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Plyometric Exercise in the Rehabilitation of Athletes: Physiological Responses and Clinical Application

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Plyometric exercise was initially utilized to enhance sport performance and is more recently being used in the rehabilitation of injured athletes to help in the preparation for a return to sport participation. The identifying feature of plyometric exercise is a lengthening of the muscle-tendon unit followed directly by shortening (stretch-shortening cycle). Numerous plyometric exercises with varied difficulty and demand on the musculoskeletal system can be implemented in rehabilitation. Plyometric exercises are initiated at a lower intensity and progressed to more difficult, higher intensity levels. The progression to higher-intensity plyometric exercise is thought to resolve postinjury neuromuscular impairments and to prepare the musculoskeletal system for rapid movements and high forces that may be similar to the demands imposed during sport participation, thus assisting the athlete with a return to full function. While there is a large body of scientific literature that supports the use of plyometric exercise to enhance athletic performance, evidence is sparse regarding the effectiveness of plyometric exercise in promoting a quick and safe return to sport after injury. This review will describe the mechanisms involved in plyometric exercise, discuss the considerations for implementing plyometric exercise into rehabilitation protocols, examine the evidence supporting the use of plyometric exercises, and make recommendations for future research. *J Orthop Sports Phys Ther 2006;36(5):308-319.* doi:10.2519/jospt.2006.2013

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Plyometric exercise is a popular form of training commonly used to improve athletic performance.[18] The stretch-shortening cycle, which involves stretch of the muscle-tendon unit immediately followed by shortening, is integral to plyometric exercise. The stretch-shortening cycle enhances the ability of the muscle-tendon unit to produce maximal force in the shortest amount of time,[3,82] prompting the use of plyometric exercise as a bridge between pure strength and sports-related speed.[22] Maximal-effort plyometric training, or ''shock training,'' was first introduced to Russian athletes to aid the development of explosive ''speed-strength.''[92] Research on the shock method of training examined drop jump heights of over 3 m, which possibly pushed the limits of safety, but also demonstrated the high-intensity of early plyometric techniques.[26]

The focus and application of plyometric training has evolved in recent years. Now plyometric exercises in athletic conditioning programs are often performed at a submaximal level and are directed at the achievement of proper biomechanical technique.[39,58,59] Training in this manner has been effective in reducing lower-extremity injuries as well as improving performance.[34-36,61,77] Plyometric training has also crossed over into the rehabilitation field. Recently published rehabilitation protocols include plyometric exercise as a means to improve function and facilitate a return to sport.[8,23,62,89,98-100] Although plyometric exercises have been recommended for use in rehabilitation,[16,24,89,100] the body of supporting evidence is surprisingly small relative to the performance enhancement literature. In this review, we will describe the mechanisms involved in plyometric exercise, discuss the considerations for implementing plyometric exercise into rehabilitation protocols, examine the evidence supporting the use of plyometric exercise, and make recommendations for future

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research. Our goals for this clinical commentary are to relate evidence about plyometric training in the performance literature to the current trends in rehabilitation application, develop a framework for describing plyometric exercise that may be used to generate more agreement between clinical and scientific communities, and promote future research related to the use of plyometric exercise in rehabilitation.

DEFINING PLYOMETRIC EXERCISE

As plyometric training has evolved, its description and related terminology have undergone a metamorphosis as well as inconsistent usage. For example, based on origins from the shock method, plyometric exercises are often described as activities that involve maximal effort, such as high-intensity depth jumps.[17,87] On the other hand, plyometric exercises have also been described as any movement requiring either maximal or submaximal effort that involves the stretch-shortening cycle.[89,98] The terms *plyometrics* and *stretch-shortening cycle* are used synonymously by some authors,[71] whereas others use the term *stretch-shortening cycle* in lieu of *plyometric* to differentiate from the literal translation of the Greek word *pliometric* (plio, *more*; *plythein*, increase; metric, *measure*) meaning "to increase the measurement."[46] Finally, the use of terminology differs by field of study. While the term *stretch-shortening cycle* is used in the physiology literature to describe activities such as running, jumping, or throwing,[49] the term *plyometric* is used in the rehabilitation and conditioning literature to describe these activities when they are used in training to capitalize on the stretch-shortening cycle for maximizing force production or enhancing performance.[16]

The delineation of plyometric exercise into phases is another area of discrepancy. Plyometric exercise has been described as biphasic, consisting of eccentric and concentric muscle action phases,[46] or triphasic, with an additional phase for the transition between the eccentric and concentric muscle action phases.[24,98] One author has further described plyometric exercise as having 5 phases by adding momentum phases to the beginning and end of the triphasic description.[87]

