A review of plyometric training

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Plyometric training may be viewed as an extension of the shock method of strengthening muscle for athletic performance recommended by Verkoshanski (42, 43, 46). His dynamic correlation concept suggests that jumping strength can be optimized by trying to model strength training as closely as possible to the function that was to be improved. The shock method consists of rebound jumps from a height to develop the athlete’s reactive neuromuscular apparatus. Atha has referred to this principal as bounce loading, the nature of the exercise being a rhythmical hybrid of eccentric and concentric activity that loads the elastic and contractile components of muscle (4).

The reactive neuromuscular apparatus of muscles can be singled out as the specific factor of the athlete’s speed-strength abilities (33). These abilities are identified with actions that demand quick movement, such as jumps, throws and sprints. Speed-strength abilities refer to a muscle’s ability to reach maximal strength over a brief period of time (a definition of power). The reactive properties of muscle are exploited in movements that require an instantaneous switch from yielding (negative) work to overcoming (positive) work. Examples of this eccentric-concentric coupling in muscle abound in athletics. The violent extension of the take-off foot and leg in the long jump takeoff is preceded at touchdown by a slight shock-absorbing flexion of the take-off knee and ankle, which imposes a stretch on the extensor muscles of the knee and hip and the plantar flexors of the ankle. The slight flexion of the take-off knee and ankle also is referred to as the amortization phase, or the time from ground contact (eccentric contraction of extensor muscles) to reversal of the movement (concentric contraction of extensor muscles) (20).

Luhtanen and Komi, in their study of mechanical factors that influence running speed, recognized the eccentric-concentric coupling of muscles in running (31). They partitioned the total contact time (CT) of the foot on the ground into negative CT and positive CT, assuming that with initial foot plant to the lowest position of the center of gravity, the contact leg’s extensor muscles were contracting eccentrically and performing negative work. The later portion of CT consisted of concentric contractions with a rise in the center of gravity, the work being positive. The key point to remember in the eccentric-concentric cycle is that the power of the overcoming efforts of muscle increases when preceded by a forcible pre-stretch. In running, the pre-stretch is naturally created by the kinetic energy of the body.

The reactive proprieties of muscle are generally due to the inherent proprioceptive reflexes and the elastic nature of muscle. Bosco et al. suggested that the elastic component may be the most influential, but the proprioceptive reflexes cannot be ignored in fast movements that use this eccentric-concentric coupling (9). The reactive proprieties and elastic nature of muscle...
will be dealt with separately, although they tend to work in parallel response during many movements.

**Proprioceptive Reflexes**

Motor control is directed by the central nervous system, using sensory feedback from the proprioceptors. These receptors contribute to a person's awareness of his or her body and its movements, or kines thesis (39). The proprioceptors, which are of prime concern in understanding the neurophysiology of plyometrics, are the muscle receptors that include the Golgi tendon organ (GTO) and muscle spindle (MS). The proprioceptive reflexes in motor skills generally are controlled by MS and GTO, their effects being facilitation, reinforcement or inhibition of muscle contractions (35).

The muscle spindles are widely distributed throughout muscle tissue. Each consists of intrafusal muscle fibers (IF), which do not contribute to the force of contraction, and extrafusal fibers (EF), which are responsible for the development of external tension. The IF are oriented parallel to the EF fibers within muscle tissue. Because of their position within muscle tissue, an externally applied stretch results in a distension of both IF and EF. The stretching of the IF evokes a sensory discharge to the spinal cord, causing a motor response whereby the muscle begins to contract with a corresponding inhibition of the antagonist muscle. This process, called the myotatic or stretch reflex, is important in the control of movement and maintenance of posture. O'Connell and Gardner described the muscle spindle as reflecting velocity of stretch and the ultimate length finally achieved (35). When a small stretch is imposed rapidly on a muscle, there is a sharp increase in MS firing response, which drops markedly when stretching ends. The strength of a response by the MS to stretch is determined by the rate of stretch: the greater and more quickly a load is applied to a muscle, the greater the MS firing frequency, with a corresponding stronger muscle contraction.

The GTO, unlike the MS, has an inhibitory effect upon muscle. It is located near the musculotendinous junction, where the muscle blends into the tendon. The GTO lies in series with the contractile muscle fibers and is deformed by passive stretch, but is less sensitive than the MS to such movement. Because of the GTO's position, a muscle contraction creates tension in the musculotendinous structure and may elicit a response from the receptor. During a muscular contraction, the MS ceases to fire because the EF are shortening or attempting to shorten, which may bring about a temporary unloading of the MS. The GTO, however, is stimulated in such a condition and the effect is one of inhibition. Muscles have been demonstrated to show a greater contractile force than can be structurally withstood; therefore, it may be that the inhibitory reflex initiated by the GTO is a protective measure to monitor and prevent dangerously high tension within muscle (39). Although the GTO may respond to stretch or high muscular tension, the inhibitory effect may be offset during voluntary exertion until muscle tension becomes excessive and injury becomes possible.

