

CURRENT CONCEPTS OF PLYOMETRIC EXERCISE

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ABSTRACT

As knowledge regarding rehabilitation science continues to increase, exercise programs following musculoskeletal athletic injury continue to evolve. Rehabilitation programs have drastically changed, especially in the terminal phases of rehabilitation, which include performance enhancement, development of power, and a safe return to activity. Plyometric exercise has become an integral component of late phase rehabilitation as the patient nears return to activity. Among the numerous types of available exercises, plyometrics assist in the development of power, a foundation from which the athlete can refine the skills of their sport. Therefore, the purpose of this clinical commentary is to provide an overview of plyometrics including: definition, phases, the physiological, mechanical and neurophysiological basis of plyometrics, and to describe clinical guidelines and contraindications for implementing plyometric programs.

Keywords: Amortization, plyometric, rehabilitation, stretch shortening cycle

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INTRODUCTION: AN OVERVIEW OF PLYOMETRICS

There are as many strength and conditioning programs as there are individual clinicians developing the programs. Rehabilitation programs have dramatically changed over the past several years. Regardless of the purpose of the program, whether it is used in the terminal phases of rehabilitation,¹ for strength and conditioning, or for performance enhancement, plyometric exercise should play an integral part of the program. An important part of performance-based rehabilitation programs is the development of power often addressed by using plyometric exercises. Sports physical therapists strive to prevent injuries, rehabilitate injuries in a timely manner in order to rapidly return athletes back to activity, improve the strength and conditioning of athletes, and facilitate the specificity of sports performance. Because of this there is an increasing demand to progress performance as quickly as possible. Plyometrics may be incorporated as an integral component of an exercise program that can produce all the aforementioned outcomes. As tremendous forces are imposed on the extremities during sports and athletics, there is a huge demand to develop power during the performance phase of rehabilitation. The concepts of specificity of rehabilitation and the SAID (Specific Adaptation to Imposed Demands) principle imply the need for periodization programs to be incorporated in the terminal phases of rehabilitation, as well as conditioning and performance programs. Of the numerous types of available exercises, plyometrics assist in the development power, a foundation from which the athlete can refine the skills of their sport. Therefore, the purpose of this clinical commentary is to provide an overview of plyometrics including: definition, phases, the physiological mechanical and neurophysiological basis of plyometrics, and to describe clinical guidelines and contraindications for implementing plyometric programs.

PHASES OF PLYOMETRICS

Why should plyometric exercises even be used for rehabilitation or performance enhancement in sports? Both lower extremity (LE) and upper extremity (UE) sports use the plyometric concept as part of functional movement patterns and skill when performing the sport. Plyometric training utilizes the *stretch-shortening cycle* (SSC) by using a lengthening

movement (eccentric) which is quickly followed by a shortening movement (concentric).²⁻¹⁶

Eccentric Pre-Stretch

The eccentric pre-stretch phase has also been described as the readiness, pre-loading, pre-setting, preparatory, facilitatory, readiness, potentiation, counter-force, or counter-movement phase. The eccentric pre-stretch phase of a plyometric activity stretches the muscle spindle of the muscle-tendon unit and the non-contractile tissue within the muscle (series elastic components [SEC] and parallel elastic components [PEC]). This stimulation of the components of the muscle is often referred to as the neurophysiological-biomechanical response. Several researchers¹⁷⁻²⁴ have demonstrated this eccentric pre-stretch will enhance the resultant concentric muscle contraction. The pre-stretch phase is predicated on three stretch variables: magnitude of the stretch, rate of the stretch, and duration of the stretch.¹⁷⁻²⁶ Manipulating any of these variables will have a significant effect on the amount of energy stored during the eccentric pre-stretch motion.

Amortization Phase (Time to Rebound)

The term *amortization* has been developed to describe the time from the cessation of the eccentric pre-stretch to the onset of the concentric muscle action. Authors of this manuscript prefer to use the term "*time to rebound*". This phase is also frequently referred to as the electro-mechanical delay phase of plyometrics. The amortization phase is the time delay between overcoming the negative work of the eccentric pre-stretch to generating the force production and accelerating the muscle contraction and the elastic recoil in the direction of the plyometric movement pattern.¹⁵⁻²¹ This phase is the key to the performance of plyometrics, because the shorter the amortization phase the more effective and powerful is the plyometric movement because the stored energy is used efficiently in the transition. If the amortization phase is delayed, the stored energy is wasted as heat, the stretch reflex is not activated and the resultant positive work of the concentric contraction is not as effective.²⁷ One of the primary goals of plyometric training is to decrease the time to rebound phase.

Concentric Shortening Phase

The concentric phase can also be referred to as the resultant power production performance phase. This

phase has also been described as the facilitated or enhancement phase of plyometrics.²⁷ These terms actually describe what happens during the plyometric activity. This final phase of the plyometric movement results from many interactions including the biomechanical response that utilizes the elastic properties of the pre-stretched muscles.²⁸⁻³⁰

The blending of these three phases to perform a plyometric movement is used to enhance the muscle's power performance.^{17,18,30} Designing the periodization programs^{31,32} and execution of the actual plyometric drills described later in this article is what makes these exercises so effective in performance enhancement.

EXAMPLES OF PLYOMETRICS IN ATHLETICS

This rapid deceleration-acceleration produces an explosive reaction that increases both speed and power of the limb during athletic activities.³³ This explosive reaction facilitates the production of maximal force in the shortest amount of time.^{34,35} Plyometric training is often considered the missing link between strength and return to performance.³⁶ An example of the SSC is illustrated during the overhead pitching motion. When the pitcher goes into the late cocking position, the muscle spindle and the PEC and SEC of the shoulder internal rotator muscles are pre-stretched, in order to enhance the acceleration phase of the pitching motion. The necessity of plyometrics for the shoulder complex can be illustrated in the context of the incredible demands placed on the shoulder with different sporting activities. For example, overhead throwing produces angular velocities that exceed 5000-7000 degrees per second,³⁷ which makes the SSC necessary to help generate the forces required. With a short amortization phase, the time from the cessation of the eccentric pre stretch to the onset of the concentric muscle action, the SSC permits stretching (eccentric lengthening) to contribute to the maximal explosive shortening (concentric contraction).

