Stretch-Shortening Drills for the Upper Extremities: Theory and Clinical Application

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Enhanced athletic performance emphasizes the muscle's ability to exert maximal force output in a minimal amount of time. Exaggerated maximal muscular force develops due to athletic movements producing a repeated series of stretch-shortening cycles. The stretch-shortening cycle occurs when elastic loading, through an eccentric muscular contraction, is followed by a burst of concentric muscular contraction. A form of exercise called plyometrics employs a quick, powerful movement involving a prestretch of the muscle, followed by a shortening, concentric muscular contraction, thus utilizing the stretch-shortening muscular cycle. The literature contains numerous references to plyometric training for the lower extremity, but there is a lack of information on the upper extremity plyometric program. Overhead activities, such as throwing, necessitate elastic loading to produce maximal, explosive, concentric muscular contractions. Plyometric exercise employs the concept of the stretch-shortening muscular cycle. The rehabilitation concept of specificity of training suggests plyometric exercise drills should be performed by the throwing athlete. This paper discusses the basic neurophysiological science and theoretical basis for plyometric exercise, and it describes an upper extremity stretch-shortening exercise program for the throwing athlete.

Key Words: stretch-shortening cycle, exercise, muscle spindle

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In the rehabilitation of athletic injuries and in sport training, the concept of specificity is an important parameter in determining the proper exercise program (2). The imposed demands during training must mirror those incurred during athletic competition, especially during the advanced phases of rehabilitation. In most athletic events, these stresses center around a muscle's capacity to exert its maximal force output in a minimal amount of time. Success depends on the speed at which muscular force can be generated. To simulate the explosive strength needed in athletics, Verkhoshanski advocated the "shock" method of training when he introduced the concept of plyometrics in Russia in 1969 (42, 43).

While the term plyometric exercise is relatively new, the basic concepts have been well established. The roots of plyometric training can be traced to eastern Europe, where it was simply known as jump training or shock training (44, 45). "Plyo" originates from the Greek word, "plythein," which means to increase. "Plio" is the Greek word for "more," and "metric" literally means to measure (48). The practical definition of plyometrics is a quick powerful movement involving a prestretching of the muscle, thereby activating the stretch-shortening cycle. Therefore, one purpose of plyometric training is to increase the excitability of the neurological receptors for improved reactivity of the neuromuscular system. This type of sports performance training can be referred to as reactive neuromuscular training (47). In effect, this type of approach is simply a muscle stretch-shortening exercise.

A literature review demonstrates that since 1969, many authors have used variances of Verkhoshanski's methodology in an attempt to establish the best stretch-shortening technique and training program (3, 6–8, 11, 32, 36). There is agreement on the benefits of basic stretch-shortening principles, but controversy exists regarding an optimal training routine (12, 16, 29, 38). Today, the chief proponents of the stretch-shortening approach are still found in the track and field society, since they continue to use Verkhoshanski's "reactive neuromuscular apparatus" for reproducing and enhancing the reactive properties of the lower extremity musculature (1, 5, 32, 36). Numerous authors have documented lower quarter stretch-shortening exercise drills and programs, but the literature is deficient in upper extremity stretch-shortening exercise programs (16–18, 42–45).

Adaptations of the stretch-shortening principles can be used to enhance the specificity of training in other sports that require a maximum amount of muscular force in a minimal amount of time. All movements in competitive athletics involve a repeated series of stretch-shortening cycles (5, 13, 15). Specific functional exercise must be performed to prepare the individual for return to activity. Perhaps in no one single athletic endeavor is the use of elastic loading to produce a maximal explosive concentric contraction and the rapid decelerative eccentric contraction seen more than in the violent activity of throwing a baseball. To replicate these forces during rehabilitation is beyond the scope of every traditional exercise tool. For example, the isokinetic dynamometer that reaches maximal velocities of 450–500°/sec is not specific to the greater than 7,000°/sec of shoulder angular velocity seen during a baseball pitch (20, 34). Consequently, specific exercise should be an intricate part of every upper extremity training program to facilitate a complete return to athletic participation. The purpose of this paper is to explain the theoretical basis of stretch-shortening exercise and to present a philosophy for utilizing the stretch reflex to produce an explosive reaction in the upper extremity.

THEORETICAL BASIS OF STRETCH-SHORTENING EXERCISE

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

There is agreement on the benefits of basic stretch-shortening principles, but controversy exists regarding an optimal training routine.

The proprioceptors of the body include the muscle spindle, the golgi tendon organ, and the joint capsule/ligamentous receptors (10, 23, 25). Stimulation of these receptors can cause facilitation, inhibition, and modulation of both agonist and antagonist muscles (25, 26). Both the muscle spindle and golgi tendon organ provide the proprioceptive basis for plyometric training.

The muscle spindle functions mainly as a stretch receptor. The muscle spindle components that are primarily sensitive to changes in velocity are the nuclear bag intrafusal muscle fibers, which are innervated by a Type 1a phasic nerve fiber (25, 37, 41). The muscle spindle is provoked by a quick stretch, which reflexively produces a quick contraction of the agonistic and synergistic extrafusal muscle fibers (Figure 1). The firing of the Type 1a phasic nerve fibers is influenced by the rate of stretch; the faster and greater the stimulus, the greater the effect of the associated extrafusal fibers (4, 25, 33, 41). This cycle occurs in .3–.5 msec and is mediated at the spinal cord level in the form of a monosynaptic reflex, such as the knee jerk (4) (Figure 2).

The golgi tendon unit, which is sensitive to tension, is located at the junction between the tendon and muscle both at the origin and insertion (22). The unit is arranged in series with the extrafusal muscle fibers and, therefore, becomes activated with stretch. Unlike the muscle spindle, the golgi tendon organ has an inhibitory effect on the muscle. Upon activation, impulses are sent to the spinal cord, causing an inhibition of the alpha motor neurons of the contracting muscle and its synergists and, thereby, limiting the force produced. It has been postulated that the golgi tendon organ is the protective mechanism against overcontraction or stretch of the muscle (24). Because the golgi tendon organ uses at least one interneuron in its synaptic cycle, inhibition requires more time than Type 1a monosynaptic interneuron excitation (9).

During concentric muscle contraction, the muscle spindle output is reduced because the muscle fibers are either shortening or attempting to shorten. During eccentric contraction, the muscle stretch reflex generates more tension in the lengthening muscle (28). When the muscle tension increases to a high or potentially harmful level, the golgi tendon organ fires, thereby generating a neural pattern that reduces the excitation of the muscle. Consequently, the golgi tendon organ receptors may be a protective mechanism, but in correctly carried out plyometric

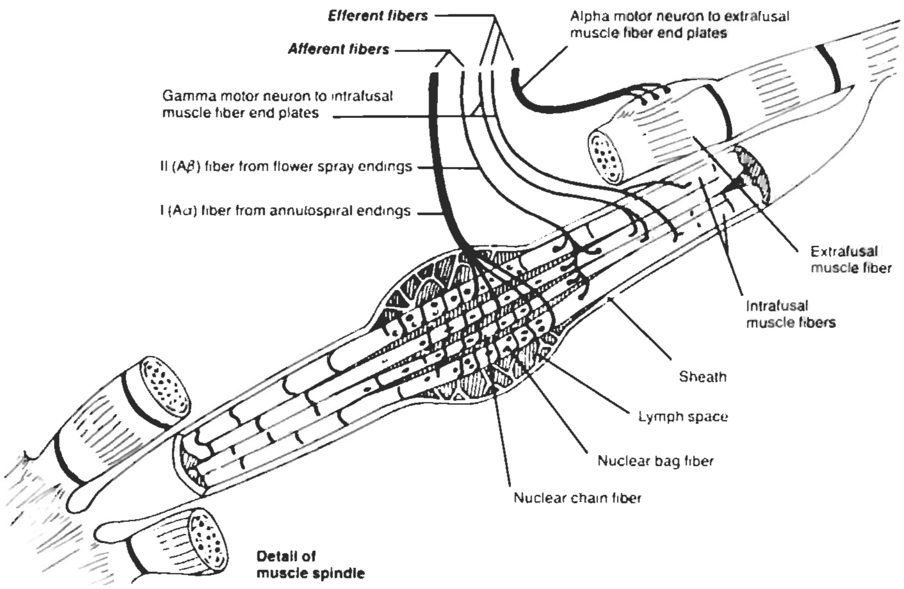


FIGURE 1. *The muscle spindle complex is a receptor consisting of intrafusal muscle fibers. Each spindle receives afferent innervation from group Ia (Aα) fibers and group II (Aα) fibers. The purpose of the muscle spindle is to provide information regarding muscular length to the central nervous system.*

