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Plyometrics: A Look at the Biomechanical Basis of Its Use in the Realm of Sports Performance Enhancement and Physical Rehabilitation

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PLYOMETRICS:
A LOOK AT THE BIOMECHANICAL BASIS OF ITS USE
IN THE REALM OF SPORTS PERFORMANCE ENHANCEMENT
AND PHYSICAL REHABILITATION

by

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An Independent Study
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This Independent Study, submitted by Sara Fetsch in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

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ABSTRACT

Plyometrics is a rather new and somewhat foreign concept that is becoming more popular in athletic training programs in the hopes of providing optimal gains in power, which is difficult to obtain by other means of exercise. With its increasing acceptance in the athletic environment, it is also being incorporated into rehabilitation programs as a means of providing strength and proprioceptive feedback.

Little is currently known about the principles that govern the use of plyometrics and the efficacy that has been demonstrated with this training method. The purpose of this independent study is to analyze the basic concepts underlying plyometrics and to examine its role in both the athletic and rehabilitative environments. With the information provided in this Independent Study, it is hoped that those who take advantage of plyometrics can better understand the biomechanics involved that lead to its demonstrated success.
CHAPTER 1
INTRODUCTION TO PLYOMETRICS

In the realm of competitive sports you may often hear about athletes striving to achieve that "competitive edge." This may come in a variety of forms, including nutritional, spiritual, emotional, or physical. Trainers and athletes alike are constantly looking at new and innovative ways of improving performance. One of the training techniques to enhance athletic performance physically that is becoming more and more popular today is plyometrics.

It is obvious that to enhance power in competitive sports, one must incorporate strength training. Timing, however, is just as important and is an area that tends to be overlooked when training. Power is improved when more force can be generated in less time. Therefore, the faster a muscle can produce force, the more powerful the contraction will be. The theory of plyometric training involves attempting to bridge the gap between speed and strength to optimize athletic performance.\(^1\)

Plyometrics is a relatively new concept in sports performance enhancement and, although it has been shown to be beneficial for improving power, the principles involved with its efficacy remain unfamiliar to many who take advantage of this training method. The purpose of this study is to analyze the biomechanical basis of plyometric training and to examine how it enhances athletic performance in those events requiring strength and speed. Also, its usefulness in the rehabilitative setting will be examined as well. If
athletes and trainers using this method understand the neuromuscular factors involved, it will further aid them in the development of strategies based on plyometric principles that will result in power gains. This study examines the efficacy of various plyometric training techniques for the upper and lower extremities and identifies sport-specific activities that can greatly benefit from the use of this training mechanism. If the techniques are used optimally, plyometrics can be very effective in producing power and strength gains. This study will attempt to examine the ways plyometrics can be used to achieve maximal benefits.

PLYOMETRICS DEFINED

Commonly referred to as stretch-shortening drills, the word "plyometric" can actually be broken down into two separate terms: "plyo," from the Greek work plythein, which means "to increase," and "metric," which simply means "to measure." There are several varying definitions for plyometrics. Epley4 simply defines it as a type of training that develops explosive power, while Wilk2 describes the concept as a quick, powerful movement involving prestretching of the muscle, thereby activating the stretch-shorten cycle. Radcliffe and Farentinos5 define plyometrics as powerful muscular contractions after rapid stretching or dynamic loading of the same muscle group. All of these definitions basically state the same idea: that plyometrics involves putting a muscle on stretch to develop a more forceful subsequent muscle contraction.

Plyometrics does not refer to a specific type of exercise but rather encompasses many types of drills and techniques designed to enhance power in those activities requiring both speed and strength. As a matter of fact, we perform functions in everyday life based on those concepts that underlie plyometrics. Albert3 states that all movement
in both competitive athletics as well as normal activities of daily living (ADL) involves a repeated series of stretch-shortening cycles, which is the basic element behind any plyometric activity. Blanpied et al\(^6\) describe the stretch-shortening cycle as a naturally occurring pattern of motion that occurs during a muscle contraction, involving an initial lengthening of the muscle through an eccentric contraction (stretch), followed by a shortening of the muscle through a concentric contraction. Furthermore, they provide examples of how the stretch-shortening cycle is utilized in the simple function of gait. During the loading response and early midstance phases of the gait cycle, the knee extensors are first stretched and contract eccentrically before shortening via a concentric contraction. In a similar fashion, the biarticular knee flexors are stretched and contract eccentrically during midswing and terminal swing before subsequently shortening via a concentric contraction during early loading response.\(^6\)

**PLYOMETRIC ROOTS**

Contrary to what may be popular belief in the United States, plyometrics was not introduced as a training technique in America; rather, it is believed that the roots of plyometric training originated in Eastern Europe in 1966, although at the time it was known as jump-training or shock-training.\(^2\) Often regarded as the founder of plyometrics is a Russian jump coach by the name of Yuri Verkoshanski, who advocated its use after finding that it improved vertical jump performance among high school basketball players by increasing power as well as coordination.\(^3,7\) Verkoshanski is the leading researcher in what is now referred to as speed-strength training in the Soviet Union. Plyometrics actually were initially used mainly with Soviet track and field athletes in the 1960's, especially jumpers. Marked improvements in performance were noted after using
plyometrics as a training technique for these athletes. Eventually, its popularity as a training method spread throughout the Eastern-bloc countries and it began being used as a means of increasing power for athletes in nearly every sport.  

Although the Soviets are credited with developing the concept of plyometrics, it actually was being utilized by American coaches for many years in the forms of exercises such as bench hops and rope jumping. However, the basis behind how it improved performance was not fully understood at the time and therefore the Eastern-bloc sport-scientists, particularly Verkhoshanski, are given credit for organizing the concept of plyometric training.  

This concept was not introduced into western culture until the 1970's, almost ten years after its origin in the Eastern-bloc countries.  

The popularity of plyometric training increased markedly after the 1972 Olympics due to a Russian by the name of Valery Borzov. After Borzov unexpectedly won the gold medal in the 100- and 200-meter sprints, word was out that he had included various forms of plyometric exercise on a regular basis in his training regimen. Experts attributed those surprising victories to the plyometric training. Because of its origins in the track and field realm of athletics, plyometrics was and continues to be used most frequently as a means of increasing speed and anaerobic power in sprinters and jumpers. However, it is certainly not limited to these types of athletes. In recent years, it has been incorporated into a wide variety of sports and recreational training programs.  

Athletes in virtually any sport can benefit from plyometric training with a variety of programs having been developed to target sport-specific activities in baseball, basketball, football, soccer, ice hockey, swimming, cycling, and tennis, as well as many others. Of course, these programs are designed to be an adjunct to other exercises and training regimens such as
weight training, resistance exercises, stretching, and endurance exercises. Plyometrics itself is not likely to be beneficial if the athlete does not make an effort to improve in other areas of performance as well. Hewett et al\(^{11}\) state that jump-training programs which incorporate stretching, plyometric exercises, and weight lifting have been advocated to increase performance as well as decrease the risk of injury in competitive athletes.

REPORTS OF EFFICACY OF PLYOMETRIC PROGRAMS

There are varying reports of the efficacy of plyometric training in the enhancement of athletic and rehabilitative performance. Wilk et al\(^{12}\) conclude that through clinical observation, patients performing stretch-shortening exercise drills have accelerated muscular performance gains compared with individuals who have not trained in this fashion. They believe that the muscular performance gains are a result of neural adaptation and enhanced neuromuscular coordination rather than from morphologic change. Parcells\(^{13}\) conducted a study which compared the effects of plyometric training with isotonic training and found that a significant gain in vertical jump was noted with plyometric training. These same gains were not achieved with the traditional isotonic training. Blattner and Noble\(^{14}\) compared plyometric training with isokinetic training and found that both mechanisms improved vertical jump performance; however, neither technique was superior to the other. In a study conducted on female subjects, it was found that after a jump-training program lasting six weeks the hamstring-to-quadriceps muscle ratio in these women jumped from 51% to 65%, respectively. The latter is the equivalent of male ratios.\(^{11}\) A jump-training program implemented by the 1984 U.S. Olympic Gold Medal Volleyball Team over a two-year period resulted in a surprising 4-
in increase in vertical jump. After eleven months of training, Dunham et al reported a 1.25-in increase in the vertical jump of female collegiate volleyball players. Pestolesi reported a 0.45-in increase in vertical jump after a jump-training program consisting of a group of both male and female high school athletes over a six-week period. In a study conducted by Cordasco et al on ten healthy male subjects, it was found that the use of medicine ball training (a plyometric activity for the upper extremity) is beneficial as a bridge between static resistive training and dynamic throwing in the rehabilitation of the overhead athlete. Medicine ball activities will be further addressed in Chapter 5.

Heiderscheit et al studied the effects of isokinetic training versus plyometric training on the shoulder internal rotators, measuring both power and kinesthetic sense. Neither the control group nor the plyometric group showed significant eccentric or concentric isokinetic increases, while the isokinetic group showed increases in both eccentric and concentric muscle activity. None of the groups showed a significant change in kinesthetic score. Fort et al added plyometrics to a weight training program and found no improvement in performance of the 40-yd dash, vertical leap, or pull-ups. In another study by Clutch et al on college-aged subjects, it was found that depth jumps (a plyometric activity) were effective in increasing vertical leap but no more effective than a regular jumping routine. Scoles also performed a study on college-aged subjects and determined that after an 8-week program of twice-weekly depth jumping, no improvements in vertical leap or long jump could be obtained.