The follow through phase of the throwing motion actually generates the highest electromyographic (EMG) activity of the posterior shoulder complex as well as the core stabilizers and the scapulo-thoracic muscles.³⁸ Volleyball players and tennis players use

an abbreviated cocking motion to strike the ball, but still use the SSC during their functional tasks. Baseball or softball pitching motions are movements with a controlled plyometric movement, whereas the volleyball and tennis motions are usually reactive movement patterns, which occur more quickly. The other common overhead activity is swimming which actually involves more repetitions in the overhead position than most other sports; however, swimming involves minimal ballistic plyometric movements.

There are many examples of plyometric activities in the lower extremities, such as running, jumping and kicking. The angular velocities of the knee have been recorded at around 1,000 degrees/second.^{39,40} With each foot contact, there is an eccentric stretch followed by the concentric shortening contraction. Jumping, cutting and pivoting activities occur in almost all sports and each has plyometric demands, thus the concept of power development is the key for many activities of daily living, work related activities, recreational, and competitive sports.

Realizing the fast angular velocities and tremendous forces required in various activities of daily living and sporting activities, illustrates the need for plyometric training in preparing the patient or athlete for return back to their activities. Rehabilitation and conditioning programs are designed to return patients and athletes back to their respective activities as safely and quickly as possible based on functional specific activities. Plyometric exercises should play a critical role in this important role to develop power for performance.

DEFINITION

Plyometrics have been used for many decades in the Russian and eastern European training of track and field athletes.^{2,3,5-7, 37,41-44} Verkhoshanski,⁴⁵⁻⁴⁶ a well-known track and field coach in Russia, began the concept that he referred to as shock training or jump training. However, former Purdue University women's track coach Fred Wilt first coined the actual term plyometrics in 1975. The word plyometrics is actually a derivation from the Greek words *plythein* or *plyo*, which means to increase and *metric*, which means to measure. Consequently, the purpose of plyometrics may be thought of as "to increase the

measurement.” Typically the measurement is sports performance outcomes demonstrated in testing or competition such as throwing, serving velocity, jump height or sprint speed.⁴⁷⁻⁴⁹

SCIENTIFIC FOUNDATION FOR THE APPLICATION OF PLYOMETRICS

Physiologic Basis

The contractile component of the actin and myosin cross bridges with the sarcomere plays an important role in motor control and force development during plyometrics. The plyometric movement uses the pre-stretch of the muscle-tendon unit physiological length-tension curve in order to enhance the ability of the muscle fibers to generate more tension and resultant force production.^{15,27} Biomechanically “priming” the muscle is supported by the work of Elftman.⁵⁰ The Elftman proposal simply states that the force production of muscle is arranged in a predictable hierarchy. This orderly format is that eccentric muscle contractions create the most force, followed by isometric contractions and then concentric contractions. Concentric muscle contractions therefore, are actually the weakest of the three modes of muscle actions. However, plyometrics create the greatest forces during the concentric power production phase. It is for this reason that the eccentric pre-stretch and the short amortization phases are so critical for the optimum power development in a muscle.

However, whenever an eccentric muscle action occurs, there is concern for the development of delayed onset muscle soreness (DOMS).^{14,15,57} DOMS will always occur in the skeletal muscles following an unaccustomed eccentric exercise. When a maximal eccentric muscle action occurs, it generates 10-40 percent more force than concentric contractions. The reason it generates more force is because during the eccentric muscle action the SEC and PEC are being stretched which generates more force (than during concentric), which in turn causes microtrauma to the connective tissue. The microtrauma to the SEC and PEC releases hydroxyproline which creates a noxious stimulus to the muscles and that creates the participants perception of the DOMS response.⁵²⁻⁵⁷ Therefore, it is important to inform the athlete when starting a plyometric program they will experience a DOMS response.¹⁵

It is critical to explain to the athlete that DOMS is a self-limiting conditioning and usually resolves in approximately 7-10 days. If the participant is a highly trained athlete, due to a repeated bout effect, they will not usually experience a DOMS response.⁵⁸ The education of athletes about DOMS is important when implementing plyometrics into the terminal phases of a rehabilitation program or into a performance enhancement 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. Slow twitch (ST) fibers are typically recruited at sub-maximal intensity efforts, and then as the intensity increases, the fast twitch (FT) IIa fibers are recruited at approximately 30 percent up to about 80 percent of maximal intensity. At approximately 70-80 percent intensity, the fast twitch IIa, IIb fibers are then recruited. Thus, plyometrics need to be performed with high intensity efforts, above 80 percent, to recruit the fast twitch fibers that are crucial to power development. FT muscle fibers respond better to high-speed small amplitude pre-stretch, therefore, specificity of rehabilitation and performance enhancement via specific exercises, intensity, sets and reps, are important in the design and execution of specific exercises.^{15,26,59,60}

Lovering⁶¹ performed muscle biopsies of the rotator cuff and found the muscles to be comprised of approximately 55-60 percent FT fibers. Furthermore, Irlenbusch⁶² performed muscle biopsies of the rotator cuff in patients with rotator cuff injuries and found that the FT fibers were most affected. Consequently, when trying to selectively activate FT fibers in rehabilitation or performance enhancement the therapist needs to perform activities to recruit the FT muscle fibers. There are generally three ways to recruit FT fibers: 1) maximum intensity effort, 2) electrical stimulation, and 3) fast movement patterns like plyometric exercises.