Lastly, the term *amortization* is a source of confusion when used to describe plyometric activity. Amortization means a "gradual extinction, extinguishing or deadening."[81] In reference to a depth jump, amortization has been described as the time from initial ground contact to reversal of motion,[18] the time from initial ground contact to take-off (entire stretch-shortening cycle),[15] and the transition between muscle lengthening and shortening.[14,78,89] The liberal use of the term *amortization* has even mutated into a description of the transition between concentric actions of antagonistic muscle groups.[90]

In this clinical commentary we operationally define plyometric exercise as activity that involves and capitalizes on the mechanisms of the stretch-shortening cycle to increase the efficiency of force production at a joint or increase performance. For clarity, we will delineate between submaximal (low intensity) and maximal effort (high intensity) when describing plyometric activities. In instances where there are discrepancies in terminology, we provide a rationale for our chosen term. Our attempt to standardize the terminology and descriptors of plyometric exercise may facilitate the crossover of scientific methods, interpretation of research findings, and application of plyometric exercise among coaches, clinicians, and scientists.

PHYSIOLOGY OF PLYOMETRIC EXERCISE

Knowledge related to the physiology of the stretch-shortening cycle has increased in recent years. It is beyond the scope of this paper to discuss these findings in depth; however, key findings will be summarized here to highlight current understanding and provide considerations for the application of plyometric exercise in rehabilitation settings.

Loading Phase

The first phase of a plyometric movement can be classified as the loading phase. This phase has also been called the eccentric, deceleration, yielding, counter movement, or cocking phase.[3,7,15,20,24,53] In the loading phase of a plyometric exercise the muscle-tendon units of the prime movers and synergists, which in the lower extremity are typically the antigravity muscles, are stretched as a result of kinetic energy or loading applied to the joint. The kinetic energy may come from the preceding action, such as flight from a preceding jump, from an external source, such as an approaching medicine ball, or from the concentric action of the antagonistic muscle group (countermovement). Stretching of the muscle-tendon unit during the loading phase elicits the stretch-shortening cycle, which results in enhanced force production and performance when compared to the absence of stretch.[3,82] The loading phase begins when the muscle-tendon units begin to perform negative work.[49] Termination of the loading phase has been variably defined. Studies that consider movement of the entire body use the time point in which the center of mass reaches its lowest position, velocity of the center of mass reduces to zero, or the ground reaction force curve begins to reverse direction.[4,6,48,51] Because multiple joints are involved in whole-body movements, such as jumping, and because the joints are likely to undergo different timing and amplitudes of angular changes, delineation of the loading phase by a combination of ground reaction force and individual joint angular velocity[6] may allow for a more specific application and understanding of the mechanisms involved at a particular joint.

Stretch of active muscle during the loading phase elicits 2 mechanisms associated with the stretch-shortening cycle: muscle ''potentiation'' and the stretch reflex.[6,45] Muscle potentiation is an alteration of the muscle contractile properties that leads to higher force production.[6] Both an increase in the proportion of cross-bridges attached to actin[82] and a decrease in the cross-bridge detachment rate[83] are found when active muscle is stretched. Muscle stretch also stimulates the muscle spindle. Sensory information from the muscle spindle is passed through a monosynaptic reflex loop to provide excitatory feedback to the same muscle. This results in short-latency reflex muscle activity (myotatic or stretch reflex).[76] The rate and magnitude of loading modulate the stretch reflex output, with faster rates and higher magnitudes of loading contributing to an increased stretch reflex. In lower extremity muscles, the stretch reflex is completed in about 30 to 40 milliseconds and, after accounting for electromechanical delay, force is produced about 50 to 55 milliseconds after reflex initiation.[47] The reported duration of the loading phase for a variety of plyometric jumps exceeds 100 milliseconds; hence it is probable that the stretch reflex can even augment muscle activity in the loading phase of a plyometric exercise.[4,5,45]

Data suggest that the stretch reflex may not be elicited in all muscles that are stretched during a plyometric activity. Rather, the muscle response is dependent on the number of joints that are crossed and the specific activity. For example, during stretch-shortening activities, reflex muscle activity is apparent in the soleus, a monoarticular muscle,[69] but the reflex muscle activity is inconsistent for the biarticular gastrocnemius, a synergist to the soleus at the ankle.[64,94] Differences in reflex muscle activity between monoarticular and biarticular muscles may be explained by differences in muscle length changes during loading. Using ultrasonography in vivo, it appears that the fascicles of the biarticular gastrocnemius muscle undergo lengthening (eccentric action) during some, but not all, stretch-shortening activities.[44,49] Instead, in certain activities, gastrocnemius muscle fascicles act nearly isometrically. Consequently, tendon lengthening is responsible for lengthening of the gastrocnemius muscle-tendon unit in these activities.[30,42,44] Without muscle fascicle lengthening, muscle spindles are not stimulated, which may explain the inconsistent reflex muscle activity in the biarticular gastrocnemius during plyometric activities. This suggests that monoarticular muscles may benefit more than biarticular muscles from stretch reflex force augmentation for enhanced work output.