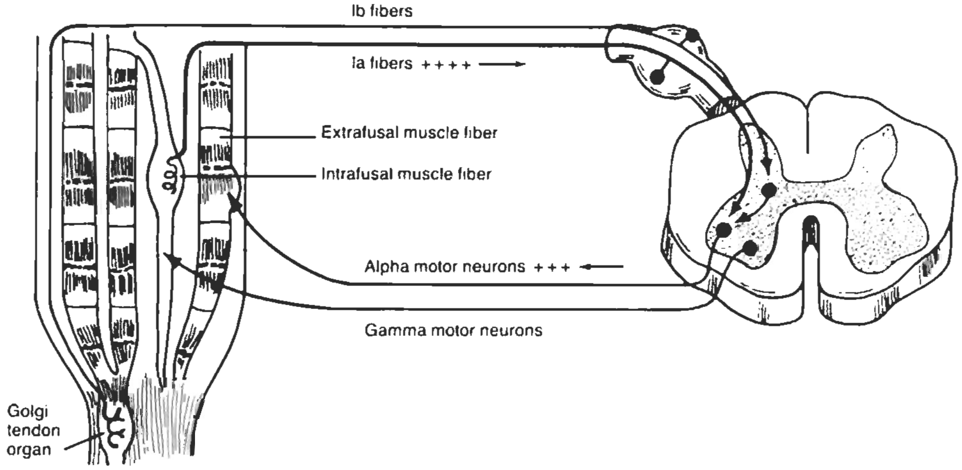


FIGURE 2. *Passive stretch (reflex). Both intrafusal and extrafusal muscle fibers are stretched. Sensory information is sent to the spinal cord via Ia fibers. The Ia fibers synapse on a motor nerve cell and excite it. As a result, motor impulses are sent back to the muscle via the alpha motor neurons, thereby causing muscle contraction.*

exercise, their influences are overshadowed by the reflex arc pathway incorporated with excitation of Type 1a nerve fibers (Figure 3).

Another principle to consider when discussing the quick explosion philosophy of plyometrics involves determining which muscles are affected. Patten (35) has embryologically classified muscles into phasic and tonic groups according to how muscles develop from the myotomes. Group one muscles (phasic or fast twitch) are innervated by anterior divisions of the nerve plexus and include the flexors, adductors, and internal rotators. Also included in this category are most two-joint muscles (24). Group two muscles (tonic or static) include the extensors, external rotators, and the abductors. The group one muscles possess more influence by the Type 1a phasic nerve endings, resulting in a greater chance of facilitation by the stretch-shortening manuever.

In addition to the neurophysiological stimulus, the positive results of stretch-shortening exercise can also be attributed to the recoil action of elastic tissues (11, 12, 14). Several authors have reported that an eccentric contraction immediately preceding a concentric contraction will significantly increase the force generated concentrically as a result of the storage of elastic energy (3, 6, 8, 14). The mechanism for this increased concentric force is the ability of the muscle to utilize the force produced by the elastic component (3, 6–8, 14). During the loading of the muscle, which occurs when stretching, the load is transferred to the elastic component and stored as elastic energy. The elastic elements can then deliver increased energy as it is recovered and used for the concentric contraction (3, 7, 8).

The muscle's ability to use the stored elastic energy is affected by time, magnitude of stretch, and velocity of stretch. Increased force generation during the concentric contraction is most effective when the preceding eccentric contraction is of short range and is performed quickly without delay (3, 6).

The improved or increased muscle performance that occurs with the prestretching of the muscle is the result of the combined effects of both the storage of elastic energy and the myotatic reflex activation of the muscle (3, 6, 12). The percentage of contribution from each component is not known at this time (6). In addition, the degree of enhanced muscular performance is dependent upon the time frame between the eccentric and concentric contractions (12).

PHASES OF STRETCH-SHORTENING EXERCISE

Three phases of the plyometric exercise have been described: the setting or eccentric phase, the amortization phase, and the concentric re-

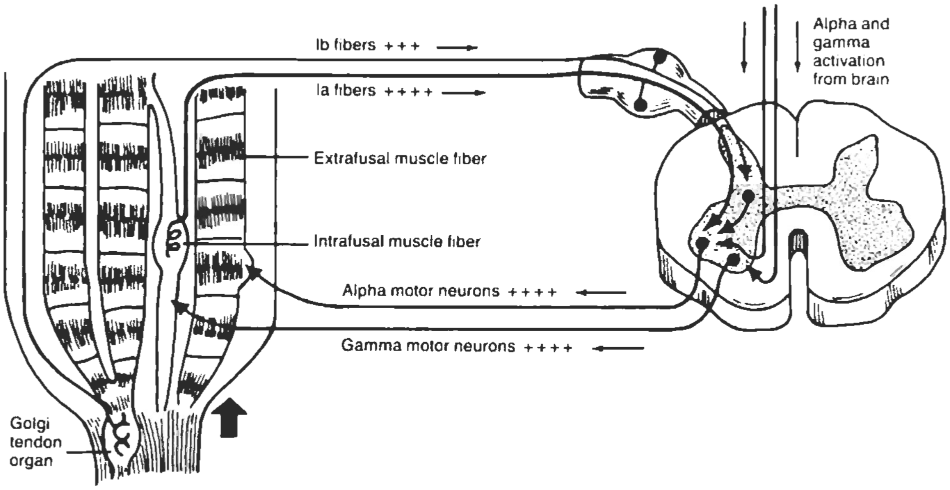


FIGURE 3. *Active eccentric-muscle contraction in which the muscle fibers lengthen. The muscle spindle and golgi tendon organs oppose each other. The regulation of force is controlled by descending pathways from the brain.*

sponse phase (Table 1). The eccentric or setting phase begins when the athlete mentally prepares for the activity and lasts until the stretch stimulus is initiated. Advantages of a correct setting stage include increasing the muscle spindle activity by prestretching the muscle prior to activation and mentally biasing the alpha motor neuron for optimal extrafusal muscle contraction (21, 29). The duration of the setting phase is determined by the degree of impulse desired for facilitation of the contraction. With too much or prolonged loading, the elapsed time from eccentric to concentric contraction will prevent optimal exploitation of the stretch-shortening myotatic reflex (27, 43).

The second phase of the stretch-shortening response is the amortization phase. This phase is the amount of time between undergoing the yielding eccentric contraction and initiation of a concentric force. By definition, it is the electromechanical delay between the eccentric and concentric contractions during which the muscle must switch from overcoming work to imparting the necessary amount of acceleration in the required direction (44).

Phase I	Eccentric Phase—(setting) preloading period
Phase II	Amortization Phase—time between eccentric and concentric phase
Phase III	Concentric Phase—facilitated contraction (pay-off)

TABLE 1. *Stretch-shortening phases.*

In addition to the neurophysiological stimulus, the positive results of stretch-shortening exercise can also be attributed to the recoil action of elastic tissues.

Successful training using the stretch-shortening technique relies heavily on the rate of stretch rather than the length of the stretch. If the amortization phase is slow, elastic energy is wasted as heat, and the stretch reflex is not activated. The more quickly the individual is able to switch from yielding work to overcoming work, the more powerful the response.

The final period of the stretch-shortening exercise is the concentric response phase. During this phase, the athlete concentrates on the effect of the exercise and prepares for initiation of the second repetition. The response phase is the summation of the setting and amortization phases. This phase is often referred to as the resultant or payoff phase because of the enhanced concentric contraction (16, 17, 44, 45).

Theoretically, stretch-shortening exercise assists in the improvement of physiologic muscle performance in several ways. While increasing the speed of the myotatic stretch-reflex response may increase performance, such information has not been documented in the literature. Research does support that the faster a muscle is loaded eccentrically, the greater the concentric force produced (29, 33). Eccentric loading places stress on the elastic components, thereby increasing the tension of the resultant rebound force.