Mechanical Basis

Muscles function in various sporting activities as force production generators, and eccentric decelerators/shock absorbers primarily due to the active and elastic properties within the muscles.⁶³ These elastic proper-

ties form the mechanical basis of muscle mechanics and are due to the three structural components within the muscles: contractile components (CC), SEC, and PEC.¹⁸⁻²⁰ All three of these components interact with one another to produce force output. The mechanical behavior of the SEC is a major contributor in the plyometric action. Increased force generation during the concentric phase of the plyometric movement occurs from the mechanical elastic issue loading. During the pre-stretch motion, potential kinetic energy is stored in the SEC. This stored energy then contributes to the concentric force production as the muscle returns to its normal length. This is referred to the rebound force response. The SEC acts like a spring, where 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.^{22,23,64} The SEC accounts for 70-75 percent of the concentric force increases of muscle thereby making the plyometric training very efficient.⁵¹

Neurophysiological Basis

The proprioceptors of the body include the muscle spindle, the Golgi tendon organ (GTO), and the mechanoreceptors located in joint capsules and ligaments. Stimulation of these receptors can cause facilitation, inhibition, and modulation of both agonist and antagonistic muscles.^{7,65-67} When the muscle spindle is stretched, there is an increase in afferent nerve firing. 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 neurological signal sent from the muscle spindle, and as a result, the greater the efferent muscle contraction (the shortening cycle of the plyometric movement). The other mechanoreceptor that plays a significant role in the plyometric stretch-shorten cycle is the GTO. The function of the GTO is to act as a protective reflex preventing over-contraction or too much tension in the muscle. Thus, the GTO assists with modulating forces during plyometric exercises. Consequently, the purpose of plyometric training is to increase the excitability of the neurologic receptors for improved reactivity of the neuromuscular system while desensitizing the GTO.⁶⁶⁻⁶⁹ Explosive plyometric exercises may improve the neural efficiency through enhancement of neuromuscular coordi-

nation. Therefore, plyometric training increases neuromuscular performance by increasing the set speed in which the muscles may act. Ultimately this mechanism results in the enhancement of the neurologic system to allow neuromuscular coordination to become more automatic.⁶⁸

THEORETICAL TRAINING BENEFITS OF PLYOMETRIC EXERCISES²⁸

The potential and theoretical training benefits of plyometric exercises for the upper and lower extremities include, but are not limited to the following concepts: ability to increase average power and velocity; increased peak force and velocity of acceleration; increased time for force development; energy storage in the SEC; the ability for heightened levels of muscle activation; and the ability to evoke stretch reflexes.⁷⁰⁻⁷⁶

By desensitizing the GTO, plyometric exercises allow muscles to generate 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 creating automation of activity, which improves neural efficiency and increases neuromuscular performance. The increase in performance often occurs without a concomitant increase in morphological changes within the muscle.⁷⁷ This training effect of the neural system predominates in the first six to eight weeks of any training program,⁷⁸ and then after several additional weeks, hypertrophic changes of the muscles begin to occur.

CLINICAL GUIDELINES WHEN BEGINNING A PLYOMETRIC PROGRAM

As a plyometric training program is initiated, there are some general considerations and guidelines that should be considered:^{1-7,27,41,42,79,80} the age of the patient or participant, the injury history, the type of injury, appropriate warmups before beginning the actual plyometric drills, foundational strength, and resistance training experience.

Although there are some empirically based guidelines for initiating plyometrics in the LE, there are no scientific or evidence-based guidelines that serve

as criteria for beginning an UE plyometric training program in a rehabilitation setting.⁸¹ Specific recommendations will be made for a testing hierarchy for initiating both UE or LE plyometrics in the following sections. Davies and Matheson²⁷ indicate clinicians should make the training specific to the individual goals of each patient. The authors of this manuscript believe that each specific movement pattern involved in the activity should be trained initially in isolation to work each kinematic chain link, allowing the sports activity to be dissected into smaller components and trained with isolated movements first. Then, smaller components can be integrated back 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. The authors of this manuscript feel that plyometric training should 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. One way to design the program is through the application via the periodization model.

PERIODIZATION PROGRAM AND TRAINING COMPONENTS

Periodized training, in essence, is a training program that changes the workouts at regular intervals of time.^{7,31,32} For a full review of periodization training readers should refer to the paper by Lorenz as a part of this special issue. The plyometric program should use the principles of progression and overload. This can be accomplished by manipulating the volume dosage (reps, sets, weight, etc.) of many different variables. The quality of the work is more important with plyometrics than the quantity of the work. In order to recruit the fast twitch fibers, the intensity of the work should be performed at high levels of intensity 80-100% maximum volitional contraction (MVC). Additionally the rate of the muscle stretch is more important than the length of the stretch. During the training session, if the quality of the movement performance deteriorates and is not able to be performed correctly, then the athlete is probably experiencing fatigue and the plyometric portion of the exercise session should be terminated. Based on

the rest, recovery and reparative phase following high intensity resistive plyometric exercises, there should be increased recovery time when compared to other types of exercise. Although no evidence exists regarding the optimum rest period between high intensity plyometric workouts, the authors recommend 48-72 hours between sessions.

CLINICAL GUIDELINES FROM THE LITERATURE

There is no consensus in the published literature on the specific criteria, parameters, guidelines, specific exercises, or principles of progression that should be used during plyometric training. Most of the recommendations are empirically based upon Level 5 evidence with minimal scientific research supporting any of the recommendations. For example, Chu^{3,8,9,41,80} recommends the typical plyometric exercise program using a medicine ball should follow the concept of periodization with training occurring in the following order: preseason general body conditioning, beginning of a season sport-specific conditioning, and in-season sport specific maintenance. Wilk, et al^{12,82,83} disagrees and recommends plyometrics be used only in the first and second preparation phases of training according to the periodization model.

DESIGNING A PLYOMETRIC PROGRAM: TRAINING VARIABLES TO CONSIDER^{27,84,85}

Neuromuscular Overload: Applied Loads and Distances

With plyometric exercises, neuromuscular overload usually takes the form of a rapid change of direction of a limb or the entire body without external loads. The amount of total work in repetitions, sets, etc., and/or the range of motion (ROM) the athlete moves through both contribute to the total overload amount.

Spatial Overload: Range of Motion

Movements can have the effects of overload from the standpoint of ROM. The ROM can be performed throughout a larger range via an exaggerated movement pattern. The concept is to employ the muscle activation and stretch reflex within a specific ROM. As previously described, the reflex mechanisms help facilitate the movement pattern to enhance the 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 time to rebound (amortization phase) as short as possible, is one of the keys to performing plyometric exercises for increased power production. A shorter time to rebound and electro-mechanical delay allows for effective force transmission from the eccentric pre-stretch to the concentric power performance phase of the plyometric movement.