Obviously the literature supporting the usefulness of plyometrics is countered by literature which disputes its efficacy. Nonetheless, more research needs to be done to
determine who can benefit from this training mechanism and how to optimize the training program to provide the best results.
CHAPTER 2
THE FOUNDATION OF PLYOMETRICS

The concepts underlying plyometric exercises are based on sound physiological principles. To fully understand the mechanics involved in this type of activity, one must have knowledge of the anatomy and function of the neuromuscular system. Because plyometrics involves prestretching and subsequently activating a given muscle, it is important to understand the basic structure of the muscle and how it interacts with the nervous system to produce forceful work output.

AN OVERVIEW OF MUSCLE STRUCTURE

The epimysium is a connective tissue sheath surrounding the muscle and is continuous with the tendon. Within the muscle are bundles of fibers bound together by sheaths of perimysium to form fascicles. Each bundle of muscle fibers is encased in a sheath termed the endomysium. These connective tissue elements transfer the force generated by muscle contraction to the tendons.

The sarcolemma is the cell membrane of the muscle. Muscle fibers contain long, parallel myofibrils, which make up 75% of the muscle's total volume. Myofibrils are made up of repeating subunits called sarcomeres, which, in essence, are the contractile functional units of the muscle. Adjacent sarcomeres form the characteristic striated pattern seen in muscle tissue under a microscope. The striations are formed by the
arrangement of bands of actin and myosin; the presence of myosin produces dark bands, while light bands designate areas of actin not overlapping myosin.

Sarcomeres are formed by the overlapping of thin and thick filaments, which contain the contractile proteins actin and myosin, respectively. The thin filaments appear smooth, while the thick filaments contain protrusions called crossbridges. A relaxed sarcomere, when viewed from the side, contains a central H zone in which the thick filaments are not overlapped by thin filaments. On either side of the H zone there is overlapping of the thin and thick filaments. The A band is that region of the sarcomere occupied by thick myosin filaments. The regions at each end of the sarcomere are termed the I bands; in these regions the thin filaments are not overlapped by thick filaments. Finally, the Z lines mark the ends of the sarcomere and the beginning of the new adjacent sarcomere. The thin filaments are attached to these Z lines. The sarcomeres of all the myofibrils are typically aligned such that all the Z lines form continuous, thin bands. It is the thin and thick filaments that are thought to overlap during muscle contraction, giving us what is termed the sliding filament theory. In order for the thick and thin filaments to slide across one another, physical links that generate force must form between the two filament types during contraction. By using electron micrographs, it was revealed that numerous crossbridges are formed in muscles chemically fixed during activity. The degree of overlap of thick and thin filaments was greater and sarcomere length was shorter in muscles that were contracting when they were fixed for microscopy as opposed to muscles at rest.

Skeletal muscle is composed of two types of fibers: extrafusal and intrafusal fibers. The extrafusal fibers are responsible for generating the contractile force that is
used to produce work and comprise by far the greater share of the mass of the muscle. They are innervated by $\alpha$ motor neurons. The intrafusal fibers are very important to the muscle structure in that they constitute the muscle spindles. These provide the central nervous system with information about the muscle length and are innervated by $\gamma$ motor neurons. The intrafusal fibers are in parallel with the extrafusal fibers and cause contraction of the latter if there is significant change in length of the muscle spindle or a change in the rate of stretch of the spindle.

There are two types of intrafusal fibers: nuclear bag fibers (type Ia) which are located primarily in the central region of the spindle, and nuclear chain fibers (type II) which are smaller and uniform in diameter throughout the length of the spindle. The central regions of bag and chain fibers contain no myofibrils and are the most elastic parts of the fibers; therefore, stretching the muscle spindle stretches the central regions of the intrafusal fibers preferentially. These elastic central regions are wrapped by endings of group Ia afferent neurons, while the lateral, contractile regions of chain fibers are where the endings of smaller group II afferent neurons are located. There are no endings of group II neurons on nuclear bag fibers.

When a muscle is stretched, the responses of its spindles include a phasic component in which activation occurs due to the rate of stretch of the muscle spindle and a tonic component in which the muscle is activated based upon muscle length. Bag fibers are affected primarily by rate of stretch and chain fibers primarily by lengthening. Both bag and chain fibers have group I afferent endings in their central regions, so the group I response contains both a phasic and a tonic component. Group II afferents have endings only on chain fibers, so their activity relays only information on muscle length.
The function of a given muscle determines the density and response characteristics of the stretch receptors present. For example, muscles that are typically involved in fine, highly controlled movements, such as those in the fingers, have a high density of spindles containing both bag and chain fibers. Therefore, they provide information on both stretch and length. Muscles that are involved in more gross motor activities contain relatively few spindles and consist largely of chain fibers, which are primarily receptive to changes in muscle length. These are the muscles primarily involved when performing plyometrics and are referred to as fast twitch muscles. Slow twitch muscles, which are primarily postural muscles such as the erector spinae muscle group, are not commonly recruited in plyometric activities. Because nuclear chain fibers provide most of the afferent input in fast twitch muscles, it can be observed that plyometric activities have a predilection for type II fibers (activated upon changes in muscle length) rather than Ia fibers, primarily involved with slow twitch muscles.

THE STRETCH REFLEX

It is widely accepted that one of the fundamental principles on which plyometrics is based is that of the myotatic, or stretch, reflex. This reflex is perhaps the most simple and easily-understood reflex occurring in humans. It is present in all skeletal muscles but is more active in extensor muscles, which function as joint stabilizers and help to maintain posture. This reflex is monosynaptic and is evoked by placing the muscle on stretch, which, in turn, stimulates the primary terminal in the muscle spindle. The Ia afferent muscle fibers then activate the motor neuron to the stretched muscle, resulting in a brief contraction.
As stated, a muscle must first be put on stretch before it can develop explosive power. This type of sports performance training can also be referred to as reactive neuromuscular training in which an augmented myotatic reflex is desired. This type of training demands that the athlete have an intact proprioceptive system to optimize the effects of the stretch reflex. Namely, the muscle spindle and golgi tendon organ need to function optimally. This would result in an increased excitability of the neurological receptors for improved reactivity of the neuromuscular system. The stretch prior to the shortening, or concentric, muscular contraction activates the muscle spindle, which in turn then assists in a more explosive shortening contraction. This can be referred to as reflex potentiation. In reflex potentiation, the stretch phase causes increased muscle spindle activity. This leads to an increase in reflexive input to the motor neurons, which likewise results in increased muscle activation. Albert states that eccentric lengthening loads the elastic components of the muscular system which then increases the tension of the resultant rebound force. The stretch reflex, in turn, may increase the stiffness of the muscular spring by recruiting additional muscle fibers, a situation that would not be possible with concentric contraction alone. This additional stiffness may allow the muscular system to reutilize more of the external stress in the form of elastic recoil. Specifically involved at the ultrastructural level are the nuclear bag intrafusal muscle fibers, which are innervated by the type Ia phasic nerve fibers. The firing of these Ia fibers is influenced by the rate of stretch, with a faster and stronger stimulus resulting in a greater effect on the associated extrafusal muscle fibers. The rate or frequency of this stretch is significant, and some plyometric experts believe that muscle contractions occurring from the stretch reflex are more powerful than voluntary muscular
contractions. This cycle from stretch to concentric contraction is very brief, occurring in as little as 0.3 to 0.5 msec, and is mediated at the spinal cord in the form of the myotatic reflex. Komi offers the possibility of reflex potentiation through a variety of other pathways as well, including a cortical loop.

THE GOLGI TENDON ORGAN

The golgi tendon organ (GTO) is located at the musculotendinous junction both at the origin and at the insertion of the muscle. It is sensitive to tension, and because it is arranged in series with the extrafusal muscle fibers, it is activated when the muscle is placed on stretch. However, unlike the muscle spindle, it is thought that the GTO serves as a protective mechanism and has an inhibitory effect on the muscle. When excessive tension is produced or deformation of the muscle occurs, sensory impulses are sent from the GTO to the spinal cord and ultimately the cerebellum. When the impulses arrive at the spinal cord, the alpha motor neurons of the contracting muscle and its synergists are inhibited, limiting the amount of force that is developed in the muscle. Because the great amount of tension that develops with an eccentric contraction is potentially harmful, it is vital that an intact GTO system is present to prevent overexcitation of the muscle which could in turn result in injury. However, with plyometric exercise the influence of the GTO is overshadowed by the reflex arc pathway incorporated with excitation of the type Ia nerve fibers. Also, Heiderscheit et al point out that plyometrics are thought to raise the firing threshold of the GTO, thereby desensitizing it and allowing a greater accumulation of force during the eccentric preload. It can be presumed, then, that detrimental effects of plyometric training can occur despite
the protective function that the GTO attempts to serve. It can be assumed that during plyometric activities the GTO function may be compromised.

FORCE DEVELOPMENT THROUGH ECCENTRIC CONTRACTION

The purpose of the stretch-shortening cycle is to allow the final action, which is the concentric contraction, to take place with greater force or power output than if the movement were to be a concentric contraction alone. Therefore, a large amount of force needs to be generated through the eccentric contraction to produce an explosive concentric contraction. Dintiman\(^1\) explains this concept very simply when he states that more power can be generated in any muscle group by first starting the movement in the opposite direction. He gives the examples of a golf or tennis swing and hitting a baseball because both of these motions involve prestretching by movement in the opposite direction before the explosive power of the swing occurs. Furthermore, he states that it is possible to exert as much as two times more tension during the concentric contraction, or explosive phase, if the muscle is first prestretched through the eccentric contraction. Parker\(^2\) also points out that a concentric contraction of any given muscle is much stronger if it immediately follows an eccentric contraction of that muscle. This, in essence, is the myotatic reflex. This stretch reflex inhibits overstretching of the muscle and instead produces a powerful contraction.