A second possible mechanism for the increased force production involves the inhibitory effect of the golgi tendon organs on force production. Since the golgi tendon organ serves as a protective mechanism limiting the amount of force produced within a muscle, its stimulation threshold becomes the limiting factor. Desensitization of the golgi tendon organ may be possible, thereby raising the level of inhibition and, ultimately, allowing increased force production with greater loads applied to the musculoskeletal system.

The last mechanism by which plyometric training may increase muscular performance centers around neuromuscular coordination. The ultimate speed of movement may be limited by neuromuscular coordination. Explosive plyometric training may improve neural efficiency and increase neuromuscular performance. Utilizing the prestretch response may allow the individual to better coordinate the activities of the 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 adaption (44). In other words, the neurological system may be enhanced to become more automatic.

The implementation of the stretch-shortening program begins initially with the development of an adequate strength and physical condition base. The development of a greater strength base results in greater force generation as a result of both the increased cross-sectional area of the muscle and the resultant elastic component. In order to produce optimal strength gains, a structured plan must be instituted to prevent potential over-use injuries.

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. This improved stretch reflex allows the muscle to contract concentrically with maximal force. Since the stretch-shortening program attempts to modify and retrain the neuromuscular system, the exercise program should be designed with sport specificity in mind. It has been the authors' clinical observation that patients performing stretch-shortening exercise drills have accelerated muscular performance gains compared with individuals who have not trained in this fashion. It appears the muscular performance gains are not from morphologic change but rather from neural adaptation and enhanced neuromuscular coordination. It also appears this enhanced muscular performance is sensitive to detraining effects.

AN EXAMPLE OF A STRETCH-SHORTENING EXERCISE PROGRAM

A sample upper extremity stretch-shortening exercise program is presented in an attempt to illustrate the clinical applications of such a training program. The program is organized into four different exercise groupings: *1*) warm-up exercises, *2*) throwing movements, *3*) trunk extension/flexion exercises, and *4*) medicine ball wall exercises (Table 2).

Warm-up Exercises

Warm-up exercises are designed to provide the body, especially the shoulder, arm, and trunk, with an adequate physiologic warm-up before beginning a plyometric program. An active warm-up should facilitate muscular performance by increasing blood flow, muscle/core temperature, speed of contraction, oxygen utilization, and nervous system transmission (1, 4, 19, 23, 31). The warm-up exercises are listed in Table 2. The first three warm-up exercises utilize a 9-lb medicine ball or a rubber-coated ball called a plyoball® (Functional Integrated Technologies, Watsonville, CA). These warm-up exercises include trunk rotations (Figure 4), trunk side bends (Figure 5), and trunk wood chops (Figure 6). Additionally, warm-up exercises are performed with exercise tubing and include internal and external rotation movements of the shoulder with the arm in a position of 90° of shoulder abduction and 90° of elbow flexion (Figure 7) to simulate the throwing position. Finally, push-ups with both hands on the ground can enhance the warm-up period (Figure 8). Athletes should perform two to three sets of 10 repetitions for each of these warm-up exercises prior to beginning the exercise session.

Stretch-shortening exercise trains the neuromuscular system by exposing it to increased strength loads.

Warm-up exercises
Medicine ball rotation
Medicine ball side bends
Medicine ball wood chops
Tubing ER/IR
Tubing diagonal patterns (D2)
Tubing biceps
Push-ups
Throwing movements
Mecicine ball soccer throw
Medicine ball chest pass
Medicine ball step and pass
Medicine ball side throw
Tubing plyos IR/ER
Tubing plyos diagonals
Tubing plyos biceps
Plyo push-up (boxes)
Push-up (clappers)
Trunk ext/flexion movements
Medicine ball sit-ups
Medicine ball back extension
Medicine ball wall exercises
Soccer throw
Chest pass
Side-to-side throw
Backward side-to-side throw
Forward two hands through legs
One-hand baseball throw

IR = internal rotation.
ER = external rotation.

TABLE 2. *A stretch-shortening exercise program.*

Throwing Stretch-Shortening Movement Drills

Throwing movement stretch-shortening exercises attempt to isolate the muscles and muscle groups necessary for throwing. These exercises are performed in combined movement patterns similar to the throwing motion and are listed in