Intensity

Intensity is the actual percentage of effort required by the athlete to perform the activity. In plyometrics, the type of exercise performed controls the intensity. Plyometric exercises can come in many forms and intensities. Some activities such as bilateral jumping to a box are lower level plyometrics while others such as single leg jumps from a box are intense. These variables 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 calculating the load, counting the number of repetitions, sets, etc. of the specific activity (number of throws, jumps, etc.) Fifty foot contacts during a training session would be considered low volume, while 200+ would be considered high volume. Volume should be increased in a progressive manner to decrease risk of injury or overtraining.

Frequency

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

Recovery

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

Specificity

Specificity in a plyometric program should be designed dependent upon the athletes sport and position whenever possible to enhance the specific goals of the program and to replicate the athletes given sport specific activities. Specificity in plyometric training could include motions, angular velocities, loads, metabolic demands, etc.

CONTRAINDICATIONS FOR PERFORMING PLYOMETRIC EXERCISES

Examples of contraindications for using plyometrics include, but are not limited to: pain, inflammation, acute or sub-acute 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 foundational strength or training base upon which a plyometric program can be built. If an athlete does not meet the minimum criteria in regards to foundational strength or training base that have been delineated, then the coordination and motor control may not be present to progress the subject or patient to high demand plyometric exercises.

LOWER EXTREMITY PLYOMETRIC EXERCISE

Competitive sports and recreational activities often require athletic movements that combine both strength and speed to create the byproduct known as power. For years, numerous clinicians including strength and conditioning specialists, performance enhancement coaches, and athletic trainers have sought ways to increase power in order to enhance performance. More recently sports physical therapists have begun to utilize these techniques to prevent injuries and improve performance during rehabilitation.¹ In an effort to return athletes to play at the highest levels, rehabilitation professionals also have come to rely on the use of plyometric exercises. In the LE, plyometric exercises are often performed through jumping, bounding, and hopping.

EVIDENCE FOR LOWER EXTREMITY PLYOMETRIC EXERCISE

There are numerous studies that have established the effectiveness of plyometric exercises in improving power and performance in the lower extremities.

Evidence for the use of plyometric exercises in the LEs is available with regard to enhancement of performance in uninjured subjects and also in those with injury or previous injury. Numerous authors have described increased jump height, sprint time reduction, improved running economy and improved joint position sense and postural control as a result of LE plyometric training.

JUMP HEIGHT

Multiple authors have demonstrate that plyometric training programs can increase maximal vertical jump height.⁸⁶⁻¹²⁷ These studies included various jump training programs ranging from six to 24 weeks, including pre-pubertal, pubertal, and adult athletes. A variety of jump training tests have been measured to evaluate improved vertical jump height including squat jumps (Figure 1), split squat jumps (Figure 2), bounding (Figure 3), countermovement jumps with and without arm swings, and drop jumps (Figure 4). More advanced techniques include tuck jumps (Figure 5), depth jumps (Figure 6), and single-leg hops (Figure 7). To achieve improved jump heights training has been anywhere from one to five

sessions per week or tallied as total training sessions from six to greater than 25 sessions. Volume of jump training has ranged from 400-1700 jumps. Despite the large variety of variables that have been manipulated within these studies, improved vertical jump performance is a consistent outcome after plyometric training.

SPRINT SPEED

Plyometric training of the LEs been shown to increase sprinting speed or velocity.^{95,99,111,128-142} Sprinting velocity is important for sports requiring quick bursts of speed or repetitive change of direction. This is valuable for sports like soccer, handball, volleyball and tennis. These studies included various forms of plyometric training ranging from three to 12 weeks in duration. Weekly dosage ranged from once per week to four times per week at most. Volume of greater than 80 jumps per session seem to result in the greatest benefit.^{95,99,128-142} One consistent finding is that sprint performance improvement was not found to be significantly greater when plyometric exercises are performed combined with other types of exercises (such as plyometrics + weight training) as compared