An eccentric muscle contraction develops more tension than either a concentric or isometric contraction in any muscle regardless of cross-sectional area or type of muscle (for example, whether it contains primarily slow-twitch or fast-twitch fibers). This fact was first acknowledged after a study conducted by two pioneers in the field of exercise...
science, Singh and Karpovich. They were able to measure the effective force of the elbow flexors and extensors as a function of elbow position during maximal voluntary efforts with the use of a constant velocity motor coupled to a force transducer. Through their efforts, it was found that at all positions throughout the entire range of motion the effective force of the elbow flexors was greater during the eccentric muscle action than during the isometric or concentric muscle action.

Stauber states that the tension developed by an active muscle decreases as the shortening velocity increases, as in a concentric muscle contraction. However, if the force imparted to the muscle overcomes the ability of the muscle to actively resist, the muscle lengthens but only after producing additional tension. This would be an example of an eccentric muscle action. This could be observed by catching a medicine ball, which is a large, heavy, padded ball commonly used in plyometric exercises for the upper extremities. The eccentric contraction in this case would be performed by the biceps as they resist the straightening (extension) that the weight of the ball imparts on the arms as it is caught. The biceps would be stretched during the catch; however, they would be resisting this stretch in an effort to keep the ball from being dropped to the ground. It should be noted that this is not a plyometric exercise because a concentric contraction does not occur after the ball is caught, and hence no positive work is being performed. If the ball were to subsequently be tossed immediately after being caught, this would be a plyometric drill. The biceps would be put on stretch as the ball is caught and subsequently would contract as the ball is then tossed upward in an underhand motion.

As previously noted, muscle contraction involves the forming of crossbridges between actin and myosin filaments. If, immediately after this binding occurs, the
crossbridge is forcibly pulled apart, the bond that was established would break before transduction of energy could occur. As a result of this separation, more force would be required in an attempt to maintain the actin-myosin bond than in a normal crossbridge which is not being pulled apart. The energized myosin, maintaining its potential energy, could reattach only to be pulled apart again if the load, or applied force, continues to be applied. Tension develops with each of these attachment-separation reactions; however, no energy is consumed because there is no cycling of the crossbridges occurring. Rather, the crossbridges remain in the high-energy form (potential energy) because of the stretch from the external force that is applied.²⁸ Hagerman¹⁰ notes that these stretched muscles are imparted with stored energy and essentially become energy-charged.

**ENERGY STORAGE IN MUSCLE**

It has been determined that the stretch-shortening cycle is purely elastic in nature and that the stretching of the activated muscle enhances the force output of the subsequent muscle contraction. In an experiment using both isolated frog sartorius muscle and intact human elbow flexor muscles to investigate this phenomenon, it was found that when active muscle is stretched or when passively stretched muscle is suddenly activated, the muscular tension increases and potential elastic energy is stored in the series elastic component of the muscle. It is the recovery of this stored potential energy that enables favorable concentric muscular output.²⁴ To further understand this phenomenon, it is imperative to have a basic understanding of the viscoelastic components of muscle.

There are essentially two elements of intact muscle: contractile and viscoelastic. The viscoelastic components of muscle can further be broken down into parallel elastic
components and series elastic components. The parallel elastic components include contributions from the endomysium, perimysium, epimysium, sarcolemma, and some of the proteins existing in the sarcomere. Resistance to passive stretch of muscle is thought to be provided by the parallel elastic components. The series elastic components can be broken down into two separate entities: one that is found in the tendon and one that is found within the contractile component, which includes contributions from actin and myosin. Also included in the contractile component are interactions between the actin and myosin within the sarcomere.

Asmussen and Bonde-Petersen suggested that it is possible that imparted mechanical energy may be temporarily stored in the series elastic components of active muscle. This stored energy is then used in a subsequent muscle action; for example, the cocking and subsequent throwing of a baseball. This storage and use of elastic energy depends on three factors: the velocity of the stretch, the length of the stretched muscle, and the force attained at the coupling time between stretching and shortening phases of muscles. Through good utilization of this elastic energy, metabolic demands of muscles are likely to decrease, resulting in increased mechanical efficiency. Mechanical efficiency is a term used to describe the amount of work done as a proportion of the energy expended. It has been found that jumping exercises utilizing the stretch-shortening cycle have a mean net efficiency of positive work that ranges from 30.1% to 38.7%. Despite the research done so far on the use of muscle in the stretch-shortening cycle, we still know surprisingly little about the specifics of the optimal parameters for energy storage and release from the musculotendinous tissue during function.
PLYOMETRICS AND ENHANCED NEURAL FUNCTION

Besides the large amount of force produced via the eccentric contraction, plyometrics also may improve muscular performance by facilitating neuromuscular coordination and making the neurological system more “automatic”.\textsuperscript{12} Utilizing the prestretch response may improve neural efficiency and increase neuromuscular performance by allowing the athlete to better coordinate the activities of the various muscle groups. This enhanced neuromuscular coordination could lead to greater net force production, even in the absence of morphologic change within the muscles themselves, referred to as neural adaptation.\textsuperscript{3} Stretch-shortening exercise trains the neuromuscular system by exposing it to increased strength loads. Utilizing the stretch reflex improves the ability of the nervous system to react with maximal speed to the lengthening muscle. Because of the improved stretch reflex, the muscle contracts concentrically with maximal force.\textsuperscript{12} It may be that the benefits of plyometrics derive from increased muscle loading (overload principle) and from improved proprioception in involved muscle groups (specificity principle), or perhaps from an increase in the load tolerance of the musculotendinous unit. At this time the mechanisms by which plyometrics enhance performance must be considered undefined.\textsuperscript{32}

PHASES OF THE STRETCH-SHORTENING CYCLE

From what has been stated thus far, it can be deduced that there are three stages involved in any plyometric activity. These are the eccentric phase, amortization phase, and concentric phase. These stages can be broken down into definite moments in time. The eccentric phase begins when the athlete prepares mentally for the activity. It lasts until the stretch stimulus is initiated. This phase, which also may be referred to as the
setting phase, has its advantages when used correctly. The muscle spindle activity is increased by the prestretching of the muscle. The duration of this eccentric phase is apparently determined by the degree of impulse desired for facilitation of the contraction. Prolonged loading of the muscle will prevent optimal exploitation of the stretch-shortening cycle.\(^\text{12}\) This is most likely due to the muscle spindle adapting to the increased length over time. The prestretch may very well be the most important phase because it increases the excitability of the neurological receptors, which in turn enhances the reactivity of the neuromuscular system.\(^\text{12,33}\)

The second phase is the amortization phase. This phase constitutes that brief amount of time (coupling time) between the stretching and subsequent shortening of the muscle. It is very rapid, occurring in about 0.3 to 0.5 msec.\(^\text{12,25}\) The importance of optimal coupling time cannot be overemphasized. Nearly every form of literature on plyometrics expands on the concept of a brief amortization phase to enhance the force output of the concentric contraction. Heiderscheit et al\(^\text{9}\) state that the amount of increased work performed is dependent upon the amortization phase, with the shorter the phase the greater the work output by the muscle due to maximal utilization of the stored elastic energy. Stauber\(^\text{28}\) offers two distinct features of the stretch-shortening cycle. First, electromyographic (EMG) activity apparently increases as the muscle lengthens and reaches a maximum just prior to the concentric muscle action (again supporting the fact that there is greater tension in an eccentric contraction versus a concentric contraction). Second, the tension decreases as more time passes between the stretch and shortening phases. A drop in force can be seen if the stretch is held for about one second, although some sources state even less time. Komi\(^\text{24}\) believes that if the stretch is
maintained too long, most of the stored energy is wasted as heat. However, if the shortening occurs immediately after stretching, much of the energy can be made available for external work. A long stretch will cause sarcolemmal “slipping”, which will not allow the elastic potential of the respective crossbridges to be utilized; on the other hand, a short coupling time associated with short-range prestretch will prevent detachment of the crossbridges. This would then allow better utilization of the stored potential energy in the series elastic components during the subsequent concentric contraction.

It is interesting to note that a study on the effects of coupling time was conducted by Bosco and Rusko\textsuperscript{34} in 1983. Their research was based on the fact that human experiments had demonstrated a markedly reduced prestretch potentiation effect in rebound jump exercises after voluntarily prolonging the coupling time. Expanding on this phenomenon, they increased the length of the coupling time not voluntarily but rather through prolongation of the total stretch-shortening cycle in the form of caushing (wearing special soft shoes to increase the amount of time that the feet are in contact with the ground). During running, caushing decreases the force between colliding bodies by increasing the time of collision. This is best accomplished by either running with soft shoes or on a soft surface, which prolongs the stretch-shortening cycle of the leg extensor muscles. The coupling time is consequently increased. This study compared the energetic cost of running steadily on a treadmill while wearing either normal running shoes or special soft shoes. It was found that running with soft shoes required greater energy consumption than running with normal shoes, except at a slow speed of 0.2 m/s. It was suggested that the effect of coupling time as limiting factor for recoil of elastic energy was relevant in fast twitch muscle fibers, which were progressively recruited as
running speed was increased. At slow speed, only slow-twitch fibers were recruited and the enhancement of coupling time was not long enough to allow detachment of crossbridges of these fibers. This finding is consistent in that, unlike the slow twitch muscle fibers, the crossbridge life span in fast twitch fibers is quite short, and subsequently more sensitive to coupling time.