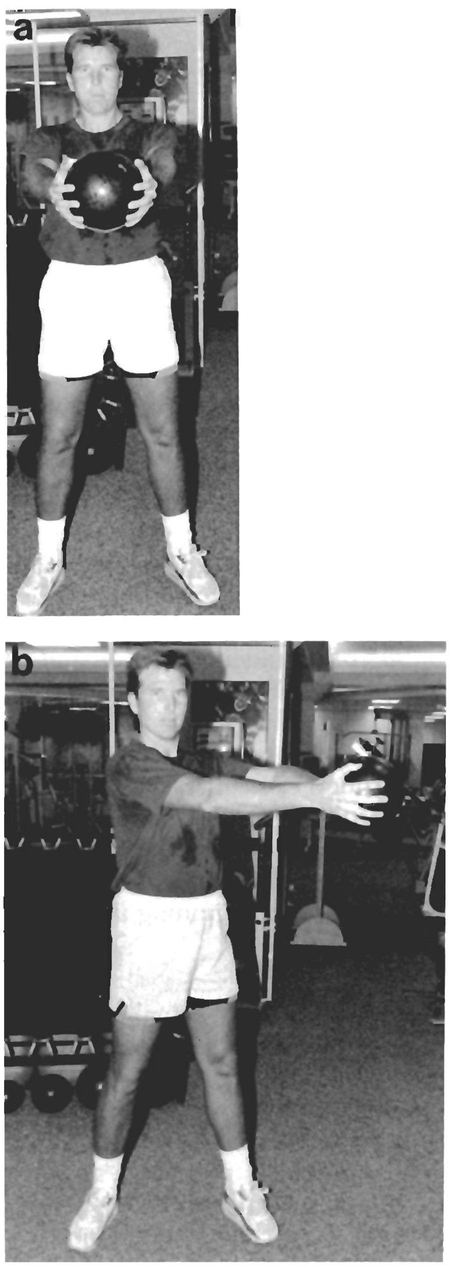


FIGURE 4. *Warm-up exercise; trunk rotations with 9-lb plyoball.*

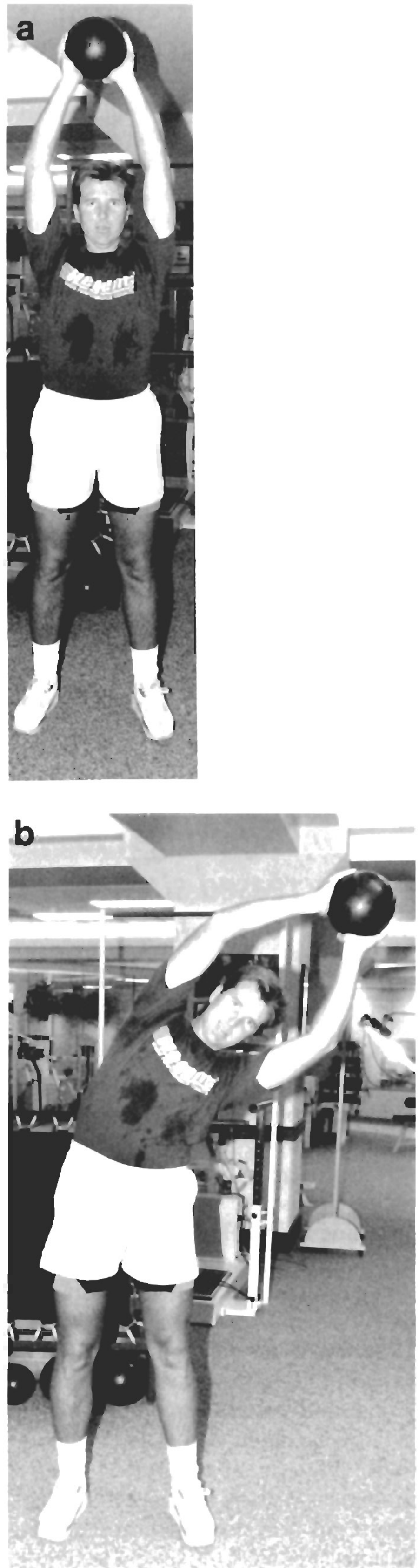


FIGURE 5. *Warm-up exercise; trunk side bends with 9-lb plyoball.*

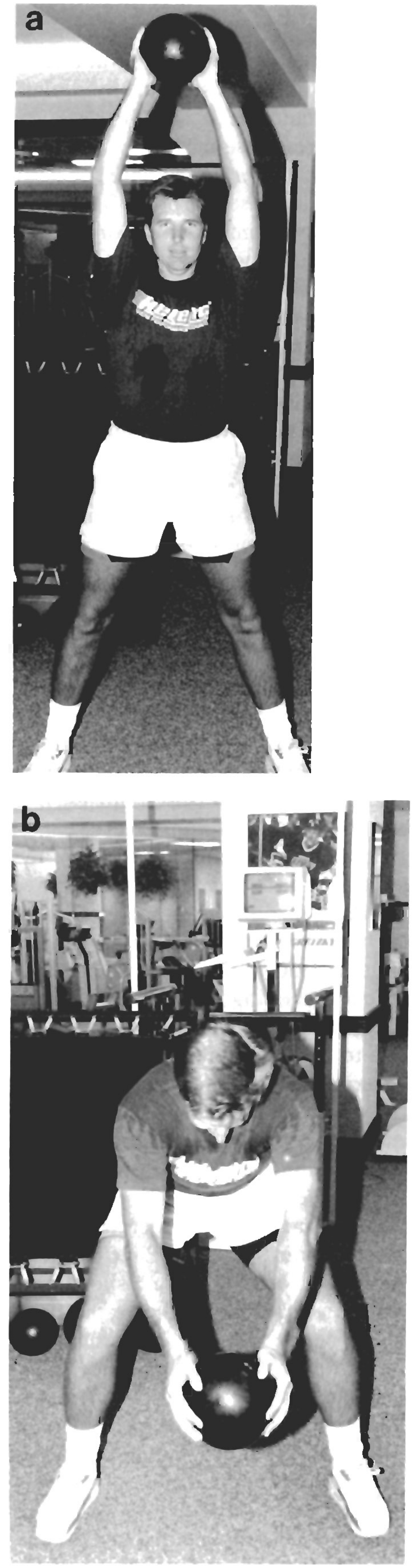


FIGURE 6. *Warm-up exercises; wood-chop with 9-lb plyoball.*

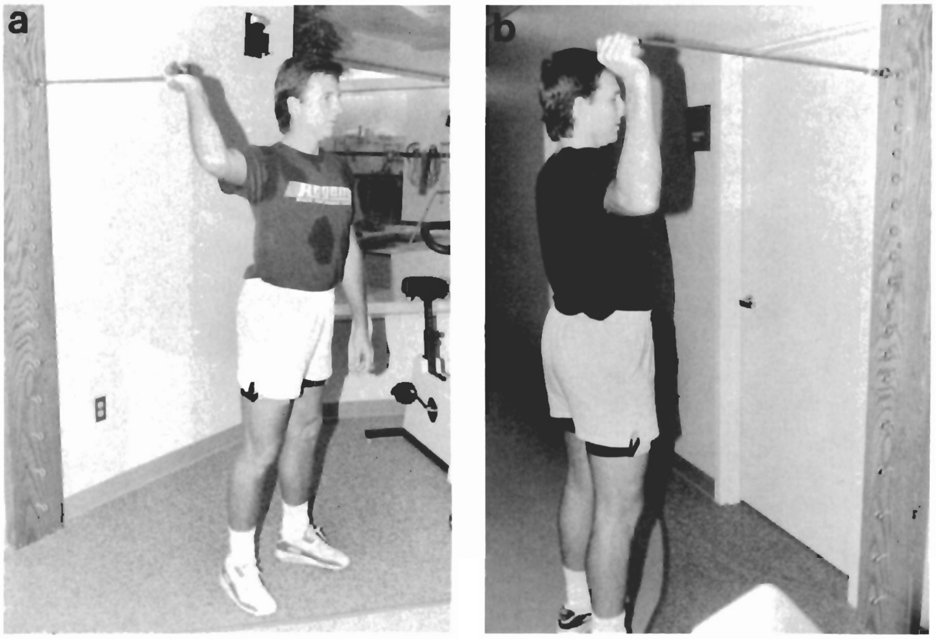


FIGURE 7. *Warm-up exercises; internal/external rotation with shoulder abduction of 90° and elbow flexed 90° utilizing exercise tubing. a) illustrates internal rotation stretch-shortening drill, b) illustrates external rotation stretch-shortening drill.*

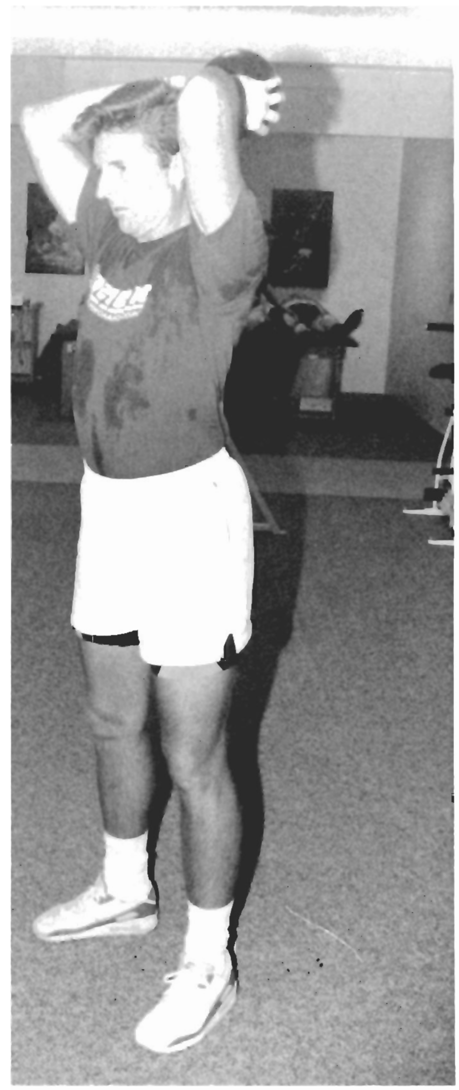


FIGURE 9. *Throwing movement exercises; two-hand overhead soccer throw with a 4-lb plyoball.*

FIGURE 8. *Warm-up exercises; push-ups with two hands on the ground.*

Table 2. Beginning drills are throwing movement plyometrics using a 4-lb plyoball. The first drill is a two-hand overhead soccer throw (Figure 9), followed by a two-hand chest pass (Figure 10). The next two throws incorporate a step and pass (Figure 11) and a side throw (Figure 12). These exercises can be performed with a partner or with the use of a spring-loaded, bounce-back device called the plyoback* (Functional Integrated Technologies, Watsonville, CA)

Additionally, four stretch-shortening drills require exercise tubing. The first movement involves stretch-shortening movement for the external rotators (Figure 13), during which the athlete brings the tubing back into external rotation and holds that position for 2 seconds. The athlete then allows the external rotator musculature to release this isometric contraction, thus allowing the tubing to pull the arm into internal rotation. Thus, the external rotators eccentrically control this movement. Once the arm reaches full internal rotation (horizontal), the external rotators contract concentrically to bring the tubing back into external rotation. This constitutes one stretch-shortening repetition. Similar movements are performed for the internal rotators (Figure 14) and for proprioceptive neuromuscular facilitation diagonal patterns, including D2 flexion (Figure 15) and D2 extension of the upper extremity (26, 39, 40, 46) (Figure 16). The stretch-shortening technique can also be performed for the elbow flexors utilizing exercise tubing (Figure 17). Push-ups to enhance the strength of the serratus anterior, pectoralis major, deltoid, triceps, and biceps musculature can also be incorporated into the program. Push-ups can be advanced to a plyometric exercise by utilizing a 6–8-in box or the ground in a depth-jump training manner (Figures 18 and 19). All of these exercise drills are performed for two to four sets of six to eight repetitions, two to three times weekly.