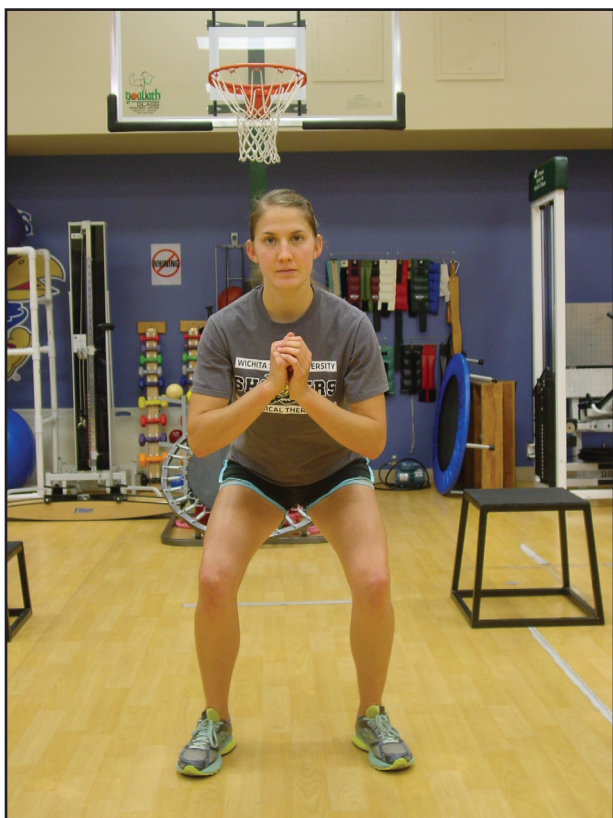


Figure 1. Squat jumps



Figure 2. Split squat jumps



Figure 3. *Lateral bounding*

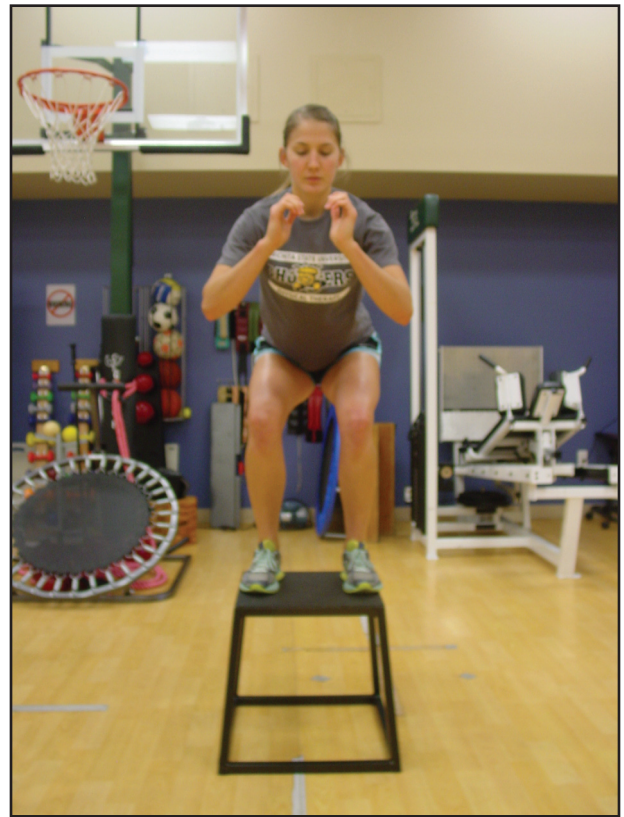


Figure 5. *Jumping to box*



Figure 4. *Tuck jumps*



Figure 6. *Depth jumps*



Figure 7. *Single leg hops*

to when they are performed alone. Lastly the effects of plyometric training for sprint-specific programs appear to be the greatest over initial portion of a sprint (10-40 m) as compared to longer distances (>40 m). These results suggest that sports participants who are accustomed to sprints over distances of 40 m could still improve times by improving in the initial acceleration phase of sprinting, by adding plyometric exercises to their program.¹¹¹ Controversy exists as several authors have not shown improvements in sprint times with plyometric training.^{125,143-145}

INJURY PREVENTION

Further research has evaluated plyometric training in patients who have been injured, most specifically related to injury prevention of first time non-contact anterior cruciate ligament (ACL) injury. A growing amount of evidence exists indicating that LE plyometric exercises and training may help prevent first time noncontact ACL injuries.^{93,16,147} Hewett and colleagues have also reported that the introduction of a proper plyometric training program can increase neuromuscular control in all three planes which will decrease stress on the ACL and transfer it to the muscles, tendons and bones which allows for

improved force dispersal resulting in less torque applied directly to the knee.^{93,148} Váczi¹⁴⁹ and colleagues demonstrated the effectiveness of plyometrics in enhancing the components inherent in soccer performance such as strength, power, and agility.

LOWER EXTREMITY PLYOMETRIC IMPLEMENTATION

Not everyone in rehabilitation and sports require plyometric exercises. Based on the principles of training specificity, exercise, training and rehabilitation should as closely match the ultimate performance as possible.^{150,151} Therefore, only those patients or subjects that need explosive powerful movements for their recreational or competitive athletic activities really need to train using plyometric exercises. These types of activities generally occur at faster speeds, incur higher forces, and involve multiple planes of movement. Because general traditional exercises are not matched to the actual demands of sports performance it has been suggested that plyometric exercises can bridge the gap between rehabilitation and sports specific activities.¹⁵²

BASIC LOWER EXTREMITY PLYOMETRIC PRE-TRAINING REQUIREMENTS (TABLE 1)

Pending the athlete's present physiologic level (healthy, injured), plyometric activities may or may not be even indicated. General contraindications for plyometric training has been described earlier in this manuscript, however, specific relative contraindications to the LE include joint pathology such as cartilage and ligament injury, arthritis, bone bruises and muscle tendon injuries until tissue healing has occurred enough to allow the tissue to tolerate repetitive, rapid high compressive and shear forces that occur during lower extremity plyometric exercise.

Before initiating a plyometric exercise program, there should be a systematic functional testing algorithm developed to screen the subject or patient for the ability to participate with LE plyometrics.¹⁵³⁻¹⁵⁸ The athlete must have an adequate strength base to safely perform these higher level exercises. These criteria include full ROM, as well as adequate base level of strength, endurance and neuromuscular control to properly perform plyometric exercise without symptoms or risk of injury. This article will describe several tests and methods that can be used

Table 1. Suggested testing algorithm for preparation for plyometric training

Tests & Methods	Specific Criteria
Pain	None in lower extremities
ROM	Full ROM of all joints
Swelling	None
Balance-Eyes open	30 seconds
Balance-Eyes closed	30 seconds
Muscle strength	20% bilateral comparison
Muscle endurance	20% bilateral comparison
Neuromuscular control	Qualitatively good movement patterns with no compensations
Single-leg half squat	No pain and good qualitative movement patterns
Free weight squat: 1.5 to 2.5 times body mass	No pain and good qualitative movement patterns
Squat 60% of body mass 5 times within 5 seconds	No pain and good qualitative movement patterns
Lower level plyometric drills	No pain and good qualitative movement patterns

to determine readiness but it must be remembered that there is never a good substitute for sound, practical clinical judgment during assessment of any athletic patient, healthy or injured. This is especially important because guidelines for initiating plyometric exercises during rehabilitation and in general healthy population have been not clearly described. Ability to perform a 30-second single leg stance with eyes open and closed has been recommended by Voight and Tippett¹⁵⁹ before initiating a LE plyometric program. Voight and Draovitch¹⁶⁰ also describe assessment of a single-leg half-squat that can additionally be evaluated. Wathen⁷ suggests LE plyometric activity should be initiated only after achieving minimum strength levels including the ability to perform a full, free-weight squat 1.5 to 2.5 times body mass and/or squat 60% of body mass five times within five seconds. If strength is not adequate to perform these tests it is recommended that the athlete continue to work on adequate technique and strength training and delay plyometric activity until an adequate strength base is met.³⁶

LOWER EXTREMITY PLYOMETRIC PROGRESSION

Because of the amount of stress created in even lower level plyometric activities, many exercises are not appropriate for early phases of rehabilitation or those individuals who may be deconditioned.¹⁶¹ Certainly before initiating higher level jump training, lower level plyometric or plyometric type activities can be used to test the athlete's tolerance. A progression of plyometric intensity is always prudent, especially in those returning to activity from previous injury. Plyometric drills should be progressed from low – medium – high. Generally two legged drills are a good starting point for low to medium intensity drills. Forward, backward and lateral step ups and downs from progressively increasing heights are a good first step and provide low intensity stimulus in a plyometric fashion. Controlled testing of limbs can be performed by using shuffling, and carioca drills to determine readiness to advance loading. Vertical jumping and horizontal and medial to lateral bounding are a few other ways as are running and jogging in place. Running and jogging require the athlete to individually load each limb to full body weight. Table 2 describes examples of parameters that can be manipulated when designing plyometric activities and progressions for plyometric training programs. All of the variables listed need to be considered and designing and when executing a plyometric program.