A third mechanism associated with the stretch-shortening cycle is the storage of elastic potential energy in the series elastic component.[86] Even though all the parts of the series elastic component (actin and myosin filaments and the tendon) are stretched when the joint is loaded,[85] the tendon has been found to be the main contributor to muscle-tendon unit length changes[85,86] and the storage of elastic potential energy.[2,85] The Golgi tendon organ, which lies in the tendon, is stimulated by stretch of the tendon.[38] Sensory information from the Golgi tendon organ synapses on an interneuron in the spinal cord and inhibitory feedback is sent to the contracting muscle.[76] It was previously thought that the inhibitory feedback allowed the Golgi tendon organ to function as means of protecting muscle from excess tension[9,76] and could interfere with the forces generated during plyometric exercise.[24,89,100] However, this hypothesis has been challenged[9,76] because the Golgi tendon organ can respond to submaximal forces[38] and has been found to initiate excitatory reflexes during locomotion, a plyometric activity.[55]

Though not commonly considered with the stretch-shortening cycle, more complex reflex mechanisms can be initiated during plyometric exercise and may assist with motor coordination and joint stability. These reflex mechanisms, called ''length feedback'' and ''force feedback,'' result from neural signals generated by muscle receptors that project back to the muscle of origin as well as other muscles.[102] Signals generated by muscle stretch are called length feedback and those generated by muscle force are called force feedback. Length feedback, which occurs around the same timeframe as the stretch reflex, links muscles that are synergists through excitatory feedback and those with opposite actions by reciprocal inhibition.[67] Length feedback also links monoarticular muscles, like the vastus lateralis and soleus, with excitatory feedback.[102] Force feedback, which is provided by stimulation of the Golgi tendon organ, connects muscles that cross different joints and exert torque in different directions through inhibitory feedback.[67] Length feedback contributes to joint stiffness, while force feedback regulates coupling between joints.[67,68] Together, length and force feedback induced during the loading phase of a plyometric activity have the potential to improve neuromuscular control.

Coupling Phase

The transition between the loading and unloading phase of a plyometric exercise may be described as the coupling phase (Figure 1). This phase is commonly referred to as the amortization phase in the rehabilitation literature[89,100] and has also been called the transmission phase.[37] Amortization may not be