The purpose of the 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 pro-

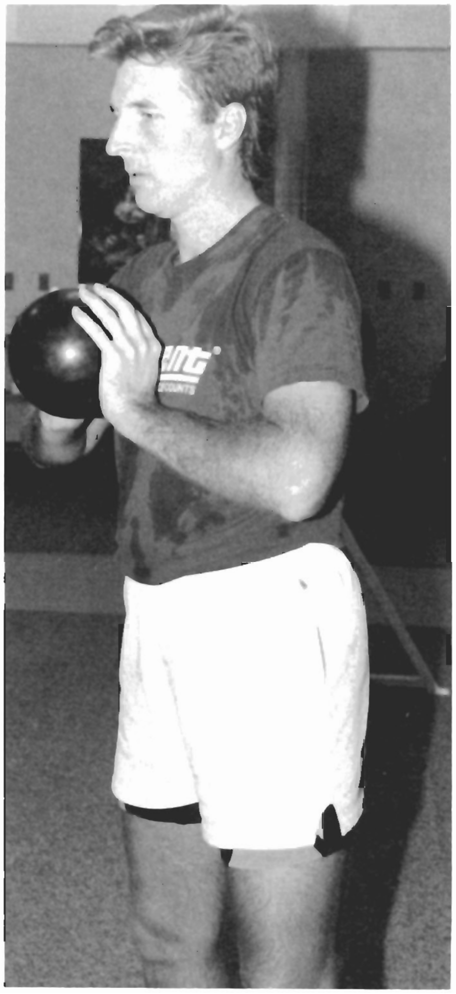


FIGURE 10. *Throwing movement exercises; two-hand chest pass throw with a 4-lb plyoball.*

FIGURE 11. *Throwing movement exercise; one-hand step and pass throw with a 4-lb plyoball.*

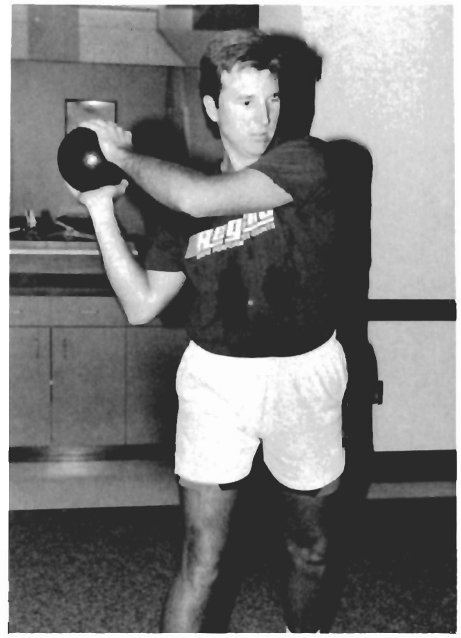


FIGURE 12. *Throwing movement exercises; two-hand side throw with a 4-lb plyoball.*

FIGURE 13. *Throwing movement exercises; external rotators stretch-shortening with exercise tubing.*

FIGURE 14. *Throwing movement exercises; internal rotators stretch-shortening with exercise tubing.*

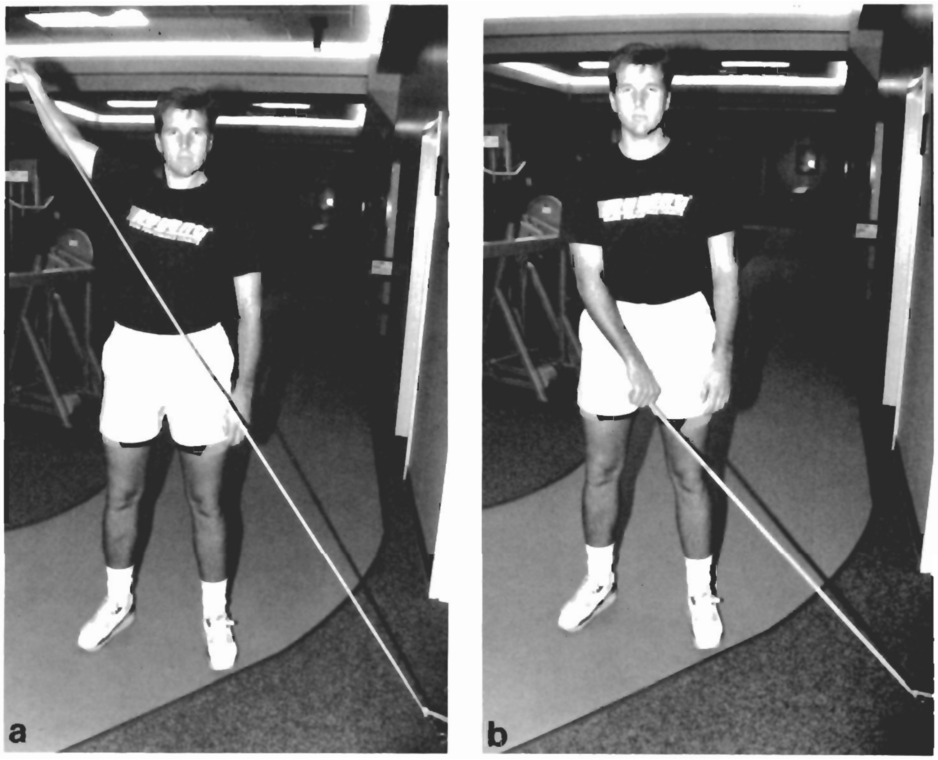


FIGURE 15. *Throwing movement exercises; PNF diagonal pattern D_2 flexion stretch-shortening with exercise tubing.*

vided by a simple isotonic dumbbell exercise program. These programs can only be utilized once the athlete has performed a strengthening program for an extended period of time and exhibits a satisfactory clinical examination.

Trunk Extension/Flexion Stretch-Shortening Exercises

Two groups of stretch-shortening drills for trunk strengthening purposes emphasize the abdominal and trunk extensor muscles. Exercises in this group include medicine ball sit-ups (Figure 20) and prone back extension (Figure 21). Trunk exercise drills are performed for three to four sets of six to eight repetitions, two to three times weekly.

Medicine Ball Wall Exercises

The last group of exercises or drills uses a 2- and a 4-lb medicine ball or plyoball and a wall, which enables the athlete to perform plyometric medicine ball drills without a partner. These activities serve as an excellent warm-up prior to sport competition.

In addition, these exercises and drills can be performed with the plyoback* device (Functional Integrated Technologies, Watsonville, CA), which enables the athlete to train alone. Sample exercises in the plyoball program include a two-handed overhead soccer throw (Figure 22), a two-handed chest pass (Figure 23), a two-handed side-to-side throw (Figure 24), a backward two-handed side-to-side throw (Figure 25), and a forward two-handed pass through the legs (Figure 26). Lastly, using a smaller 2-lb medicine ball, the athlete can perform a one-handed plyometric baseball throw (Figures 27 and 28). To further challenge the athlete, exercises can be performed in the kneeling position to eliminate the use of the lower extremities, which will increase the demands on the trunk and upper extremities.

CONTRAINDICATIONS TO STRETCH-SHORTENING EXERCISE

Contraindications to performing plyometric upper extremity exercises include acute inflammation or pain, immediate postoperative pathology, and gross shoulder or elbow instabilities. The most significant contraindication to an intense stretch-shortening exercise program is noninvolvement in a weight training program. Intense stretch-shortening exercise programs are intended to be advanced strengthening programs for the competitive athlete to enhance athletic performance and are not recommended for the recreational athlete. The clinician should be aware of the adverse reactions secondary to this form of exercise, such as postexercise soreness and delayed onset muscular soreness. In addition, it should be noted that this form of exercise should not be performed for an extended period of time because of the large stresses that occur during exercise. More appropriately, stretch-shortening exercise is used during the first and second preparation phases of training, utilizing the concept of periodization (30) (Figure 29).

SUMMARY

The purpose of this paper was to provide the reader with an introduction to the concept of stretch-shortening exercise. This paper has provided the reader with the historical review of the concept, a review of the neurophysiological response during plyometric training, the theoretical basis, and a sample stretch-shortening training program. The clinician is encouraged to implement these concepts when rehabilitating the competitive throwing athlete. In addition, alterations to this sample program while using the stretch-shortening concepts are encouraged.