General progressions of plyometric exercises for rehabilitation and conditioning are illustrated in Table 3. Additionally, progressing from general to very specific plyometric exercises can be performed.

Another important concept in plyometric progression is volume of exercise. During LE plyometric exercise and training this is typically achieved through total foot contacts. Recommended total foot contacts for various levels of athletes have been recommended by Chmielewski and colleagues¹ (Table 4).

Furthermore, volume via foot contacts can also be determined based on general exercise intensity (Table 5).

Examples of the progression of LE plyometric exercises are divided into beginner, intermediate and advanced categories for stratification into a hierarchy of training stress in Table 6.

Table 2. *Parameters that can be manipulated when designing training progressions for plyometric programs*

Repetitions
Sets
Frequency
Rest intervals (Recovery)
Intensity (Sub-maximal during the orientation or beginning phases or training, although maximal intensity plyometrics are most effective)
Duration
Pattern
Type
Progression
Weight
Resistance implement (body weight, external weight vest, weights, etc.)
Position of patient
Quality of the movement patterns
Body parts involved in the activity (isolated joint movements vs multi-joint movements)
Effects of fatigue

Table 3. *Examples of a progressions for a lower extremity and upper extremity plyometric training program*

Warm-ups
General or systemic
Specific joint related
Lower extremity (LE)/Upper extremity (UE) plyometrics
Trunk (core) stability plyometrics
Trunk flexion/extension
Trunk lateral flexions
Trunk rotations
Trunk PNF functional patterns
Total pattern plyometrics
Sport specific simulations
Jumping activities/shoulder complex activities
Bounding activities/combination glenohumeral and scapulothoracic joints
Isolated plyometrics of the primary joint
Examples include single leg hops, prone drops

Table 4. *Plyometric exercise volume (foot contacts) based on athletic ability*

Beginner	Intermediate	Advanced
80-100	100-120	120-140
Data taken from: Chmielewski, Myer, Kauffman, Tillman ¹		

Table 5. *Plyometric exercise volume (foot contacts) based on exercise intensity*

Low	Moderate	High	Very High
400	350	300	200
Data taken from: Chmielewski, Myer, Kauffman, Tillman ¹			

Table 6. *Examples of progression of plyometric activities for the lower extremity*

Beginner	Intermediate	Advanced
Squat jumps (Figure 1)	Jump and reach	Depth jumps (Figure 6)
Split squat jumps (Figure 2)	Medial and lateral jumps	Box jumps
Bilateral mini jumps	Anterior and posterior jumps	Single leg hops (Figure 7)
Skipping	Double leg tuck jumps (Figure 4)	Single leg tuck jumps
Lateral bounding (Figure 3)	Pike jumps	Drop jump to second box
Ankle bounces	Jumping to box (Figure 5)	Squat depth jump
Shuffling	Zigzag jumps	
In place jumps	Side to side push off jumps	
Single leg push off box	Step from box	

TECHNIQUE

A major consideration when training with plyometric exercise is the need to closely monitor technique. Acquisition or reacquisition of skill should occur to ensure biomechanical safety. Improper technique should not be allowed, as faulty motor patterns should not be reinforced. It could be the athlete's poor motor control that has caused problems to begin with.^{162,163} Feedback to poor performance or technique should be given immediately and continuously to increase awareness of faulty mechanics that might put the athlete at risk of injury or re-injury. Feedback can be given through verbally addressing the fault or through visual means from either a mirror or video camera recordings. Just because the athlete is able to initially perform the techniques perfectly, the clinician should not assume they have enough endurance to continue their flawless performance. When technique declines the clinician should immediately stop the activity. The goal should be for the athlete to be able to increase the volume via number of repetitions or exercises while still maintaining excellent technique.

UE PLYOMETRICS

Scientific Research Supporting UE Plyometrics

Despite the large number of studies on LE plyometrics described earlier, few studies address plyometric training and the UE: five intervention studies, three descriptive studies, three case studies and one descriptive EMG study. Many clinicians and practitioners assume that the UEs will respond to plyometric training in a similar fashion as the LEs. The authors assert that external force applied during the eccentric preload phase could need to be reduced due to the smaller mass of the UEs and the high

potential for iatrogenically causing an injury to the shoulder complex from overloading the structures in an unaccustomed position.

McEvoy and Newton¹⁶⁴ have demonstrated that medicine ball plyometric training increased throwing velocity. Heiderscheidt et al¹⁶⁵ studied untrained subjects performing plyometric training for eight weeks, however, there were no significant improvements in any outcome measures. Fortun et al¹⁶⁶ replicated the Heiderscheidt study using trained subjects and found improvements in most of the outcome measures, including improvements of isolated shoulder power of internal rotators measured with isokinetics and improvement in a throwing performance test.

Using plyometric training, Swanik et al,¹⁶⁷ demonstrated improvements in swimmers proprioception, kinesthesia, and muscle performance characteristics. Schulte-Edelmann et al¹⁶⁸ performed shoulder and arm retro-plyos did not see increases in shoulder outcome measures, however, the elbow extensors did improve in isokinetic power testing. Carter et al¹⁶⁹ used a high volume Ballistic 6 plyometric training program with a DI baseball team and found selected improvements in isokinetic shoulder power. Carter et al based his training program on the work of Pretz.^{170, 171} Gelen et al¹⁷² demonstrated that high volume UE plyometric activities benefit the service speed of elite junior tennis players. Fernandez-Fernandez et al¹⁷³ using an UE plyometric training program improved shoulder ROM and increased the tennis serve velocity. Chelly et al⁹⁵ performed an eight-week in season plyometric training program on elite adolescent handball players and found that the participants increased their ball throwing velocity.