Advantages may result from spindle activity by stretching a muscle before activation. This is naturally caused by preparatory movements in the opposite direction of the anticipated movement. The slight flexion at the knee joint in jump takeoffs, at footplant in sprinting, or from the glide to the power position in the shot put, are examples of how the leg and foot extensors are stretched and how MS activity may be exploited to increase force of the following concentric contraction. To ensure full advantage of the stretch reflex, the muscle must be forcibly stretched so the stretch velocity is emphasized, bringing about a rapid rise in the firing frequency of the MS (3, 35). There should be minimal hesitation between the muscle's eccentric and concentric contractions to capitalize on the increase in MS activity and to maximize the storage and release of elastic energy in the muscle itself.

**Elastic Properties of Muscle**

The storage and release of elastic energy has been investigated extensively by Cavagna et al. (16, 17, 18, 19). Cavagna found that the positive work in level running was appreciably higher than predicted from energy expenditure (18). The efficiency of running was found to increase steadily with speed. The authors suggested that positive work (the propulsive phase of running) is derived mainly from the recoil of elastic elements, and to a lesser degree from the active shortening of the extensors at higher running speeds. An appreciable fraction of the external positive work performed during running came from the elastic elements stretched by the kinetic energy of the body during the preceding phase of negative work. Fukashiro et al. reported that when repetitive vertical jumps (VJ) are performed, the elastic component amounts to one-half to two-thirds of the total positive work (25).

Bosco et al. noted that contact time with the take-off board during the long jump takeoff correlated negatively with jump length (12). This was also found by Klishouras and Karpovich (29). In good performances, the center of gravity began to rise immediately after the
first touch of the board, while in poorer jumps it remained at about the same height during the early contact phase. The investigators concluded that the takeoff should rely on the use of elastic energy stored in the muscles during eccentric contraction of the extensors at takeoff. As mentioned previously, any increase in the time between the yielding and overcoming phase of the eccentric-concentric coupling leads to a reduction in stored elastic energy. This results in longer contact times and a lowering of the center of gravity, characteristics generally associated with poorer performances in long jumping.

Bobbert et al. examined the performance of depth jumps (DJ) from a height of 40 centimeters, and of countermovement jumps (CMJ) (8). Analysis of performance variables allowed the investigators to divide the subject into DJ subgroups. Group 1 consisted of subjects with a small amplitude of knee movement and a push-off duration of less than 200 milliseconds, while Group 2 consisted of subjects with a greater amplitude of movement (resembling CMJ) and a push-off phase of more than 200 milliseconds. While no difference was observed between CMJ and DJ variables in Group 2, differences were noted in Group 1. In Group 1, the center of mass was lowered less, push-off duration was shorter, ground reaction force was greater, and total work done and energy gain during the push-off phase were smaller in DJ than in CMJ. However, there was no difference in VJ performance between DJ and CMJ. During DJ performance, a pre-stretch of leg extensors occurs immediately after touchdown. This rapid stretch may evoke the stretch reflex and permit the shortage and use of elastic energy. A decrease in the influence of the prestretch over time may explain why in Group 2 no differences were found in force and movement variables between DJ and CMJ.

The ability to change quickly from a lengthening to a shortening contraction is the key to using the elastic structures of the muscles. Bosco and Komi proved this experimentally when they compared damped and undamped DJ (11). Undamped jumps had minimal knee flexion upon landing from a height, with an immediate rebound. The investigators concluded that the power values were much higher under undamped conditions, because the muscle’s elastic behavior decreased if knee flexion increased significantly, as in the damped jumps. Knee flexion during the damped jumps affected the short-range stiffness of the muscle, with part of the stored elastic energy being dissipated as heat.

In similar investigations, the height attained in VJ performances were found to be greater when performed with a preliminary countermovement versus static squat jumps (2, 10, 13, 30, 32). In another study, which examined the differences in mechanical efficiency between rebound and non-rebound jumps, results indicated higher efficiency values for rebound jumps (41). These differences could be attributed to the greater use of muscle elasticity allowed in the eccentric-concentric coupling of the leg extensors in countermovement jumps, compared to that of static squat jumps with no such action. Asmussen and Bonde-Peterson noted that VJ height becomes increasingly greater if preceded by a DJ, but only up to a height of 0.40 meter. At a height of 0.69 meter, VJ height becomes smaller. Thus, when the load on the muscle was too small or too great, efficiency decreased. This may suggest an optimal loading intensity for the athlete to maximize the storage and use of elastic energy (2).