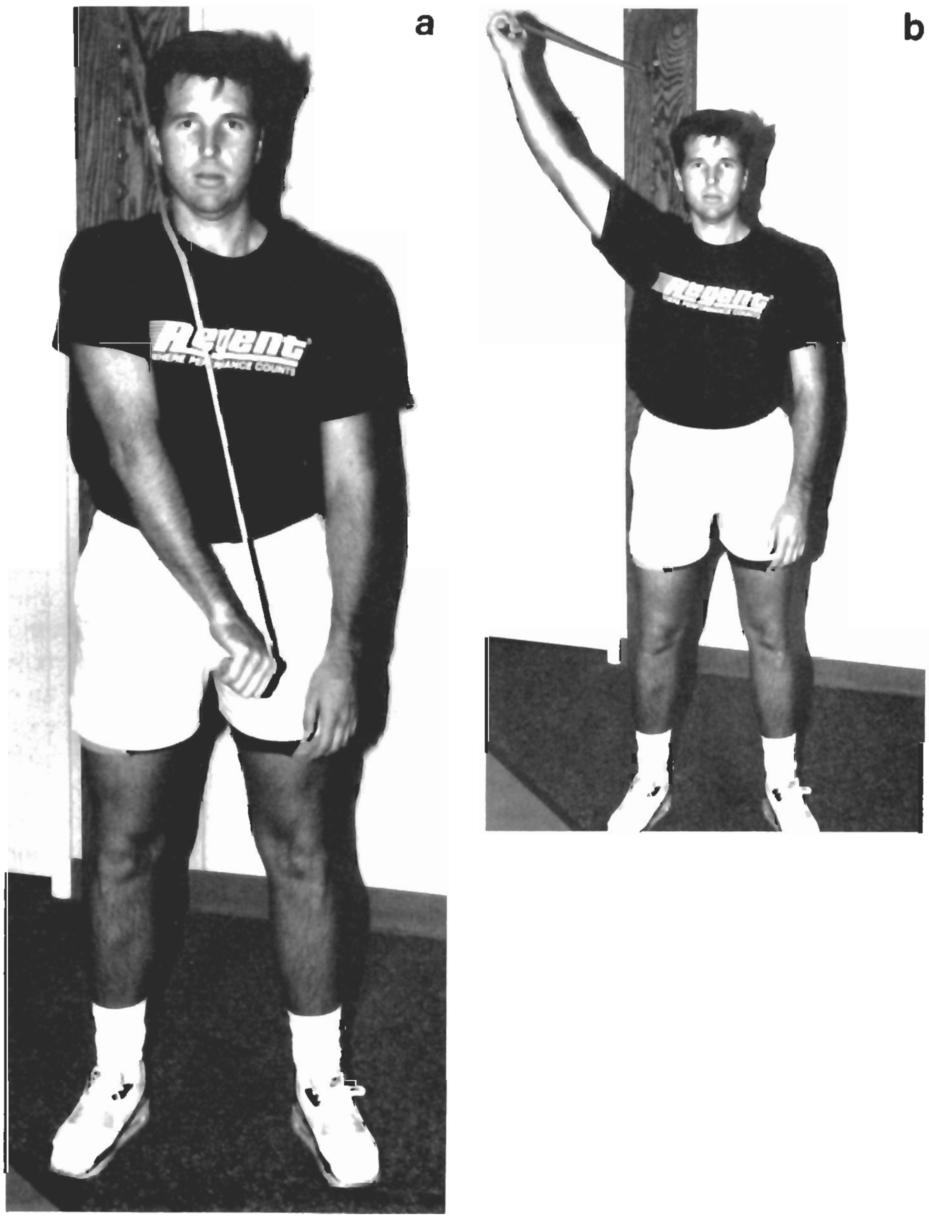
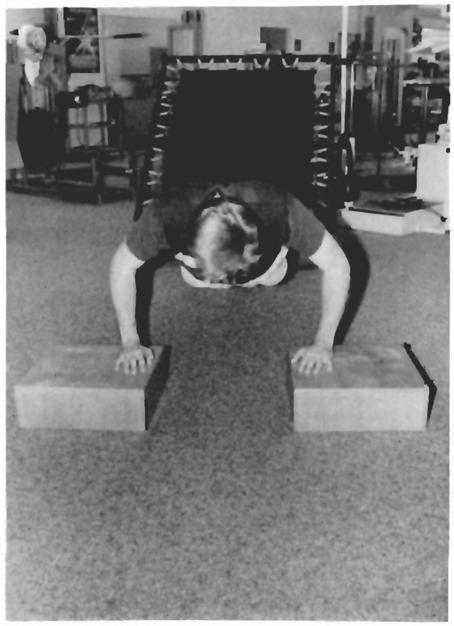


FIGURE 16. *Throwing movement exercises; PNF diagonal pattern D_2 extension stretch-shortening with exercise tubing.*

FIGURE 17. *Throwing movement exercises; elbow flexion plyometrics with exercise tubing.*



FIGURES 18 and 19. *Throwing movement exercises; stretch-shortening push-ups utilizing a 6-in box.*

FIGURE 20. *Trunk extensor/flexor exercises; plyoball sit-ups (4-lb plyoball).*

FIGURE 21. *Trunk extensensor/flexor exercises; prone back extensions with a 4-lb plyoball.*