CLINICAL GUIDELINES WHEN BEGINNING AN UE PLYOMETRIC PROGRAM

As a plyometric training program for the UE is initiated, there are some general considerations and guidelines that should be considered.¹⁷⁴⁻¹⁷⁶ Davies²⁷ indicated since there are no real guidelines for criteria to begin a plyometric training program for the shoulder, the clinician should make the training specific to the individual goals of each patient. For best results, the training program should be individualized as much as possible to the athlete and his or her sport to develop the best motor performance pattern through neuromuscular dynamic stability.^{177,178}

Plyometric training for the UE should always be preceded by and coincide with other forms of resistance and flexibility training until and 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. One way to design the program is through the application via the periodization model described earlier in the manuscript.

CRITERION-BASED RECOMMENDATIONS FOR INITIATING AN UE PLYOMETRIC PROGRAM

The authors utilize a quantitative and qualitative functional testing algorithm as a way to measure improvement, so the patient's progression can be managed through a rehabilitation program^{49,153,158,0,179-190} As an example, soft tissue healing times must be respected following the injury or surgery, the patient must not have any pain from the site of the injury or surgery, the swelling must be absent or minimal, the ROM should be within normal limits (WNL) based on a bilateral comparison and relative to normative data, proprioceptive tests need to be WNL based on a bilateral comparison and relative to normative data, manual muscle testing must be at least a 4/5 for the muscles mostly involved with the injury/surgery whereas all synergistic muscles must be 5/5, negative neurological tests, special tests should be normal without signs or symptoms, isokinetic testing should be 80% of peak torque in a bilateral comparison, the closed kinetic chain upper extremity stability test (CKCUEST) score should be within 20% of normative data (males-21 touches;

females-23 touches), and the seated shot put should be within 20% in a bilateral comparisons and relative to normative data. Because of the intensity and potential for overuse with plyometrics, these are empirically-based suggested guidelines used to determine readiness to begin an UE plyometric program. Other clinicians also have empirically-based qualitatively assessments as to when to progress a patient to a plyometric throwing program, particularly when progressing them during a rehabilitation program as opposed to a performance enhancement conditioning program. However, as evidence-based practice indicates, this is an example of when the clinician must integrate the best evidence, the patient's expectations and desires, and the clinician's experiences and expertise.

DESIGNING AN UE PLYOMETRIC PROGRAM

There are numerous considerations when designing a UE plyometric program.⁸⁵ The following aspects can be manipulated when initiating an UE plyometric program: components of the program, ROM progressions, CKC and OKC plyometric exercises, general progressions, perturbation guidelines, examples of general plyometric exercises for the athlete, specific plyometric exercises for the overhead athlete, specific guidelines for volume dosage, and examples of progressions for core stability and the overhead athlete.

When beginning an UE plyometric program following an injury or surgery, and the patient meets the criteria to initiate the program, oftentimes the plyometric program will begin by limiting the ROM using a bolster so the patient can start working on power development in a shortened ROM without compromising healing structures. Then the patient's arm can be progressed through the ROM as appropriate. Table 7 and Figures 8 through 10 offer examples of the ROM progression.

UE Plyometric exercises can be performed in both the closed kinetic chain (CKC) and open kinetic chain (OKC) positions of the UE. As an example, CKC UE plyos can be initiated in a partial weight bearing position by performing wall plyo push-ups (Figure 11) and then progressed to full weight bearing plyo push-ups, depth drop plyo push-ups, and clap push-ups (Figure 12). Moreover, the UE plyos

Table 7. Range of motion progression following an injury or surgery and the initiation of plyometric exercises.

Limited range of motion (short-arc exercises) using a bolster (Figure 8)
Limited range of motion (short-arc exercises) using table as a support (Figure 9)
Full range of motion (full-arc exercises) with patients arm off the side of the table (Figure 10)



Figure 8. Limited range of motion (short-arc exercises) using a bolster

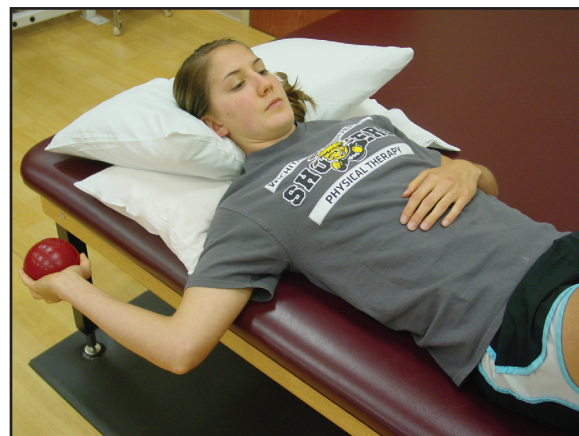


Figure 10. Full range of motion (full-arc exercises) with patients arm off the side of the table

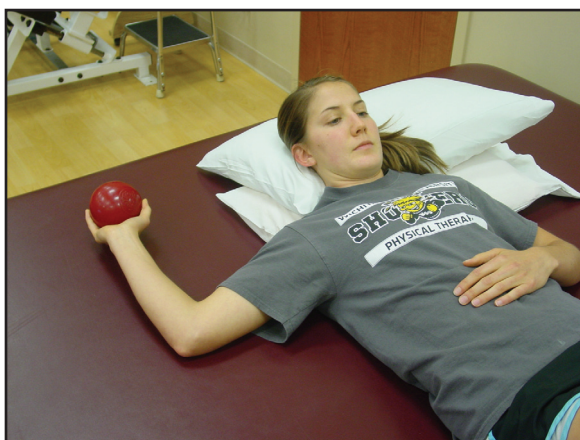


Figure 9. Limited range of motion (short-arc exercise) using table as support

can be performed in an OKC position using a progression outlined in Table 8.