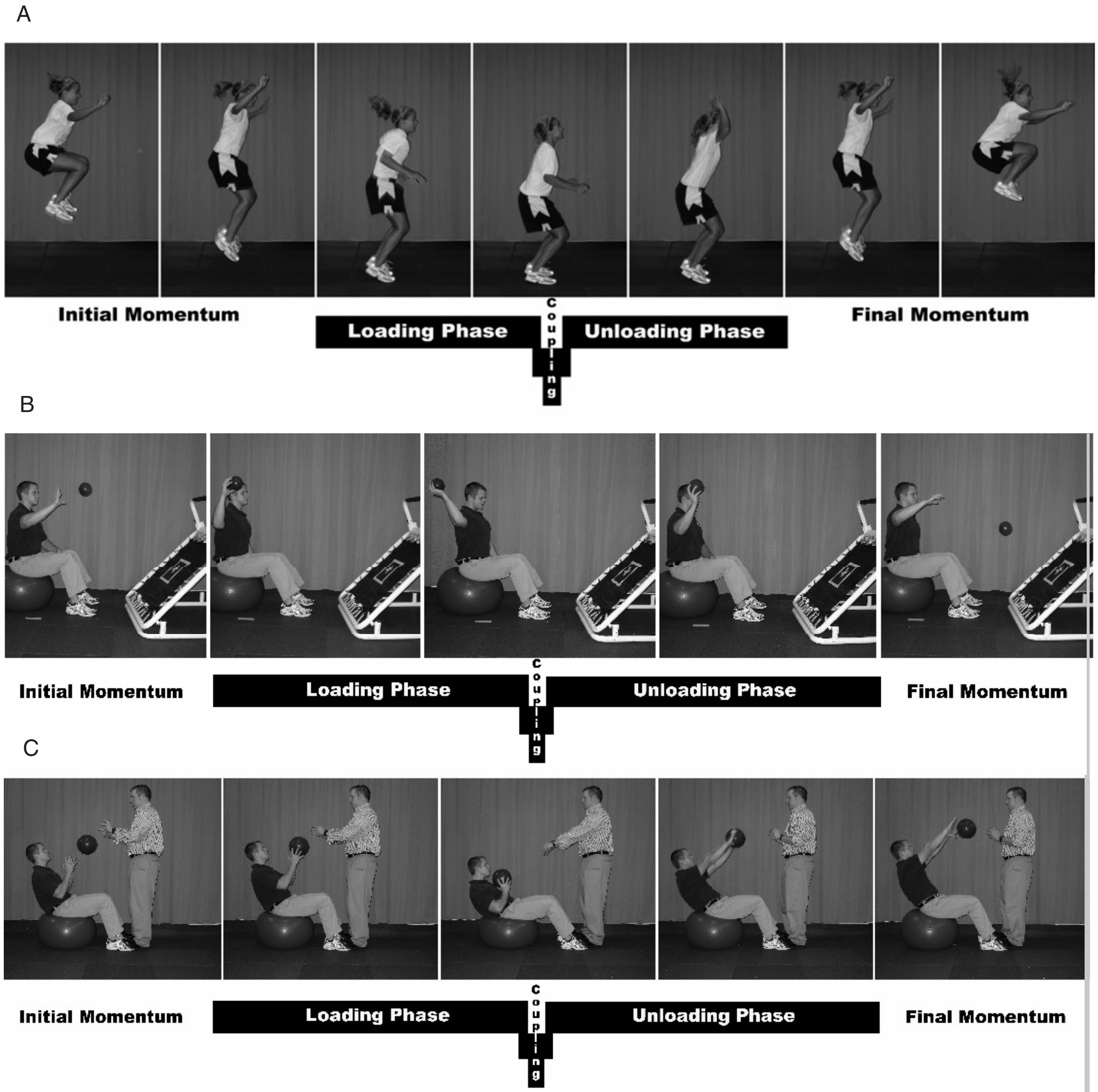

FIGURE 1. The phases of a plyometric activity. A plyometric activity can be delineated into 3 phases: loading, coupling, and unloading. The loading phase involves stretch of the muscle-tendon unit, which initiates the stretch-shortening cycle. The coupling phase is the transition between loading and unloading and is characterized by quasi-isometric muscle activity. The unloading phase involves shortening of the muscle-tendon unit and capitalizes on the mechanisms of the stretch-shortening cycle. (A) Lower extremity plyometric exercise. (B) Upper extremity plyometric exercise. (C) Trunk plyometric exercise.

the best descriptor of this phase because the physiological mechanisms do not agree with the definition of amortization as "gradual extinction, extinguishing or deadening."[81] Studies that use a biphasic framework for defining plyometric activities do not include a coupling phase.[4,5] Instead, the coupling phase is combined with the unloading phase, which may oversimplify the physiologic description of plyometric exercise.

The coupling phase is generally a period of quasi-isometric muscle action, and movement variables are often used to define the beginning and end of the coupling phase.[6,30,31,40,49] For the most part, muscle fascicle length does not change at the time when the joint angle, vertical ground reaction force, or center of mass of the body is about to change direction. Studies of the medial gastrocnemius muscle during sagittal plane ankle movements in standing or supine confirm that the muscle fascicle length is relatively stable, or reaches a transition between lengthening and shortening, at the time when the joint angle and the vertical ground reaction force change direction.[31,49] Similarly, during drop jumps performed on a sledge apparatus, the vastus lateralis muscle fascicle length is relatively stable at the time when the sledge velocity and vertical ground reaction force reverse direction.[40] On the other hand, the medial gastrocnemius muscle fascicle has been shown to be in the midst of shortening at the time when joint angle and center of mass of the body reverse direction during a counter-movement jump.[51] The findings of these studies point out that muscle fascicle behavior may vary during the coupling phase, depending on the muscle and task.

The coupling phase is the definitive phase of plyometric exercise.[87] If the transition is not continuous, the activity will no longer be considered plyometric because the benefits of the stretch-shortening cycle will be lost. In fact, measurable decrement of stored elastic energy occurs in coupling phases lasting over 25 ms.[10,103] The average duration of the coupling phase for countermovement jumps has been calculated to be 23 ms,[6] and Siff[87] suggests that the ideal coupling time is less than 15 ms. Exercises involving the stretch-shortening cycle with a visible pause in joint movement may have muscle-strengthening benefits, but would not be classified as a plyometric activity[87] as one could assume prolonged coupling and energy dissipation.

Unloading Phase

The unloading phase of a plyometric exercise occurs immediately after the coupling phase and involves shortening of the muscle-tendon unit.[42,43,49] This phase has also been called the rebound, shortening, push-off, or propulsion phase.[5,41,87] For a single lower extremity joint the unloading phase has been defined as beginning when the joint angle curve reverses direction and ending when the ground reaction force goes to zero,[6] or beginning when the muscle-tendon unit begins to shorten and ending at toe-off.[51] In the biphasic analysis of plyometric jumps, the unloading phase begins at the start of upward movement of the center of mass and ends when ground contact ceases.[5]

