoulder) while perturbation training (neuromuscular reactive training) is superimposed on the contractions.[3,7,9,76,85–88]

Figure 12 demonstrates the classic isolated glenohumeral plyometrics drills being performed in the 90°/90° position. This allows for the isolated training of the movement pattern.

Similar to the concept discussed in the training drill illustrated in Figure 11A, if the emphasis is to develop a posterior dominant shoulder and to work on the eccentric deceleration component that occurs in almost all overhead activities, the isolated retro-throwing drill can be incorporated as illustrated in Figure 13A–D.

SUMMARY

This article has provided an overview of the application of plyometrics for the overhead athlete. Peak athletic performance in the overhead athlete depends on combining high speed and large muscular forces, i.e. power, into a sports specific task. In the past, rehabilitation programs have attempted to return the athlete to competition using resistance training alone in an attempt to maximize power. However, because power is a combination of strength and speed, goals of increased power must incorporate both exercises that incorporate large muscular forces as well as decreasing the time in which these forces are generated. Plyometric drills for the upper extremity offer the clinician a means to increase athletic power and improve sports specific demands. Although the effects of plyometrics training require further investigation and research, the rehabilitation specialist can safely progress a patient using periodization, functional testing, clinical guidelines, and common sense.

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