General progressions of UE plyometric exercises for rehabilitation and conditioning are illustrated in Table 3. Examples of core plyometric exercises are

listed and seen in Figures 13-15. Additionally, progressing from general to very specific plyometric exercises can be performed.

Perturbation training can utilize many variables, and when performed in an alternating agonist/antagonistic movement patterns, actually mimics a plyometric motion with each perturbation. Examples of ways to perform and progress the perturbation plyo training guidelines are listed in Table 9

Progressions for training the shoulder complex from general to specific are listed in Table 10 and illustrated in Figures 16-24

If the patient is an athlete who participates in overhand throwing sports, then plyometric drills that may enhance the throwing motion due to the SAID principle are recommended. Examples of some sport

Table 8. Example of progression of upper extremity plyometric exercises from CKC to OKC positions

Closed kinetic chain (CKC) exercises-wall plyo push-ups (Figure 11)
Closed kinetic chain (CKC) exercises-plyo push-ups (Figure 12)
Open kinetic chain (OKC) exercises – multiple joints
Open kinetic chain exercises – isolated joint activity with assistance (Shoulder Horn)
Open kinetic chain exercises – isolated joint activity without assistance



Figure 11. Closed kinetic chain (CKC) exercises-wall plyo push-ups



Figure 13. Trunk flexion



Figure 12. Closed kinetic chain (CKC) exercises-plyo push-ups



Figure 14. Trunk rotations



Figure 15. Prone ER drops

Table 9. *Perturbation training guidelines*

Beginning Guidelines	Advanced Guidelines
Sub-maximal intensity	Maximal intensity
Slow movement pattern	Fast movement patterns
Know movement pattern (allows patient to preset muscles)	Random pattern (challenges subject to react to imposed demands-simulates functional activities)
Position of stability (protected/restricted ROM)	Position of less stability (higher-risk position)

Table 10. *Examples of general plyometric exercises used for rehabilitation and/or training the shoulder complex in the overhead athlete^a*

Two-hand chest pass (Figure 16)
Two-hand overhead soccer throw
Two hand rotations from side (Figure 17)
Two hand rotations from overhead (Figure 18)
Two hand rotations underhand (Figure 19)
Two hand overhead step and throw
One hand side arm throw (Figure 20)
Eccentric decelerations followed by trunk rotations and concentric tosses
Proprioceptive neuromuscular facilitation (PNF) patterns
90°/90° Baseball throw (90° GH abduction/90° GH ER) (Figure 21)
One arm eccentric deceleration follow-through movements (i.e., retro-plyos) (Figure 22)
Eccentric decelerations/concentric "flip drills" (Figure 23 and 24)
^a Many of these are demonstrated in the figures throughout the article



Figure 16. *Two-hand chest pass*



Figure 17. *Two hand rotations from side*

specific overhead throwing plyometric exercises are listed in Table 11 and Figure 22.

Based on the references^{79,191,192} the following guidelines for volume dosage are recommended when designing a plyometric program for the shoulder (Table 12).



Figure 18. *Two hand rotations from overhead*



Figure 20. *One hand side arm throw*



Figure 19. *Two hand rotations underhand*

Table 11. *Plyometric throwing motions specific to the overhead athlete.*

Total body movement pattern with throwing
Two-arms (i.e., chest toss)
One arm eccentric deceleration follow-through movements (i.e., retro-plyos) (Figure 22)
Specificity for sports performance

Table 13 demonstrates a hierarchy of UE plyometric exercises ranging from low level intensity for the beginner though intermediate to advanced or maximum intensity exertion.

SUMMARY

The purpose of this clinical commentary was to provide an overview of plyometric exercises including historical information, definitions, phases of plyometrics, and the scientific foundation for the application of plyometrics. The physiological, mechanical and neurophysiological basis of plyometrics has also been described with supporting evidence regarding its effectiveness. The theoretical basis for the use plyometrics and clinical guidelines for designing plyometric programs have been listed, with evidence support as available.



Figure 21. 90°/90° Baseball throw (90° GH abduction/90° GH ER)



Figure 23. Wrist flexor flips



Figure 22. Retro-Plyos (reverse throw) for plyometric eccentric decelerations)



Figure 24. Wrist extensor flips

Table 12. Specific guidelines for volume dosage for an upper extremity plyometric program

Recommended Parameters	Plyometric Training Programs
Reps	5-10 reps/set
Sets	1 set per motion/exercise (physically Active individuals) 3 sets - athletes
Frequency	2x/week
Rest Intervals	60 second rest between each exercise 48 hours between workouts
Intensity	80-100% MVC (FT fibers)
Duration	6-8 weeks (4 weeks-too short)
Pattern	Minimum 6 different exercises
Type	Isolated to multi-joint 2-arms to 1-arm
Progression	5-10 %/week

Suggestions regarding the use of plyometrics for training of the LE and UE are presented, and contraindications and empirically based suggestions for criteria to begin a plyometric programs are included. Acknowledging the lack of evidence in this realm, recommendations for the volume dosage for plyometric training and a hierarchy of plyometric exercises progression are provided.

Table 13. Examples of progression of plyometric exercises for core stability and the upper extremity

Beginner	Intermediate	Advanced
Wall dribbling-2 arms		
Half twists		
Full twists		
Medicine ball throws	Medicine ball throws (increase weight, frequency, intensity)	Medicine ball throws (increase weight, frequency, intensity)
TheraBand exercises	TheraBand exercises with isometric holds and perturbation training superimposed on the position with the shoulder horn for support	TheraBand exercises with isometric holds and perturbation training superimposed on the position without the shoulder horn for support
Rhythmic stabilizations (perturbation training)	Rhythmic stabilizations (perturbation training)(increase one of variables to challenge subject)	Rhythmic stabilizations (perturbation training)(increase one of variables to challenge subject)
Clap wall pushups	Clap pushups in quadruped position	Clap pushups in full pushup position
		Plyometric rebounders off of 2 plyoballs
		Plyometric bounders off of 1 plyoball
	Eccentric drop pushups	Eccentric drop/rebound pushups
		One-arm push-ups
		Other advanced exercises:
		One arm wall pushups
		Plyometric boxes
		Theraband and PNF patterns
		Impulse Inertial Exercise Trainer

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