The unloading phase is often considered the payoff or resultant phase, as this portion of the plyometric activity is when the mechanisms elicited during the loading phase contribute to increased efficiency of force production. Data suggest that improved efficiency and force generation is not obtained from an isolated mechanism; rather, performance enhancement from plyometric activity is acquired from the summation of storage and reutilization of elastic energy,[30,31,49] muscle potentiation,[6,82,83] and the contribution of the myotatic stretch reflex.[32]

Considerations for Maximizing Adaptation to Plyometric Exercise

Most plyometric activities terminate in a momentum phase, during which body segments continue to move as a result of the forces generated in the unloading phase (eg, flight of a jump or passive follow-through after ball release). Performance during the momentum phase, such as the height of a jump, is increased compared to the same activity performed without benefit of the stretch-shortening cycle.[48] The degree of performance enhancement during the momentum phase is dependent on the magnitude of the forces[3,37,50] and quickness of movement[48] during the plyometric activity. In particular, higher forces are associated with a shorter coupling phase[6] and greater energy storage in the series elastic component.[3] Performance is also a consequence of the total contact duration (loading through unloading phases), because as the contact duration becomes shorter, higher forces and joint moments are generated,[4] and the tendon contribution to work is increased.[49]

Increasing the intensity of a plyometric exercise (eg, using a higher height in a drop jump) can improve performance, to a point.[48] As the intensity of drop jumps is increased by higher drop height, contact times initially become shorter and tendon shortening in the unloading phase becomes greater.[40,41] However, as intensity continues to increase and optimal drop height is surpassed, contact times are prolonged and the elastic recoil ratio of the tendon (shortening work divided by stretching work) is decreased.[42,43] These findings emphasize that there is a point of diminishing returns related to increasing the intensity of plyometric exercise.

In summary, the mechanisms by which performance is enhanced during plyometric exercise are optimized when the activity imparts higher forces and faster speeds of movement. The contact time is an important determinant in whether performance will be enhanced from the stretch-shortening cycle, and prolonged contact times should be avoided. Prolonged contact times may result when the intensity is too high during the loading phase or when the transition between the loading and unloading phases is not continuous. Current knowledge of the stretch-shortening cycle physiology and the factors that relate to performance gains is based largely on research in the lower extremity; similar application in the upper extremity and trunk is assumed at this time. Care should be taken when applying the physiological principles derived from lower extremity investigations to upper-body and trunk application, as it is unknown whether the upper extremity and trunk will respond in similar manner.

IMPLEMENTING PLYOMETRIC EXERCISE IN REHABILITATION

Appropriate Candidates for Plyometric Exercise

Based on the principle of specificity, meaning that training should closely match performance, plyometric exercise is indicated for those patients that desire to return to activities that include explosive movements.[98] Traditional rehabilitation exercises are performed at slower speeds, with low to moderate forces, and often in single planes of motion. These exercises promote muscle recruitment, improve muscle strength, and increase muscle endurance; however, they might not simulate the speed, forces, or planes of movement that are encountered during athletic competition or provide opportunity for skill reacquisition. Consequently, plyometric exercise has been recommended to bridge the gap between traditional rehabilitation exercises and sport-specific activities.[22]

Contraindications for initiating plyometric exercise are acute inflammation or pain, immediate postoperative status, and joint instability.[100] Joint pathologies such as arthritis, bone bruise, or chondral injury are relative contraindications, depending on the ability of the tissue to tolerate high forces and joint loading required in many plyometric activities. Musculotendinous injury is also a relative contraindication until the tissue is able to handle the rapid and high forces of a plyometric exercise.

Criteria for Initiating Plyometric Exercise

Many plyometric exercises, even at low intensities, expose joints to substantial forces and movement speeds[5] and are not appropriate in the early phases of rehabilitation. Before initiating plyometric exercise, patients should first be able to tolerate the demands of activities of daily living without pain or swelling. Otherwise, the high forces involved with plyometric exercise will likely exacerbate these impairments. Furthermore, patients must have nearly full range of motion and an adequate base level of strength, endurance, and neuromuscular control to properly perform plyometric exercise without symptoms.

Guidelines for initiating plyometric exercise in rehabilitation are poorly developed. Most of the criteria have been established for high-intensity exercise in uninjured athletes and are grounded in opinion rather than research. For example, it has been suggested that plyometric exercise should be initiated only after achieving minimum strength levels that include the ability to perform a full, free-weight squat 1.5 to 2.5 times body mass and/or squat 60% of body mass 5 times within 5 seconds (lower extremity), and perform a free-weight bench press equal to body mass and/or perform 5 hand clap pushups (upper extremity).[97] These ambitious guidelines are unlikely to be met by athletes in rehabilitation. Additionally, these guidelines may exclude a majority of female athletes and many younger athletes from participating in plyometric exercise even though these same athletes would be allowed to participate in competitive sports whose activities induce ground reaction forces 5 to 7 times body mass.[25,57] While validated clinical guidelines are currently unavailable for the initiation of plyometric exercise, empirical evidence suggests that plyometric exercise may be initiated when the patient can tolerate moderate loading during traditional strengthening exercise and perform functional movement patterns with proper form. By virtue of attaining these clinical milestones, plyometric exercise is typically implemented in later phases of rehabilitation.