Finally, the third phase is the concentric contraction, which is the enhanced product of the preceding eccentric contraction. It has been well-documented that the faster a muscle is eccentrically loaded, the greater the resultant concentric force produced.\textsuperscript{3,12} Plyometric training relies more on the rate of stretch than on the length of the stretch. It is believed that this concentric response phase is the summation of the setting and amortization phases and is that period of time that the athlete is concentrating on the effect of the exercise while also preparing for initiation of the second repetition.\textsuperscript{12}

This chapter provided an overview of muscle function and how plyometrics is thought to bias neuromuscular activity to result in explosive work output. For a more detailed description of muscle structure and neuromuscular function, the reader is advised to consult an anatomy or physiology text.
CHAPTER 3

PLYOMETRICS AND INJURY

The use of plyometrics in a properly supervised setting may improve athletic performance\textsuperscript{32} but can be dangerous if not performed correctly or under adequate circumstances. Intense stretch-shortening exercise programs are not recommended for the recreational athlete but rather are intended to be advanced strengthening programs for the competitive athlete to enhance athletic performance. These exercises should not be performed for an extended period of time because of the large stresses that are imposed on the body. Because of this, it is important to be aware of adverse reactions to plyometric activities, such as postexercise soreness and delayed-onset muscle soreness. Absolute contraindications to performing plyometrics include acute inflammation or pain, immediate postoperative pathology, and gross joint instabilities. However, the most significant contraindication to an intense plyometric program is noninvolvement in a supplemental weight training program.\textsuperscript{12}

To minimize the risks for potential injury, a thorough medical history, structural evaluation, and functional test should be conducted initially. This will help to screen for any prior or existing medical or orthopaedic condition that would warrant termination of the program. Certain aspects to consider when analyzing the risk for injury include body structure and size, previous injury history, and the role that fatigue will play in the
program. When the program is instituted, it must be structured not only to provide for optimal strength gains, but also to prevent the potential for overuse injuries.3

PLYOMETRICS: AN INJURY REDUCER?

Although it is known that plyometrics can induce injury, ironically they have also been advocated to decrease injury risk in competitive athletes taking part in jumping sports. Programs that incorporate stretching, weightlifting, and plyometric exercises are being used by a number of high school, collegiate, and Olympic sports teams. It is not known whether the programs alter jumping and landing biomechanics, but alterations in performance and injury rate have been reported.11 Incorporating early phase plyometrics into a rehabilitation program (in a well-controlled environment) is essential for the successful return of athletes to their respective sports. Of course at this stage of primary concern are the time constraints of soft tissue healing, but a plyometric program can be valuable in progressively remodeling and re-educating the injured tissues in the shortest, safest period of time. The skeletal and neuromuscular systems must be functionally trained to prepare the athlete for the specific demands required for returning to sports participation, and plyometrics can be very beneficial from this standpoint. It has been observed that when injured tendons are subjected to progressive controlled stress (as they are in most plyometric exercises), the tensile strength of the tendons increases.35 Therefore, the eccentric phase of the muscle contraction can be added as a component in the strengthening phase of the rehabilitation setting. Furthermore, it has been postulated that plyometrics may be of use in the prevention of exercise-induced muscle cramp. Bounding, hopping, and skipping drills may improve the viscoelastic properties of tendons and improve both neuromuscular coordination and running economy. Other
factors in the prevention of exercise-induced muscle cramp include adequate nutrition, stretching, aerobic fitness, strength training, correction of muscle balance and posture, mental preparation, and avoidance of certain types of drugs. Unfortunately, there is very little attention in the scientific literature on prevention of muscle cramp in sports.23

DELAYED-ONSET MUSCLE SORENESS

Plyometrics involve active prestretching under heavy loads, and when considering the muscle fibers as being elastic tissues, it can be expected that this repetitive stretching under high loads can ultimately lead to rupture of the elastic muscle tissue. These ruptures can occur at different sites along the fibers, including the myotendinous junction.36,37 This mechanical trauma to the muscle fibers seems to be the most common cause of injury following athletic activity or exercise, especially after eccentric muscle action. This exercise-induced muscle damage caused by eccentric contraction under imposed loads usually presents as delayed-onset muscle soreness.36 Other examples of muscle injury caused by eccentric contraction include partial strain injury and complete rupture of the muscle. These are all noncontact or indirect injuries that can affect muscle function.38,39 These types of strain injuries account for up to 30% of the injuries seen in a typical sports medicine practice.38,40

Despite the frequency of muscle strain injuries seen in the clinic, the understanding of the pathophysiology, treatment, and recovery of these injuries is limited. Much more is known about pathology involving the ligaments, tendons, and bones.41 Muscle strain injuries that occur when the muscle is put on stretch usually occur while controlling or regulating joint motion. Because of the rapid, forceful activity with which type II muscle fibers are associated, those muscles that contain a high percentage of these
fibers seem to be particularly susceptible to pathology. Included would be the hamstrings, medial head of the gastrocnemius, and rectus femoris muscles of the lower extremity. The fact that these muscles cross over two joints (bi-articular) and are therefore subjected to greater degrees of stretch may play a role in their susceptibility.42

Delayed-onset muscle soreness is gaining more acknowledgement in the literature today, with many studies being done to better describe the phenomenon. Through these studies, it has been found that delayed-onset muscle soreness is more likely to occur after exercises utilizing predominately eccentric contractions versus either isometric or concentric contractions.43,44 This soreness is associated with swelling,45 injury to individual muscle fibers, decreased development of muscle force,45,46,47 and enzyme efflux.43,48 The hallmarks of this condition are reversible pain, weakness, and limited range of motion.41

MECHANICS OF ECCENTRIC INJURY

Eccentric loading in delayed-onset muscle soreness results in microscopic damage to the contractile element of muscle centering on what appears to be random disruptions of the Z-lines. This is especially evident in the undertrained.49 The pain usually becomes most intense one or two days after exercise50; however, weakness and limited range of motion can last for over a week.51,52 Although less frequent, delayed-onset muscle soreness is more severe than minor muscle strains that result in small, insignificant injury to muscle fibers.53 It is important that proper rest and rehabilitation be undertaken with muscle strain injuries to avoid a more disabling injury from occurring in the future.41

The increased risk of injury during eccentric contractions arises in part from the greater average forces developed by fully activated muscles during lengthening as
compared to either shortening or isometric contractions. As a consequence, the increased force development during an eccentric contraction reflects an increased strain on individual crossbridges. The total number of crossbridges attached in a strongly-bound state during lengthening is approximately 10% greater than the number attached during an isometric contraction.

STRAIN AND SPRAIN INJURIES

Muscle and tendon strains and ligament sprains are caused by excessive tensile force that produces rupturing of the tissue, which in turn results in hemorrhage and swelling. The likelihood of strains or sprains occurring depends on two things: the magnitude of the acting force and the cross-sectional area of the muscle. Strength and cross-sectional area of muscle are directly proportional; the greater the cross-sectional area of a muscle, the greater its strength. This translates into more force being produced by the muscle as well as more force being translated to the attached tendon. Tendons with greater cross-sectional areas can withstand higher amounts of force because increased cross-sectional area translates into reduced stress. By virtue of the collagenous composition, tendons are about twice as strong as the muscles to which they attach and for that reason it is almost always the muscle portion of the musculotendinous unit that ruptures first. Tears usually develop when tendons are stretched to approximately 5% to 8% beyond their normal length.

MUSCLE STRAIN

Strains are injuries involving the musculotendinous unit and may involve the muscle, tendon, and the junction between the two, as well as their attachments to bone. Strains, or pulls, can be caused by overstretching, overstretching, violent contraction
against heavy resistance, strength imbalance between agonists and antagonists, or abnormal muscle contraction. The portion of the musculotendinous unit that is damaged depends on which component is the weakest at the moment of injury. In younger athletes, the injury more commonly involves either an avulsion of a piece of bone attached to the tendon or an epiphyseal fracture. Older athletes are more susceptible to injury of either the tendons themselves or the musculotendinous junctions.\textsuperscript{57}

Fatigue and weakness play a significant role in the susceptibility to muscle strain. It has been suggested that passive elements of muscle have the ability to absorb energy. This ability is greatly enhanced when the muscle is activated, which may also suggest that muscles are able to protect themselves and joint structures from injury. The more energy that the muscle can absorb, the more resistant the muscle is to injury. The ability of the muscle to absorb energy is influenced by both the passive and contractile elements of muscle. The passive elements include connective tissue and the fibers themselves; these do not depend upon activation. The contractile element of the muscle also participates because activation of the muscle increases the ability to absorb energy.\textsuperscript{41}

Weakness and fatigue can result in injury because they diminish the ability of the muscle to contract, which in turn reduces the ability of the muscle to absorb energy. This makes the muscle more susceptible to muscle strain injury. In normal conditions the increase in energy absorbed because of contraction is about 100\%.\textsuperscript{41}

Strains have been classified into three groups based on severity, which is determined by the amount of damage to the fibers of the musculotendinous unit.\textsuperscript{57}

1. A first degree (mild) strain involves stretching and slight tearing of the tissues. There is some discomfort with use of the involved muscle, but
generally little or no disability. Range of motion (ROM) is normal with only insignificant loss in strength. These injuries often go unreported, with continued activity.

2. A second degree (moderate) strain involves a significant tearing of fibers, yet there still remains some continuity of the musculotendinous unit. Injury may range from a few fibers to the majority of the fibers in any given unit. Signs and symptoms include varying degrees of pain, swelling, and loss of both strength and flexibility. There is an area of point tenderness on palpation, with local pain during active, resistive, or stretching movements. With this degree of strain, the athlete should be treated symptomatically and be allowed to return to activity as tolerated. This may take anywhere from a few days to several weeks.