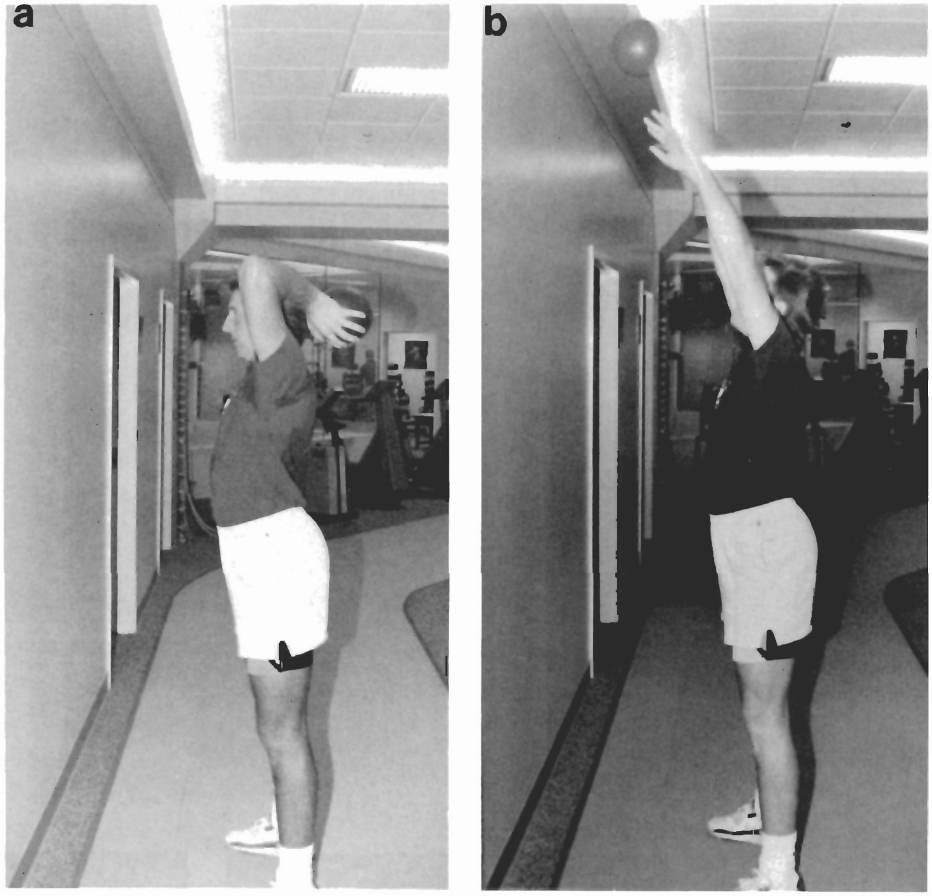


FIGURE 22. *Plyoball wall exercises; two-hand soccer throw with 4-lb plyoball.*

FIGURE 23. *Plyoball wall exercises; two-hand chest pass with 4-lb plyoball.*

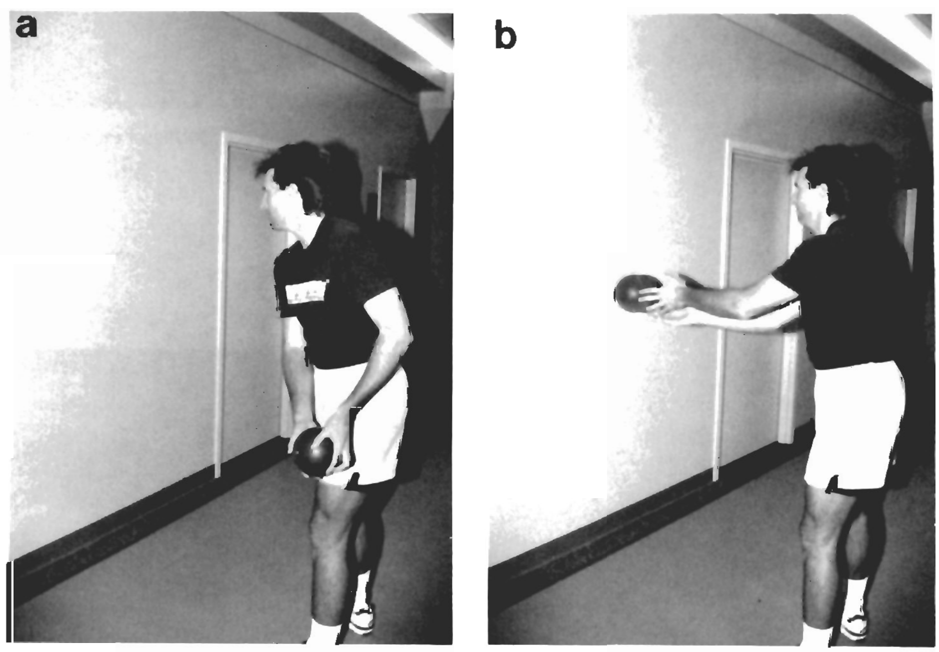


FIGURE 24. *Plyoball wall exercises; side-to-side throw with 4-lb plyoball.*

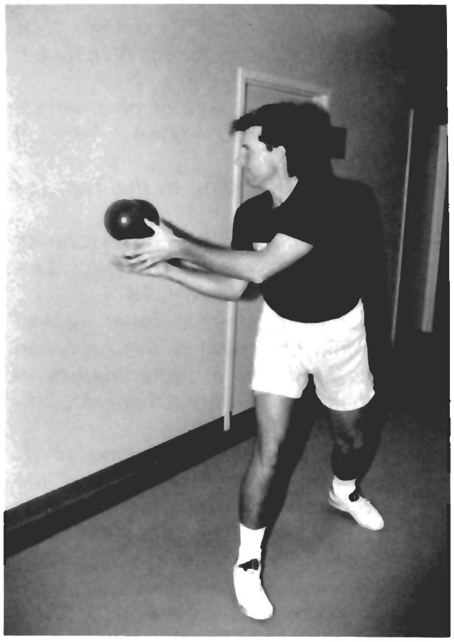


FIGURE 25. *Plyoball wall exercises; backward side-to-side throw with 4-lb plyoball.*

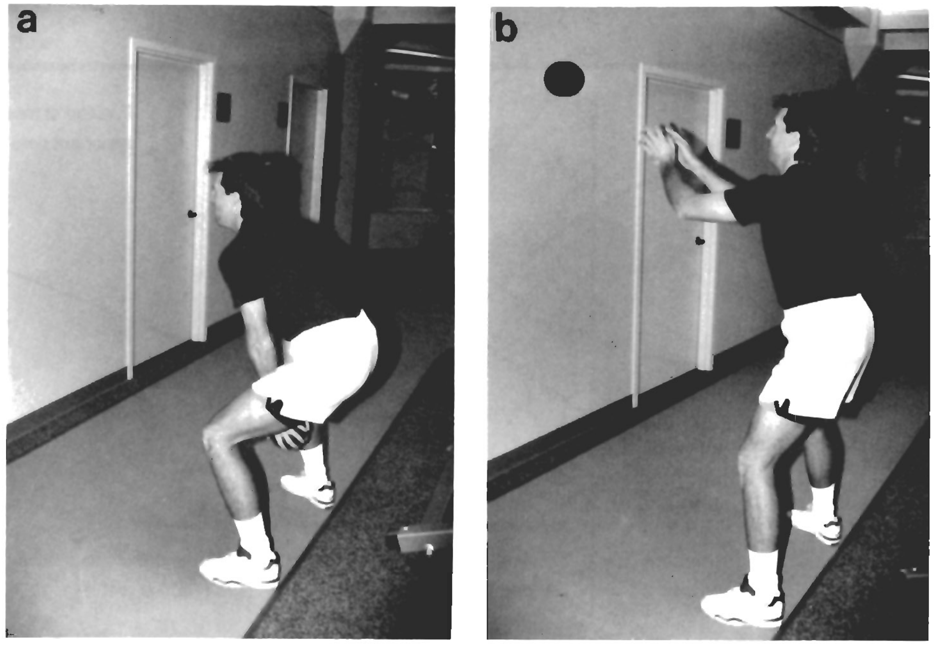


FIGURE 26. *Plyoball wall exercises; two-hand pass through the legs with 4-lb plyoball.*

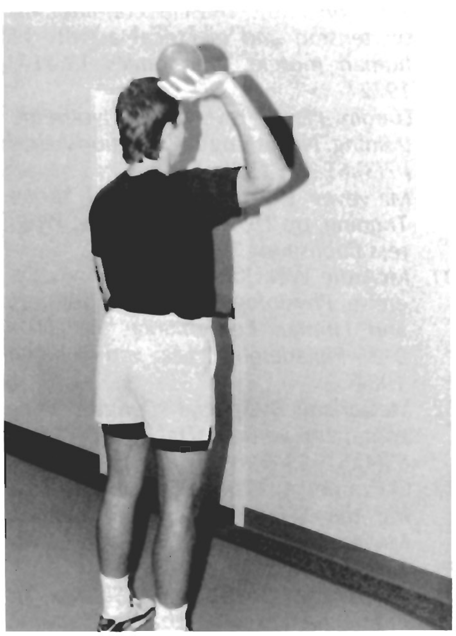


FIGURE 27. *Plyoball wall exercises; baseball throw of 2-lb plyoball into a wall.*

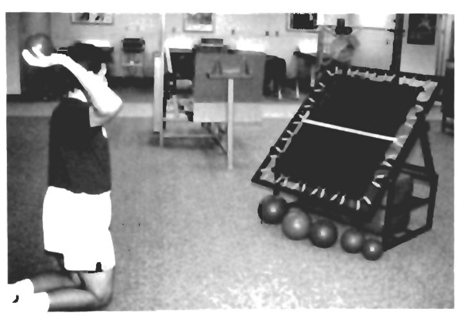


FIGURE 28. *Throwing drill; baseball throw of 2-lb plyoball into the plyoback device in the kneeling position.*