Guidelines for Implementing Plyometric Exercise

The National Strength and Conditioning Association has stated that carefully applied plyometric exercise is no more harmful than other forms of sports training and competition, and may be necessary for safe adaptation to the rigors of explosive sports.[65] In the rehabilitation setting an athlete that is unable to tolerate plyometric activities is unlikely to tolerate a return to sport participation. Additionally, the success of recent lower extremity injury prevention programs that include plyometric exercise provides evidence that this mode of training may also have prophylactic effects,[34,54,63,72,77] possibly reducing the incidence of reinjury. Nevertheless, plyometric exercise must be applied with caution to avoid adverse reactions, such as increased pain or joint swelling, which will slow progression in rehabilitation. Judicious implementation will also help patients avoid delayed onset muscle soreness (DOMS) that is associated with high-intensity eccentric exercise or novel exercise.[11] Guidelines for plyometric exercise training variables, as with the criteria for initiating plyometric exercise, have been developed for uninjured athletes, primarily performing high-intensity plyometric exercise. These guidelines do not take into account patient variables, such as tissue response and technical performance, which are often the most important consideration in the rehabilitation setting. It is thus imperative that clinicians consider and carefully manipulate all relevant training (frequency, intensity, volume, recovery, and progression) and patient (tissue response and technical performance) variables when implementing plyometric exercise into rehabilitation programs. General guidelines for the pertinent variables are discussed below.

Frequency The frequency of exercise is how often an exercise is performed within a training cycle. High-intensity plyometric exercises are often incorporated on a twice-per-week training cycle for a healthy population,[19] to allow at least 48 to 72 hours of rest for full recovery between plyometric sessions (see Recovery section).[14] Because plyometric exercise is often initiated at a low intensity in rehabilitation, patients may tolerate more frequent bouts—up to 3 times per week—without joint irritation or significant muscle soreness.

Intensity Intensity is the effort required to perform the exercise and is associated with loading force. Anything that increases the stretch load (kinetic energy) will increase the intensity of the plyometric activity (eg, increasing the mass of a medicine ball or increasing drop height).[40] Intensity and frequency are often inversely proportional in training programs. As the intensity of the plyometric exercise increases from low intensity to high intensity, the frequency typically decreases to allow for proper recovery between bouts.

The appropriate intensity for plyometric exercise is based on the ability of the healing tissue to handle loading and the ability of the patient to perform an activity with proper technique. Similar to other forms of training and rehabilitation exercises, intensity of plyometric exercise should follow a gradual progression from low- to high-intensity activities to avoid adverse responses. One method to decrease the intensity for lower extremity exercises is to initiate them on equipment that unloads the body weight (Figure 2). The intensity can then be increased by performing full–body-weight plyometric exercise against gravity, and then increasing the height and distance of jumps and bounding, ultimately progressing to single-leg activities. Additionally, joint loading impact can be reduced when plyometric activities are performed on gymnastics mats; however, this may cause a prolonged coupling phase. Eventually the athlete should progress to more rigid and sport-specific surfaces that will promote the adaptations related to the mechanisms of plyometric exercise.

Upper extremity plyometric exercise can also be initiated at a lower level by reducing the effects of gravity (eg, wall push-up versus floor push-up) or using lighter medicine balls. The intensity of upper extremity plyometric exercises can be increased by using heavier resistance, moving the body or ball through greater distances, using higher speeds, and finally progressing from double-arm to single-arm activities.

Volume The total work performed within an exercise session (sets and repetitions) is called the volume of exercise. The volume of exercise is most often defined by the number of contacts made, either with the ground or some object (eg, a ball). Volume recommendations are typically based solely on one variable. For example, volume recommendations based on experience level suggest that athletes with little experience should utilize 80 to 100 contacts per session, 100 to 120 contacts per session for athletes with some experience, and 120 to 140 contacts per session for athletes with considerable experience.[78] Conversely, recommendations based on plyometric exercise intensity suggest that up to 400 contacts is considered appropriate for low-intensity exercise, 350 contacts for moderate-intensity exercise, 300 contacts for high-intensity exercise, and 200 contacts for very high-intensity exercise.[97] Volume recommendations should not be administered with consideration of only isolated variables, especially in the rehabilitation setting. It is important that other patient variables, most importantly technical performance and patient response, be considered along with experience level and intensity of exercise. Progression of volume should only occur when technique is maintained and there are no adverse events. In general, patients must demonstrate tolerance of a low-intensity/high-volume activity before progressing to a high-intensity/low-volume activity.[19] Additionally, any plyometric activity occurring outside of the clinic (eg, drills performed with a team athletic trainer) should be considered and the volume in rehabilitation adjusted accordingly.