3. A third degree (severe) strain involves complete destruction of the continuity of the musculotendinous unit and results in instant disability. This rupture may be along the musculotendinous unit or may involve an avulsion of a bone fragment at its attachment. Often a snap is heard or felt at the time of injury, with an associated palpable, and many times visible, gap at the injured site. Significant weakness and loss of function result. In the case of a severe strain, treatment should begin initially with cold, compression, and elevation, followed by referral to a physician for diagnosis and treatment. Third-degree strains produce severe pain, loss of range of motion, and complete instability of the joint.
Although strains commonly occur when performing plyometric activities, their occurrence can be minimized. A good warm-up, warm temperature, and stretching have beneficial effects on the mechanical properties of muscle. Strength, endurance, and flexibility also protect the musculature and, furthermore, are essential for maximum athletic or rehabilitative performance. When considering the factors involved in recovery from strain injuries, it is important to also look at the susceptibility of reinjury during the recovery process.\textsuperscript{41}

Faulkner et al\textsuperscript{53} state that severe injuries to skeletal muscle are usually associated with forced stretching of fully activated muscles and are characterized by an initial mechanical injury and a secondary biochemical injury. Delayed-onset muscle soreness is reported in association with the secondary injury, with complete recovery taking anywhere from 7 to 30 days depending on the severity of the injury. Using protocols that incorporate eccentric contractions will produce a hypertrophied, stronger muscle. This muscle supposedly becomes “trained” to perform the protocol of repeated lengthening contractions that previously caused the injury; however, now no injury is sustained.

LIGAMENT SPRAIN INJURIES

Sprains, another injury commonly encountered in plyometric exercise, are injuries involving the ligaments. This type of injury occurs when the ligaments, which are basically inelastic, are forced to move in an abnormal direction and thus become stressed. Ligaments are designed to prevent abnormal motion at a joint; if forced beyond its limit, damage will occur at the weakest point in the ligament. The severity of damage depends on the amount and duration of the abnormal force. Like strains, sprains can be classified as mild, moderate, or severe, based on the extent of the ligament damage. Sprains
usually occur from outside forces, such as landing the wrong way (e.g. depth jumping in plyometrics). Physician referral is required in severe sprains if:

1. significant instability is demonstrated by passive stress tests,
2. significant joint effusion occurs within a few hours after the injury, or
3. there is doubt about the status of the sprain.\textsuperscript{57}

Plyometrics has been reported to be the leading cause of soft tissue injury in athletes that take advantage of this training method.\textsuperscript{59} The normal healing process takes place in a regular and predictable fashion, and by following various signs and symptoms exhibited at the injury site the progress of healing can be monitored. Knowing when it is appropriate to begin rehabilitation and when it is acceptable to return to plyometric exercise and, likewise, competition require knowledge and understanding of adequate soft tissue healing.\textsuperscript{60} Basically, if the signs of inflammation that occur with soft tissue injury are present, it would be wise to allow these to subside before training may continue. These signs include redness, heat, swelling, and pain.
CHAPTER 4
DEVELOPING A PLYOMETRIC PROGRAM

The use of plyometrics as a training mechanism to achieve gains in power is a relatively new concept that has been documented to improve performance. Albert\(^3\) states that “scientifically designed plyometric programs, geared towards the needs and specific limitations of each individual, can serve to provide the sports performance specialist with a viable, practical training form for developing additional measurable power.” Jacoby\(^61\) emphasized the need for plyometric strength training in addition to the accepted modes of training (i.e. skill technique and general progressive weight training) for events such as sprints, hurdles, jumps, and throws. However, plyometric exercise in itself is not an adequate training mechanism. According to Conway,\(^59\) it is simply a means of adding a strength and power development component to individual programs. It can be considered as a completion to the chain of events that occurs in the athlete’s total strength development package. It can be a very valuable asset for those athletes who have difficulty incorporating strength gains with quickness. Many competitive athletes have tremendous strength and muscle bulk (cross-sectional size of the muscle mass) but yet cannot convert this strength into movement. As pointed out previously, plyometrics attempts to bridge the gap between strength and speed of movement. This results in gains in power.\(^61\) Of course, strength and plyometric training alone are not the only aspects of competitive training. Other physical factors such as endurance, flexibility, skill, reaction
time, and speed are equally important for attaining optimal sports performance.\textsuperscript{10} A flexibility exercise program has the effect of enhancing the stretch-shortening cycle performance.\textsuperscript{6}

If the body is to be propelled from a stationary position to maximum movement in the least amount of time, the explosiveness generated in a plyometric exercise must be specifically developed in the joints and muscles involved in the actual event for which the athlete is preparing.\textsuperscript{26} The ultimate goal is to explode as quickly as possible and as strongly as possible on each repetition. It is important to design plyometric programs that are sport-specific since the exercises are essentially attempting to train the neuromuscular system by teaching it to better accept the increased strength loads. Exploitation of the stretch reflex improves the ability of the nervous system to react with maximal speed to the lengthening muscle. This, in turn, increases the ability of the muscle to concentrically shorten with maximal force.\textsuperscript{3} Plyometric programs should be based on the SAID (Specific Adaptation to Imposed Demands) principle to ensure that the body is adequately prepared to accept the stresses it will encounter in the athletic activity.\textsuperscript{3,33} Activity-specific training is associated with improved coordination, learning, synchronization of motor units, and reflex motor neuron activity. It also increases fast-twitch muscle fiber area with a reduction in EMG activity and muscle spindle sensitivity.\textsuperscript{23}

The law of specificity applies not only to training specific muscles and muscle groups but also to training at specific speeds. According to Chu,\textsuperscript{62} during complex training it is of vital importance to train at maximum speeds, because submaximal efforts will produce only submaximal results. He gives the examples of using ankle weights or
running in sand as violating the law of specificity. Although these are popular training methods and may strengthen the ankles and hamstrings, if performed repetitively the muscles will be trained to run in a slower manner.

Various factors need to be considered when planning plyometric activities. These include strength, training level, age, and recovery. Eventually plyometrics should be incorporated into strength training to enhance strength and explosive power, while aiding in the development of the technical skills needed for the event, whether it be jumping or throwing. Hagerman emphasizes the value of plyometrics in that many of the actions and movements of a sport can be incorporated in the exercises and drills. He continues by saying that in addition to being important in the improvement of speed, plyometric exercises are natural activities, easy to do, and inexpensive in that very little equipment is required. Furthermore, they take relatively little time in the training regimen. Besides physical benefits, psychological benefits may result as well. Incorporating plyometric activity into the workout may help to prevent boredom and mental fatigue from setting in and also may keep the body from becoming overly comfortable. Finally, these drills also raise skill levels by enhancing both motor coordination and hand-eye coordination.

BEGINNING THE PLYOMETRIC PROGRAM

Regardless of an athlete’s specific sport or level of fitness, it is important to develop an adequate strength base first. This is due to the fact that as one begins incorporating explosive training, the forces created may reach as much as twenty times one’s body weight. Therefore, adequate concentric, eccentric, and isometric strength is necessary to withstand these forces. The implementation of any plyometric program begins with the development of an adequate strength and physical condition base. This
results in greater force generation from the increased cross-sectional area of the muscle as well as the resultant series elastic components. \(^{12}\) The Eastern bloc countries have arbitrarily selected a one-repetition maximum in the squat at 1.5 to 2 times the person's body weight before lower body plyometrics may be initiated.\(^ {32,63}\)

Because plyometrics are demanding and place considerable stress on the body, they should be introduced slowly into the conditioning program.\(^ {3}\) An all-around reasonable level of fitness should be achieved; for the lower extremity, the athlete should be used to jumping, sprinting, and stretching. A thorough warm-up is also essential. Watson suggests jogging a quarter- to a half-mile followed by stretching exercises with particular emphasis being paid to the quadriceps, hamstrings, calves, back, and hip flexors.\(^ {8}\) Proper footwear also plays a role.\(^ {8,62}\) Chu\(^ {62}\) states that a good cross-training shoe is ideal for almost all plyometric exercises. He also points out the importance of performing the exercises on appropriate jumping surfaces such as a wrestling mat or spring-loaded floor. However, as Kulund\(^ {63}\) points out, if the landing surface is too soft it will absorb the impact too much and the elastic recoil and training effect will be reduced.

 Jacoby and Fraley\(^ {59}\) give some guidelines for introducing plyometrics into the training routine. They say plyometric activities need to be initiated early, during skill and technique development, and that all concepts and drills should be fully explained to the athlete before beginning any activity. It is wise to have the assistance of a qualified instructor when performing any new plyometric activity.\(^ {62}\) A definite progression must be followed when performing plyometric jump training, with emphasis on the proper execution of the activity rather than on the number of repetitions. It is also vital to rest or
stop the activity when fatigued, because improper performance in drills can lead to improper jump performances. 59

Albert 3 lists some pointers for initiating plyometrics. When beginning a plyometric training program, it is wise to perform exercises of low motor complexity and intensity and build up to more complex motor exercises during the competitive phase. The drills should be specific to the goals established for the athlete. For example, if the goal is to improve vertical jump, jumping would be the best method of training. If the sport-specific skills can be broken down into smaller components, these should be trained first and then rebuilt into a coordinated movement pattern. It is also important to limit the number of exercises to no more than three times weekly during the preparatory phase. 3,8 Watson 8 suggests spending the first two to three sessions learning the exercises. The following week should then be spent performing one set of 10 repetitions of each exercise at each session, with one set of each exercise being added each week thereafter. By the fifth week, five sets of 10 repetitions of each exercise are being performed.