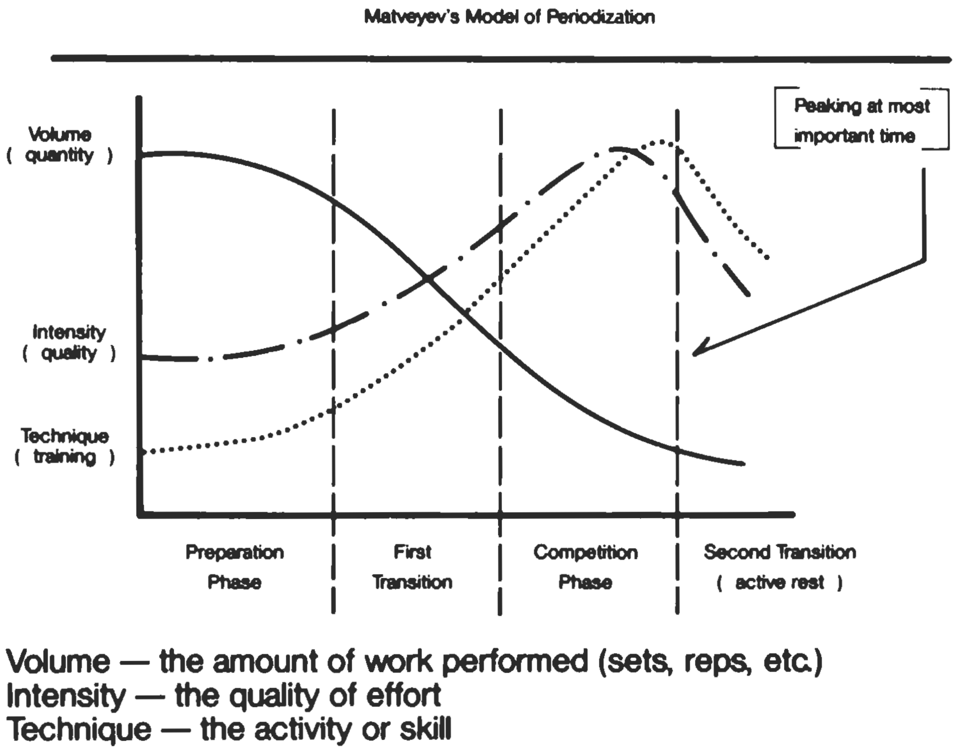


FIGURE 29. *Marveyev's model of periodization. (From "Plyometric Training: Understanding and Coaching Power Development for Sport." Reprinted with permission. © National Strength and Conditioning Association, 1988).*

Finally, clinical research to document the efficiency of stretch-shortening training programs is needed.

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REFERENCES

1. *Adams T: An investigation of selected plyometric training exercises on muscular leg strength and power. Track Field Q Rev 84(1):36–40, 1984*
2. *Allman FL: Sports Medicine, New York: Academic Press, 1974*
3. *Assmussen E, Bonde-Peterson F: Storage of elastic energy in skeletal muscle in man. Acta Physiol Scand 91:385–392, 1974*
4. *Astrand P, Rodahl K: Textbook of Work Physiology, pp 60–61. New York: McGraw-Hill, 1970*
5. *Blattner S, Noble L: Relative effects of isokinetic and plyometric training on vertical jumping performance. Res Q 50(4):583–588, 1979*
6. *Bosco C, Komi P: Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. Acta Physiol Scand 106:467–472, 1979*
7. *Bosco C, Komi PV: Muscle elasticity in athletes. In: Komi PV (ed), Exercise and Sports Biology, Champaign, IL: Human Kinetics, 1982*
8. *Bosco C, Tarkka J, Komi PV: Effects of elastic energy and myoelectric potentiation of triceps surca during stretch-shortening cycle exercise. Int J Sports Med 2:137, 1982*
9. *Brodal A: Neurological Anatomy in Relation to Clinical Medicine, New York, Oxford University, 1969*
10. *Buchwald JS: Exteroceptive reflexes and movement. Am J Phys Med Rehabil 46:121–128, 1967*
11. *Cavagna G: Elastic bounce of the body. J Appl Physiol 29(3):29–82, 1970*
12. *Cavagna G, Disman B, Margarai R: Positive work done by a previously stretched muscle. J Appl Physiol 24(1):21–32, 1968*
13. *Cavagna G, Kaneko M: Mechanical work and efficiency in level walking and running. J Physiol 268:467–481, 1977*
14. *Cavagna G, Saibene F, Margaria R: Effect of negative work on the amount of positive work performed by an isolated muscle. J Appl Physiol 20:157, 1965*
15. *Cavagna G, Komarek L, Mazzoleni S: The mechanics of sprint running. J Physiol 217:709–721, 1971*
16. *Chu D: Plyometric exercise. Nat Strength Condition Assoc J 6(1):56–62, 1984*
17. *Chu D: The language of plyometrics. Nat Strength Condition Assoc J 6(4):30–31, 1984*
18. *Costello F: Bounding to the Top, Los Altos: Tafnew Press, 1984*
19. *DeVries HA: Physiology of Exercise for Physical Education and Athletics, Dubuque, IA: W.C. Brown, 1974*
20. *Dillman CJ: Biomechanical analysis of throwing. Presented at the American Sports Medicine Institute Injuries in Baseball Course, Birmingham, AL, January 21, 1991*
21. *Eldred E: Functional implications of dynamic and static components of the spindle response to stretch. Am J Phys Med Rehabil 46:129–140, 1967*
22. *Franks BD: Physical warm-up. In: Morgan WP (ed), Ergogenic Aids and Muscular Performance, New York: Academic Press, 1972*
23. *Granit R: Receptors and Sensory Perception, New Haven: Yale University Press, 1962*
24. *Granit R: The Basis of Motor Control, New York: Academic Press, 1970*
25. *Jacobson M: Developmental Neurobiology, New York: Holt, Rinehart and Winston, Inc., 1970*
26. *Knott M, Voss DE: Proprioceptive Neuromuscular Facilitation (2nd Ed), New York: Harper & Row, 1968*
27. *Komi P, Bosco C: Utilization of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports Exerc 10(4):261–265, 1978*
28. *Komi PV, Buskirk E: Effects of eccentric and concentric muscle conditioning on tension and electrical activity of human muscle. Ergonomics 15:417, 1972*
29. *Lundin PE: A review of plyometric training. Nat Strength Condition Assoc J 7(3):65–70, 1985*
30. *Marveyev L: Fundamentals of Sports Training, pp 167–169. Moscow: Progress Publishers, 1977*
31. *McArdle WD, Katch FI, Katch VL: Exercise Physiology; Energy, Nutrition, and Human Performance, pp 310 313. Philadelphia: Lea and Febiger, 1981*
32. *McGarlane B: Special strength: Horizontal and vertical. Track Field Q Rev 83(4):51–53, 1983*
33. *O'Connel A, Gardner E: Understanding the Scientific Bases of Human Movement, Baltimore: Williams & Wilkins, 1972*
34. *Pappas AM, Zawacke RM, Sullivan TJ: Biomechanics of baseball pitching: A preliminary report. Am J Sports Med 13(4):216–221, 1985*

35. Patten BM: Human Embryology, New York: McGraw-Hill, 1953
36. Polhemus R, Burkhardt E: The effects of plyometric training with ankle and vest weights on conventional weight training programs for men. Track Field Q Rev 80(4):59–61, 1980
37. Schmidt R: Motor Control and Learning, pp 193–204. Champaign, IL: Human Kinetics Publishers, 1982
38. Scoles G: Depth jumping—Does it really work? Athl J 58:48–75, 1978
39. Sullivan PE, Markos PD, Minor MD: An Integrated Approach to Therapeutic Exercise; Theory & Clinical Application, pp 43–194. Reston: Reston Publishing Co., 1982
40. Sullivan PE, Portney LG: Electromyographic activity of shoulder muscles during unilateral upper extremity proprioceptive neuromuscular facilitation patterns. Phys Ther 60:283–288, 1980
41. Swash M, Fox K: Muscle spindle innervation in man. J Anat (112):61–80, 1972
42. Verkhoshanski Y: Perspectives in the improvement of speed-strength preparation of jumpers. Yessis Rev Sov Phys Educ Sports 4(2):28–29, 1969
43. Verkhoshanski Y: Depth jumping in the training of jumpers. Track Technique 51:1618–1619, 1983
44. Voight M, Draovitch P: Plyometrics. In: Albert M (ed), Eccentric Muscle Training in Sports and Orthopaedics, pp 45–73. New York: Churchill Livingstone, 1991
45. Voight ML: Stretch-strengthening: An introduction to plyometrics. Orthop Phys Ther Clin North Am, 1–2, pp 243–252. Philadelphia: W. B. Saunders, 1992
46. Voss DE, Knott M, Kabat M: Application of neuromuscular facilitation in the treatment of shoulder disabilities. Phys Ther Rev 33:536–537, 1953
47. Wilk KE, Voight ML: Plyometrics for the overhead athlete. In: Andrews JR, Wilk KE (eds), The Athletic Shoulder, New York: Churchill Livingstone, (in press, 1993)
48. Wilt F: Plyometrics, what it is and how it works. Athl J 55(5):76–90, 1975