Recovery Recovery is defined as the rest time between repetitions, sets, or sessions of plyometric exercise. The work-rest ratio for a plyometric exercise depends on the intensity of the exercise and the

FIGURE 2. Plyometric activity on a leg press. By performing the plyometric jump on a leg press, the force of gravity is reduced, thus decreasing the load on the lower extremity.

energy system used. In high-intensity plyometric exercise, a work-rest ratio of 1:5 to 1:10 is recommended to ensure enough rest for proper execution of the exercise.[14] For example, when performing a maximum-effort drop vertical jump, athletes may rest for 5 to 10 seconds in between repetitions. In the clinical setting, where low-intensity plyometric exercises are often used, smaller work-rest ratios (eg, 1:1 or 1:2) have been recommended.[93] An example of this would be line jumps performed for 10 seconds followed by 10 to 20 seconds of rest.

Generally, 48 to 72 hours of rest is recommended for recovery between plyometric training sessions.[14] Recovery time between sessions is often dependent on the presence of DOMS. If a patient experiences DOMS following plyometric exercise, it will be most pronounced 24 to 48 hours after the exercise bout and reduced within 96 hours.[21,80] DOMS that is induced by maximal intensity eccentric exercise causes maximal voluntary force to be decreased for up to 48 hours after the exercise session.[96] Although voluntary force decrements can also occur 24 to 48 hours after low-intensity eccentric exercise, the decrements are less severe than with high-intensity exercise.[70] Allowing proper recovery time insures that sufficient muscle force is available for the optimal performance of plyometric exercises.

Technique A major focus of plyometric exercise in rehabilitation is assisting the athlete with skill reacquisition and the establishment of biomechanically safe technique that will allow the athlete to achieve optimal performance. Special attention should be given to address undesirable technique that may stem from the injury or that may have been related to the cause of the injury.[35,62] If an athlete is allowed to perform plyometric exercise maneuvers improperly during training, then improper technique will be reinforced.

When plyometric exercise is initially implemented, clinicians should give continuous and immediate verbal feedback to the athlete both during and after each exercise bout to increase awareness of proper form and technique as well as undesirable and potentially dangerous positions.[79] Additionally, visual feedback may be provided through the use of video camera and television monitor or by having the athlete perform exercises in front of a mirror.[73] The clinician should be skilled in recognizing the desired technique for a given exercise and should encourage the athlete to maintain perfect technique for as long as possible. If the athlete fatigues to a point where technique degrades and a sharp decline in proficiency is displayed, the activity should be stopped. The goal should be to increase the volume (number of repetitions or number of exercises) or intensity (difficulty) of plyometric exercises while maintaining proper form.

Progression Like all other forms of therapeutic exercise, plyometric activities should start at the most demanding level the patient can tolerate and progress only when the activities are completed with proper form and without any increase in symptoms. Plyometric exercise is progressed by carefully manipulating the frequency, intensity, volume, and recovery of exercise. Deciding which variable to manipulate at which time is based on clinical experience, empirical evidence, and the patient's response. Generally speaking, the volume (sets and repetitions) of a particular plyometric activity is increased first to ensure appropriate neuromuscular control and endurance before increasing the intensity or frequency of exercise, or decreasing the recovery time.

Although DOMS is a possible adverse reaction to plyometric exercise, it is not obligatory. Eccentric exercise that is initially performed at a low intensity—as in rehabilitation—and is progressively increased, does not produce substantial muscle soreness or evidence of muscle injury.[52] However, even low-intensity plyometric exercise can produce indicators of DOMS that are similar to high-intensity exercise when performed at a similar volume.[74] Therefore, both intensity and volume must be carefully manipulated to maintain appropriate levels of DOMS during rehabilitation.

The presence of adverse responses, such as joint pain or joint swelling, should be used to guide and potentially limit plyometric exercise progression.[13] If an adverse response is encountered, then the recovery period should be prolonged until the impairment has completely resolved. When plyometric exercises are reinitiated, the volume and/or intensity of the plyometric exercises should be reduced to the level prior to progression. If joint pain or joint swelling are experienced postexercise, but the symptoms resolve before the next rehabilitation visit or after a warm-up, then the program should not be progressed but rather maintained and monitored for reoccurrence of symptoms.[13] Clinical experience suggests that a patient should tolerate 2 to 3 sessions at a specific intensity without any adverse responses before the intensity of the program is progressed.

EVIDENCE SUPPORTING THE USE OF PLYOMETRIC EXERCISE

A variety of positive changes in athletic performance and neuromuscular function have been attributed to plyometric training, predominantly in the lower extremity. In almost all cases uninjured subjects have been studied, as the research goal has been to determine the effect of plyometric training for inclusion in conditioning programs. The specific adaptations following plyometric training will be reviewed here.