Jacoby 61 believes that one session per week is sufficient for the beginner, and recommends a maximum of two sessions per week for the more advanced. It appears that more research needs to be done to find out what an optimal training schedule would be. More than likely it depends upon the specific activity that the athlete is going to be performing. Perhaps the best solution would be to individualize each plyometric training program to meet the participant’s specific needs and goals.

A thorough strength evaluation should be conducted before any high-intensity plyometric drills are performed. It is wise to conduct this sometime during the course of the training program; however, it is not necessary before beginning light plyometrics
early in the program. Strength is assessed to determine the correct volume and intensity for load progressions. The athlete must have adequate strength to work through the plyometric drills and to be able to recover before moving into subsequent training sessions. The evaluation should also be done to examine the athlete’s strength in terms of the requirements for different events. It can then be determined which needs to be emphasized more: the stretch reflex or maximum strength. This pertains particularly to jumpers, as elite jumpers require great amounts of eccentric and concentric strength. Long jumpers exert over 10 times their body weight during take-off, while triple jumpers exert nearly 12 times their body weight. Therefore, jump strength activities are of vital importance.

**TRAINING PRINCIPLES**

Various authors have indentified principles to keep in mind during plyometric training. Dintiman\(^1\) lays out some of the general guidelines to help achieve optimal results from any plyometric program. These are as follows:

1. The rate at which a muscle is stretched is more important than the distance it is stretched.
2. The faster the muscle is forced to lengthen, the greater the tension it exerts.
3. The faster the eccentric contraction is followed by the concentric contraction (amortization phase), the more explosive the shortening contraction will be.

The exercises should always be done vigorously and with good technique to get the most out of the program. To avoid excessive fatigue, it is wise to combine milder exercises with those that are more vigorous during each workload. This will vary the
intensity to some degree. Furthermore, a good warm-up prior to and immediately following each exercises session is necessary, as with any athletic activity.\textsuperscript{10}

The warm-up is one of the most important aspects of the training regimen. It is designed to provide the body with an adequate physiologic conditioning before beginning the plyometric program. An active warm-up can facilitate muscular performance by increasing blood flow, muscle and core body temperatures, speed of contraction, oxygen utilization, and nervous system transmission.\textsuperscript{12} Warm-up exercises can include light jogging or rope jumping, for example. It is also imperative to stretch out well before beginning plyometric activities to reduce the risk of injury to the musculotendinous junction that could otherwise occur.

The next two chapters will provide an overview of the usefulness of plyometrics when training both the upper extremity (Chapter Five) and lower extremity (Chapter Six).
CHAPTER 5

PLYOMETRICS FOR THE UPPER EXTREMITY

Any training mechanism incorporating the stretch-shorten cycle can be considered a plyometric activity. Likewise, there are numerous plyometric exercises that can be used both in an athletic as well as rehabilitative setting to improve function and increase power in both the upper and lower extremities. Plyometrics are more often regarded as sports-enhancing activities, and therefore its role in athletics has been emphasized. However, the rehabilitative aspect also needs to be addressed, since plyometrics are frequently used to restore strength and proprioception following injury.

Plyometric exercises can be divided into upper and lower extremity activities, with the latter being more often used in the form of various types of jumps. Although this is the case, plyometrics are not strictly for either the upper or lower extremity; for example, the use of adequate arm propulsion is important in achieving significant gains in vertical jump, as demonstrated by Brown et al. in their study performed on high school basketball players. Inasmuch as the arms are necessary for large gains in jump height, the legs are vital for providing a stable base of support when performing upper extremity plyometric activities. The entire body must perform as a synchronized unit with mobilization and stabilization occurring simultaneously for effective performance.
UPPER EXTREMITY PLYOMETRICS IN REHABILITATION

As previously stated, upper extremity plyometrics are much less recognized in athletic training programs than are lower extremity plyometrics. In fact, the efficacy of plyometric training for the upper extremity has not even been documented. Those athletes that participate in sports involving throwing or overhead motions (such as swinging a tennis racquet) or patients who have undergone shoulder or other upper body surgery are the most likely to utilize drills for the upper extremity.

It is important to be sure that there is full and painless range of motion in the upper extremity joints, particularly the shoulder, before instituting plyometrics. Of course, exercises incorporating flexibility and strengthening should be incorporated into the training regimen as well. The plyometric drills used should be similar to the activity to be performed if used in the athletic training environment. This could involve throwing a baseball or swinging a golf club, for instance. Muscles specifically used in the motions should be predominantly used.

The purpose of upper extremity stretch-shortening throwing exercises is to provide the athlete with advanced strengthening exercises that are more aggressive and at higher exercise levels (higher demands on shoulder musculature) than those provided by other training techniques, such as a simple isotonic dumbbell program, which is often employed. Plyometrics for the shoulder can only be utilized once a strengthening program has been performed for an extended period of time. Furthermore, a satisfactory clinical examination is also indicated. It is suggested that plyometrics be initiated when the strength of the affected extremity is 90% of the unaffected extremity. Full, painfree range of motion is also indicated before overhead plyometrics can be performed;
therefore, it is necessary that a flexibility program be initiated early in the rehabilitation process.

Pezzullo et al. stress that the functional phase of the athlete's program is the important link between well-planned rehabilitation and successful return to full competition in the overhead athlete. It is imperative that the SAID (specific adaptation to imposed demands) principle be followed so that the late stage of rehabilitation be specifically tailored to meet the individual's needs. For throwing athletes, specifically targeted are the eccentric actions of the rotator cuff and accompanying musculature.

Upper extremity plyometric exercises can be conducted in the form of push-ups either against the floor or standing and pushing against a wall, or they can be done with the use of equipment such as a medicine ball or surgical tubing. Likewise, they can be done by catching and throwing a weight, such as a heavy punching bag that is suspended by a rope from the ceiling. The athlete swings the weight away from him, and as it swings back, catches it at shoulder height, passively stretching his throwing arm, shoulder, and torso muscles. Quickly after the weight is caught it is thrown again in the opposite direction. The intensity of this type of activity can be progresssed by increasing one of three things: the weight (i.e. punching bag), the distance thrown, or the length of the rope.

THROWING BIOMECHANICS

There are three phases of overhead throwing: cocking, acceleration, and deceleration. The cocking phase serves to increase the distance through which force may be applied to the ball. At the end of the cocking phase, the glenohumeral joint is in a
position of maximum external rotation, the scapula is retracted, the elbow is flexed, and the trunk is extended.\textsuperscript{33}

The acceleration phase is very explosive. It begins with the shoulder in a position of maximum external rotation,\textsuperscript{66,67} at which point the speed of shoulder internal rotation is 0°/s. At termination, however, this speed rises to a maximum of 7000° to 9000°/s. This phase is very brief, lasting for less than a second, and ends with release of the ball.

The third phase, deceleration, allows for a quick but comfortable reduction in speed of the throwing arm. The shoulder rapidly internally rotates and horizontally adducts, with eccentric action of the rotator cuff muscles, which serves to decelerate the forward momentum of the arm while at the same time protecting the posterior structures of the shoulder complex. The scapulothoracic muscles also eccentrically contract not only to decelerate the scapula but also to provide a stable base for the rotator cuff to act upon.\textsuperscript{33}

Athletic injuries of the shoulder are quite common, especially in throwing activities, due to the accelerated open chain movement that makes it particularly susceptible. There is little inherent bony stability in the glenohumeral joint, and optimum function depends on the interaction of static soft tissue restraints and dynamic muscle stabilizers. Because of the intense acceleration during the throwing motion, a protective dynamic type of activity that will strengthen the shoulder in a functional manner should be introduced during the rehabilitation program. The two-handed overhead medicine ball throw is both dynamic and protective. By using the uninvolved arm as well, less stress is put on the affected shoulder.\textsuperscript{18}
MEDICINE BALL EXERCISES

It has been determined that the medicine ball is a valuable tool in the upper quarter plyometric program.\textsuperscript{68,69} Cordasco et al\textsuperscript{18} conducted a study which concluded that the use of the two-handed overhead medicine ball throw serves as a bridge that links the general static-type resistive programs to the more demanding and dynamic sport-specific activities. Benefits of this type of throw are listed below:

1. It is a relatively simple and straightforward throw to perform.
2. In a rehabilitation setting the use of both upper extremities provides protection and support by the uninjured arm.
3. At the end of the cocking phase this throw places the affected extremity in relatively less abduction and internal rotation, avoiding the risk of subluxation and instability.
4. Throughout the cocking and acceleration phases of the throw the shoulder is elevated in the plane of the scapula rather than the coronal plane, optimizing length-tension relationships of the shoulder abductors and rotators.
5. Trunk rotation is eliminated, resulting in less generation of momentum and energy and possibly reducing the potential for injury.

Medicine ball activities require having a partner, unless the plyoback\textsuperscript{®} system (Functional Integrated Technologies, Watsonville, CA) is used. This uses a rubber-coated ball called a plyoball\textsuperscript{®} and a spring-loaded, bounce-back device which is the plyoback\textsuperscript{®} Examples of medicine ball exercises include:\textsuperscript{3,12}

Chest pass in standing

Chest pass in kneeling (1-hand or 2-hand)
Soccer throw
Step and pass
Side throw

Pezzullo et al\textsuperscript{33} give examples of exercises that can be done using the plyoback system with a two-pound plyoball. These include internal rotation, external rotation, and reverse throw exercises.