Plyometric training programs that range from 6 to 15 weeks generally improve athletic performance variables. For example, maximal vertical jump height has repeatedly been shown to increase following plyometric training.[1,12,28,36,66,91] In addition, sprint times decrease,[84] golf club speed and driving distance increase,[29] and running economy improves.[88] Fewer studies have been conducted on the performance benefits of upper-body plyometric training and the results are equivocal. Heiderscheidt et al[33] found that maximal softball throwing distance was unchanged, whereas Vossen et al[95] found that a medicine ball put (throw) distance increased. Different training regimens may account for the dissimilar findings. Due to the scarcity of research on upper extremity performance plyometric training, the improvements in upper extremity performance remain largely anecdotal.

Lower extremity muscle performance characteristics are also improved after plyometric training. By itself, plyometric training increases leg strength, but strength gains appear to be greater when plyometric training is combined with weight training.[27,28] The combination of plyometric and weight training induces 90% increases in leg strength after only 6 weeks of training.[61] In addition to increasing strength, other muscle performance benefits attributed to plyometric exercise are a faster rate of force development[66] and delayed onset of muscle fatigue[56] during jumping. Females may particularly benefit from lower extremity plyometric training. Both Hewett et al[36] and Wilkerson et al[101] found increased knee flexion peak torque after training, which normalized the imbalance between quadriceps and hamstring musculature. As part of a comprehensive training program, plyometric exercise corrects neuromuscular imbalances that may predispose female athletes to injury,[36,58,60,61] and several prospective studies have found that training programs that include plyometric exercise result in decreased lower extremity injury risk in female athletes.[34,54,63,72,77] With regard to the effect of plyometric training on upper extremity muscle performance, there is substantially less literature. Plyometric exercise for the shoulder internal rotators has been shown to decrease the time to peak torque,[33,90] but does not change the peak torque magnitude.[90]

Plyometrics may induce other improvements in neuromuscular function, including joint position sense and postural control. For instance, Swanik et al[90] found improved shoulder joint position sense after plyometric training, both in a neutral position and near–end-range external rotation, using active repositioning and threshold to detection of passive movement tests. Although Heiderscheit et al[33] found no improvement in shoulder active repositioning after plyometric training, fewer precautions were taken to eliminate extraneous sensory input that may have influenced the results. Postural stability in single-limb stance, as assessed by the ability to maintain a level platform on the Biodex Stability System, was improved following a training program that included plyometric exercises.[75] Specific balance exercises were also included in the training program, therefore, a follow-up study was performed using a modified protocol that excluded all balance exercises.[58,60] With the balance exercises excluded, the plyometric training group demonstrated improved center-of-mass stabilization when landing from a jump, equalized landing forces between lower extremities, and reduced biomechanical measures related to lower extremity injury risk following completion of the training program.[58,60]

It is unknown whether patients recovering from injury will respond to plyometric exercise in a manner similar to uninjured subjects. Alterations in the neuromuscular system following musculoskeletal injury may impede or diminish the beneficial effects of plyometric training. In addition, most studies in uninjured controls have used a high-intensity plyometric training program and, as discussed in this article, much of the plyometric training used in rehabilitation involves low-intensity activities to avoid aggravating the injury. At this point, the ability of plyometric exercise to resolve neuromuscular impairments and promote a return to sport after injury is primarily based on anecdotal evidence.

FUTURE DIRECTIONS

One of the most glaring disparities in the research on plyometric exercise is the scarcity of studies pertaining to the upper extremity and trunk. The majority of the literature related to muscle-tendon unit physiology during stretch-shortening exercise, and documenting performance gains and positive adaptations in neuromuscular function after plyometric training, applies to the lower extremity. Research is needed to determine if the mechanisms involved in the stretch-shortening cycle are similar between the lower extremity, upper extremity, and trunk, and to demonstrate that the upper extremity and trunk receive comparable benefits from plyometric training.

Research is also needed to validate the assumption that plyometric exercise promotes a return to sport for injured athletes and to examine whether plyometric exercise is useful in the prevention of reinjury. This is especially pertinent if participation in plyometric training must extend 6 to 15 weeks to obtain the beneficial effects. Third-party payers may not reimburse for formal therapy extending for that length of time, and the time interval is longer than the duration of the return-to-function phase of rehabilitation for most musculoskeletal injuries. Furthermore, research is needed to delineate whether plyometric exercise imparts additional benefits beyond the combination of other rehabilitation interventions (strength, balance, proprioception, and interval sport activities) and to determine the most effective application of plyometric exercise. Despite the lack of evidence documenting the effectiveness of plyometric exercise in rehabilitation, the clinical success of properly applied plyometric exercise warrants the continued use and research of this therapeutic intervention.

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