Although medicine ball plyometric exercises have proven to be successful in some training regimens, not everyone experiences significant improvement in strength or power when employing this mechanism. Heiderscheit et al\textsuperscript{9} conducted a study comparing the effects of isokinetic versus plyometric training on the shoulder internal rotators. The study involved 78 female subjects that were randomly assigned to three groups: a control, isokinetic training, or plyometric training group. Measurements taken both before and after training included:

1. concentric/eccentric isokinetic power measurements of the shoulder internal rotators at 60°/s, 180°/s, and 240°/s;
2. kinesthetic measurements of shoulder internal rotation, external rotation <45°, and external rotation >45°; and
3. a softball distance test.

Both groups trained twice a week for 8 weeks. The plyometric group trained using the Plyoback System\textsuperscript{®} and the subjects stood 5 ft from the center of the trampoline and threw the weighted balls at it using a one-handed overhead throw of the dominant arm. The protocol consisted of using a 3-lb ball for three sets of 10 throws for the first 2 weeks and four sets of 10 throws for the next 2 weeks. The 4-lb ball was then used for the final
4 weeks of the study. Subjects completed three sets of 10 throws during weeks five and six and four sets of 10 throws for the final 2 weeks of the study. A rest break of 90 seconds was incorporated between each set, and subjects were instructed to throw with all their effort to ensure optimal rate of muscle stretch. Using multiple analyses of variance with repeated measures, no significant (p<.05) pre- or posttest differences were found with kinesthetic testing, while differences were significantly greater for the isokinetic group at 60°/s eccentric, 120°/s concentric and eccentric, and 240°/s concentric and eccentric. A one-way analysis of variance was performed on the softball throw data, and no significant differences were found with the two training mechanisms. The study concluded that isokinetic training of the shoulder internal rotators increases isokinetic power, but neither isokinetic nor plyometric training resulted in a functional improvement with the softball throw.3

THERABAND™ EXERCISES

Theraband™ (Hygienic Corporation, Akron, OH) is a resistive exercise system that provides an inexpensive and easy way to train the muscles of the upper extremity both concentrically and eccentrically. It is often used in the clinical setting and is an effective component of many patients' home exercise programs.17 Theraband™ is an elastic type of material that comes in a variety of colors based upon amount of resistance offered. Using these varied resistances, it can be employed to strengthen the phases of the throwing motion accordingly. Pezzullo et al33 provide examples of three exercises that can be done using the Theraband™ resistive system.

1. Internal Rotation. Initially, start in 0° of shoulder abduction and progress to 90° of abduction, based on symptoms and quality of motion. In the starting position, the
Theraband™ should be tight and positioned to resist the internal rotators of the shoulder. Concentrically contract the internal rotators until maximum internal rotation is achieved. Eccentric contraction of these muscles then follows, upon which the starting position is resumed.

2. External Rotation. As with internal rotation, start in 0° of shoulder abduction and slowly progress to 90°, again based on tolerance and quality of motion. Start with the Theraband™ taut and positioned to resist the external rotators of the shoulder. Concentric contraction of the external rotators to end range is then followed by eccentric contraction of the external rotators which returns the humerus to the starting position.

3. Diagonals. Diagonal patterns can be used to mimic the acceleration and deceleration phases of throwing. The anterior shoulder musculature can be resisted by attaching the Theraband™ to a stationary object and then standing in front of it and performing the throwing motion. This will strengthen the muscles used in the acceleration phase. By attaching the Theraband™ to a stationary object and standing behind it (and throwing), the posterior shoulders muscles are strengthened. These are the muscles that decelerate the arm in throwing. Tying the Theraband™ to a ball makes this exercise even more sport-specific.

This chapter served to provide a brief overview of the use of plyometric training for the upper extremity and some exercises that can be incorporated into the rehabilitation or training regimen of the post-surgical patient or overhead athlete. The next chapter attempts to explain the use of lower extremity plyometrics and some of the training techniques that may be beneficial to the patient or athlete that hopes to take advantage of this training mechanism.
CHAPTER 6
PLYOMETRICS FOR THE LOWER EXTREMITY

When people hear the word plyometrics, usually what first comes to mind is some kind of jumping activity. That is because plyometrics are much more frequently incorporated into lower extremity work-outs than those for the upper extremity. In fact, plyometrics were first designed as jumping programs, but it was later realized that the same principles used in the jumping exercises could be applied to throwing activities as well. Nonetheless, the use of plyometrics for the lower extremities is much more common, especially in the athletic training realm. Upper extremity plyometrics are more often found in rehabilitation programs.

MUSCLE RECRUITMENT

In Chapter Two, the distinction between fast-twitch and slow-twitch muscle fibers was made. The predilection for fast-twitch fibers that occurs with plyometrics can be seen in a study by Bosco and Rusko. In this study, ten male subjects were asked to run on a treadmill at different speeds using special soft shoes in addition to normal shoes. It was found that running with the soft shoes required greater energy expenditure than running with normal shoes, except at slow speeds (0.22 m/s). It was suggested that the effect of coupling time (amortization phase) as limiting factor for recoil of elastic energy was relevant in fast twitch fibers, which were progressively recruited when the running speed was increased. It can be deduced, then, that the fast-twitch fibers are more
sensitive to coupling time due to their very short crossbridge lifetime. Only slow-twitch fibers were recruited at slow running speeds because of their longer crossbridge lifetime. From this study it was concluded that the different recruitment of slow-twitch and fast-twitch fibers influenced the pattern of recoil of elastic energy, which was dependent on running speed.

Another interesting finding in lower extremity plyometrics, primarily drop jumps, is the tendency for the leg extensor muscles to be activated prior to the feet contacting the ground. This has been termed the preactivation, or preinnervation, phase and was demonstrated in a study by Avela et al in the triceps surae and vastus lateralis musculature. The loading of the muscles was affected using three different types of drop jump exercise, allowing separate modifications of the loading of these muscles. The loading was influenced by changing either the velocity of the center of gravity or the body mass directly. In all of the experimental conditions, the preactivation of the muscles started well before contact with the ground was reached. The duration of this preactivation, however, depended on the type of stretch exercise. From the results there appeared to be a clear interaction between the preactivation of the muscles and that part of the muscle output that was affected by the segmental stretch reflex system. It is proposed that the preactivation is preprogrammed but can be modified by proprioceptive, vestibular, and visual inputs. Therefore, the control mechanism of this preactivation phase may be from a variety of controlling centers and inputs.

THE DEPTH JUMP

One of the most common plyometric exercises is the depth jump, which is simply jumping from a predetermined height. This involves a rapid lowering of the body's
center of gravity, followed immediately by a maximal vertical jump.\textsuperscript{71} The typical drop height is within the range of 0.3 m to 1.0 m,\textsuperscript{72} although there is little consensus among researchers as to what exactly is the optimal height.\textsuperscript{73} Brown\textsuperscript{64} recommends depths ranging from 0.2 m to 3.2 m, but in his study on vertical jump performance he found that the greatest improvements were made using 0.4 m to 0.5 m heights. However, in a study performed by Lees and Fahmi\textsuperscript{73} using heights ranging from 0.12 m to 0.68 m, it was found that the peak instantaneous power output was highest with the 0.12 m height. This power was measured as the product of the instantaneous force and instantaneous velocity of the center of gravity. The power output progressively diminished as the drop height increased. It is believed by the researchers that as the drop jump height increases, biomechanics of the landing and jumping actions change and the body is obliged to protect itself. This results in a loss of the ability to recover the original potential energy available for the jump. The researchers also conclude that drop jump performance is very much a matter of jumping skill and technique as well as ability.\textsuperscript{30} It has been concluded that dropping from a height greater than 42 in may be counterproductive because increased time is spent in the amortization phase and energy is lost as heat. It is general consensus that, clinically, lower box heights should be used for children and untrained individuals, while more experienced and higher-trained athletes use higher box heights.\textsuperscript{3}

Although height is surely an important consideration when performing depth jumps, the quality of the jumps is what is most important. The response should be powerful with full body extension at push-off regardless of the box height. Certain precautions must be followed to prevent injuries due to the high stress reactions on the muscles and tendons when performing these plyometric exercises.\textsuperscript{3}
1. Before depth jumping is initiated, low to moderate in-place jump training should be performed.

2. Initial depth jump height is not to exceed 24 in.

3. Maximal depth jump height should not exceed 42 in. (Although good improvements have been noted beyond this height, both immediate and overuse injuries are far more likely to occur with excessive heights.)

4. Depth jump training with weighted vests, belts, or dumbbell weights can be extremely stressful and should be performed with great caution. Jacoby and Fraley\textsuperscript{59} suggest this type of overload training be done only after the athlete completes strength evaluation tests and should not be used early in the training period.

Albert\textsuperscript{3} lists a progression sequence that can be used when performing depth jumps to achieve optimal results while promoting safety to avoid premature injury. The sequence is as follows:

1. Box drop; rebound for maximal height
2. Box drop; rebound linear for distance
3. Box drop; rebound to another box (specific height is not stated, but is likely to be the same size or lower than the initial box)
4. Box drop; rebound vertically, sprint upon landing
5. Box drop; rebound linearly, sprint upon landing
6. Repeat above sequence with one leg hops
7. Repeat entire sequence with lightweight vest or hand weights.
To emphasize the need to rebound very quickly, the author states that the athlete should be instructed to "touch and go," or perhaps the analogy of jumping onto a hot bed of coals could be used.

A good warm-up is essential before beginning lower quarter plyometrics. Because they require flexibility and agility, the athlete should prepare for them adequately with a light jog, PNF (proprioceptive neuromuscular facilitation) stretching, form-running drills, and a few low-intensity jump-throughs. Beginners should start with low-intensity, simple plyometrics. This may include basic rope jumping, jumps from the ground (as opposed to depth jumping from a box), and double-leg bounds and hops. More advanced drills can be added as power increases and technique improves. This may include one-legged drills and depth jumps. Power gains will be seen with an increase in intensity and difficulty and progressive overloading which forces the muscles to work harder.63

The majority of lower quarter movements in sports occur in the closed kinetic chain. Incorporating lower extremity closed chain plyometric exercises into a sports rehabilitation program can be quite beneficial. Through a gradually progressed eccentric loading program, such as resisted knee extensions, healing tendinous tissue is stressed and thus yields an increase in ultimate tensile strength. Adequate progression is of utmost importance when using plyometrics in a rehabilitative setting. Eccentric loads can be applied through jump-downs (i.e. depth jumping) progressing from very low heights to higher levels (without exceeding 42 in). Bilateral simple jumping drills can be progressed to unilateral hopping activities. Lateral jumping drills can be progressed to lateral hopping activities. These lateral drills are especially useful when medial soft tissue structures of the knee have been injured, such as in a valgus stress injury. In an
effort to train the structures to accept greater valgus loads such as full speed cutting, lateral bounding drills should first be performed. Acceleration, deceleration, and momentum forces can then be added. To cover greater distances when performing lateral movements, a slide board may be used. Lateral movement exercises utilizing a sport cord can be used for increasing the lateral quickness and stability in the postoperative anterior cruciate ligament (ACL) reconstruction patient.

COMMON PLYOMETRIC ACTIVITIES FOR THE LOWER EXTREMITIES

The following is a compilation of the more frequently-performed plyometric jumps, hops, and bounds used in training programs, as outlined by Kulund. It will be emphasized again that quality of the jump is what is most important, and that no jumping technique will bring optimal results if performed incorrectly and without maximal effort. As little time as possible should be spent on absorbing the impact of the landing; beginners are often encouraged to think of the ground as a "hot stove" and spring from it quickly.

JUMPS

1. Double-leg-tuck jumps. From a standing position, spring from the ground, flexing your hips in the air until your thighs are parallel to the ground. Grasp your knees briefly with both hands and then extend your legs to the ground. Perform two sets of ten jumps with a one-minute rest between sets.

2. Standing triple jump ("hop, step, and jump"). Jump forward off both legs and land on one foot (the hop). Then let your momentum carry you forward to land on the opposite foot (the step) and conclude by jumping from that foot to a two-
footed landing (the jump). Perform five full triple jumps with a one-minute rest between each jump.

3. Standing long jump. Begin from a starting line with your feet shoulder-width apart. Leap forward as far as you can using your arms to assist in the movement. Perform five full jumps, rest two minutes, and perform five more.

HOPS

1. Double-leg-speed hops. Stand erect and hop forward on both legs, concentrating on height rather than distance. Perform two sets of ten consecutive hops, with a one-minute rest between sets.

2. Single-leg-speed hops. Start with a two-legged pushoff. Land on one foot and subsequently push off with that foot. Perform two sets of ten consecutive hops on each leg, concentrating on height rather than distance. A one-minute rest is indicated between sets.

3. Bag, box, cone, hurdle, tire, or cinder block jumps. With feet together, clear the first cone and then continue going forward over the next ones. Perform two sets over at least six cones, with a two-minute rest between sets.

4. Bag, box, cone, hurdle, tire, or cinder block hops. Stand beside a cone with your feet together. Hop over and back repeatedly. Perform two sets for 30 seconds each, with a two-minute rest between sets.

BOUNDS

Bounds are exaggerations of the normal running stride that lead to faster running and higher jumping by improving stride length. The following bound drills should each be followed by a one-minute rest between sets.
1. Single-leg bounds. With a running start, bound on a single leg for 25 yards. Shorten the radius of movement of your leg by tucking your heel against your buttocks and moving your thigh forward rapidly, extending your knee and reaching for a landing on the same leg. Perform two sets at a distance of 25 yards each.

2. Alternate-leg bounds. Use the same "reaching and pulling" technique as in the single leg bound, but land on alternate feet. Perform two sets at a distance of 25 yards each.

3. Combination bounds. Perform combinations of single-leg bounds or combine alternate and single-leg bounds rhythmically. Examples include left-left-right, right-right-left, or left-left-right-right-left-left patterns. Perform two sets at a distance of 25 yards each.

TRAINING OBJECTIVES

To ensure optimal gains in strength and power when performing plyometric jumping activities, Jacoby and Fraley\textsuperscript{59} list some training objectives to follow.

1. Use proper foot placement. This involves the ball of the foot while running and flat on the foot while jumping. In both instances, the calf muscles (triceps surae) should be sufficiently loaded so the athlete is in contact with the ground in the shortest possible amount of time.

2. Transfer as much momentum as possible from the free limbs to the support leg. (The more force directed to the ground via the support leg, the more force delivered back by the ground.) The objective in this case is to combine the forces
generated by the support leg with additional forces provided by the swinging arms and free leg into one instantaneous reaction against the ground.

3. The speed at which the muscle fibers are forced to lengthen has a direct bearing on the resultant force.

PLYOMETRICS FOR SPECIFIC SPORTS

Now that the concepts underlying the use of plyometrics have been explained and training principles have been emphasized, some of the specific sports in which plyometric training can be especially beneficial will be addressed. The following lists some common sports and plyometric activities that can be especially beneficial for each.¹⁰

ICE HOCKEY

Off-season (perform at least twice/week): step-ups and step-downs, vertical jump, bench jump, serial bench jump, side jump, tuck jump, obstacle jump, bounding.

In-season: vertical jump, bench jump, side jump. These should be performed on the same days as weight training.

SOCCER

Off-season (2 to 3 workouts/week): vertical jump, bench jump, serial bench jump, side jump, obstacle jump, bounding, stair running. Plyometrics are excellent for improving leg power and speed as well as explosive power needed for heading the ball, and for goalie play.

In-season: vertical jump, bench jump, side jump. These should be done on the same days that weight training is performed.
FOOTBALL

Off-season (2-3 times/week): vertical jump, bench jump, serial bench jump, side jump, tuck jump, obstacle jump, bounding, stair running.

BASKETBALL

Off-season (every other day): Circuit training, which involves performing a variety of different types of exercises in sequence, is recommended. For example, a typical circuit might include 15 to 20 exercises for the upper body, lower body, stomach, and back. The circuit training method recommended is as follows: vertical jump, push-ups, sit-ups, leg lifts, chin-ups or pull-ups, adductor exercise, sit-ups, isometric leg curls, squat thrust, leg raises, back arch, dips, sit-ups, vertical jump.

In-season (at least 3 days/week): vertical jump, serial bench jump, side jump (slalom), hopping and skipping. Plyometrics can greatly improve leaping ability in basketball players and can be incorporated into routine basketball jumping or rebounding drills.

VOLLEYBALL

Off-season (2-3 times/week): vertical jump, bench jump, serial bench jump, side jump, obstacle jump, weighted jump (wearing weighted vest or ankle/wrist weights), bounding, stair-running. These exercises may be the most important supplemental exercises the volleyball player can perform.

In-season (at least twice/week): vertical jump, bench jump, serial bench jump, side jump, obstacle jump, weighted jump, bounding, stair running. Again, these exercises are most likely the most beneficial in the training regimen.
SWIMMING

Off-season: Circuit training is recommended on alternating days in the following manner: Swim bench workout,* pressure tubing workout, circuit-endurance, sit-ups, shoulder circles, bench press, vertical jumps, arm circles, pull-downs, bench jumps, sit-ups, lateral arm swings, adductor exercise, lateral and forward arm raises, leg curls, sit-ups. High repetitions should be emphasized with all of these exercises.

*Swim bench workout involves lying on your stomach or back on a narrow bench and using pulleys, cables, or pressure tubing to simulate strokes.

In-season (2-3 times/week): vertical jump, bench jump.

TENNIS

Off-season (at least 3 times/week): vertical jump, bench jump, serial bench jump, side jump (slalom), tuck jump. These may be the most important exercises to improve quickness since tennis involves sudden lunges, leaps, and jumps, as well as vigorous starting and stopping.

In-season: Circuit training is recommended at least twice per week as follows: sit-ups, knee bends or leg press/squats, chin-ups or pull-ups, sit-ups, toe raises, dips or push-ups, vertical jump, sit-ups, adductor exercise, leg curls, wrist curls, bench jump, pull-down, sit-ups. Horizontal jumps, horizontal bench jumps, side jumps, or obstacle jumps may be performed additionally.
CHAPTER 7

CONCLUSION

The plyometric concept is becoming more and more popular in both the athletic training and rehabilitative aspects. When performed correctly and forcefully, these techniques can be used to an athlete’s advantage. Although there are risk factors involved, these can be avoided, especially if proper technique and adequate rest is addressed.

The preceding chapters encompassed not only the underlying principles upon which plyometrics is derived, but also provided examples of training methods both for the upper extremity as well as the lower extremity. It is of utmost importance to have an understanding of why plyometrics supposedly improves strength and power and the physiology involved before undertaking the plyometric activities themselves. Without knowing how or why plyometrics work, failure is more likely to result. Perhaps if all who engage in plyometrics, whether it be in preparation for an athletic event or to rehabilitate a knee or shoulder following surgery, are provided with education such as that provided here, they will be able to use the techniques to their advantage and achieve success.
REFERENCES