To test whether pre-stretch intensity influences the mechanical efficiency of a concentric contraction, Aura and Komi experimented with pre-stretch intensities that were varied systematically between exercises (5). The investigators found that the mechanical efficiency of concentric contractions in locomotion tasks improved with increasing pre-stretch intensity. In other words, as running speed increases, so too will the pre-stretch and the efficiency of the subsequent concentric contraction. In tasks that use this stretch-shortening cycle, elastic energy can be used and the metabolic demands in the muscles reduced. Similar findings resulted from Funato et al.’s investigation of the effect of pre-stretch velocity on the amount and use of stored elastic energy (26).

Bedi et al. recently compared male DJ performance to discover whether a difference in performance exists when dropping from different heights (6). CMJ and DJ performances also were compared. Two groups, volleyball players and physical education students, completed five jumps at each of eight heights: 0, 25, 35, 45, 55, 65, 75 and 85 centimeters. The sequence heights were selected randomly, and five minutes of rest was allowed between each set of five jumps. The best and average performances were used for analysis. The performances of the physical education students were seen to increase with dropping height, then fall with further increases in dropping height. No such pattern was found with the volleyball players, who jumped higher from all heights than did the physical education students. Surprisingly, mean CMJ jumps were significantly greater than DJ for both groups. According to the authors, differences between this study (in which they were unable to find a statistical difference between VJ performance after DJ from various heights) and
earlier ones suggest that adequate DJ performance may require a minimum reference of correctness for skilled jumping behavior.

There appears to be a difference in the storage and recoil of elastic energy in slow-twitch and fast-twitch muscle fibers as noted by Bosco et al. (14). Subjects performed VJ with and without a preliminary countermovement and with small and large amplitude of knee flexion. The study indicates that subjects with a preponderance of fast-twitch fibers benefitted more from a high speed, small amplitude of flexion pre-stretch, and that the use of elastic energy was proportional to the amount stored. In efforts with a great deal of knee flexion and a long stretch time, both types of subjects (slow-twitch and fast-twitch) exhibited a similar amount of stored elastic energy. However, this energy use was greater in the slow-twitch group (24 percent) than in the fast-twitch group (17 percent). These findings indicate that slow-twitch muscle fibers may be able to use elastic energy more efficiently in ballistic movements characterized by a relatively long and slow prestretch phase of the stretch-shortening cycle.

In conclusion, the increases in muscle force, power and jump performance, and the improved efficiency of running at higher speeds, may be attributed to two inherent properties of muscle tissue. A muscle forcibly stretched before a contraction uses the stretch reflex to activate the muscle to shorten vigorously, and the elastic nature of the muscle fibers allows the muscle to store energy during negative work (amortization), to be released during the overcoming phase or shortening contraction. It may seem sensible to attribute this improved performance to the effects of the stretch reflex and the use of elastic energy; however, it is difficult to estimate the relative contribution of the two mechanisms. However, Bosco et al., studying the effects of the stretch reflex and elastic energy in the triceps surae during the stretch-shortening cycle, found that values of 72 percent and 28 percent could be calculated for the contributions of the elastic and stretch reflex components, respectively (13).

**Review of Plyometric Training**

Studies of plyometrics are limited, with only a few writers investigating the effects of plyometrics in conditioning programs. It is difficult to make specific conclusions about plyometric training because of the variety of experimental designs and methods used by the investigators.

Although his methods were not included in the English translation, Verkhoshanski concluded that DJ were effective in the perfection of speed-strength abilities (42). He recommended using DJ with an immediate rebound after jumping from a height. A height of 0.8 meter was recommended for maximum speed in switching from yielding to overcoming work, whereas 1.1 meters brought about maximum dynamic strength. The author recommended two training sessions per week of 40 jumps (takeoffs) per session, broken into four sets of 10 repetitions. DJ height was to be alternated for the sets between 0.8 and 1.1 meters. Beginners were to limit the number of takeoffs to 20 to 30 per session. Jogging or other light activity was recommended between sets.

Additional loading by increasing DJ height (> 1.1 meters) or adding weight to the body was not recommended, because the speed of the change from eccentric to concentric contraction drastically altered the exercise and its effectiveness. The investigation noted that DJ should be built upon a base of general strength and conditioning, with DJ training being terminated 10 to 14 days before competition.

Verkhoshanski and Tayan investigated the influence of a combination of methods in one training session on the speed-strength capabilities of three groups of 36 athletes (44). Group A executed speed-strength exercises such as hops with a barbell on shoulders, maximal VJ and standing long and triple jumps after preliminary toning work. The toning effect consisted of two sets of three repetition maximum (3 RM) before the speed-strength work. Group B used the same training methods, but in the opposite order. Both groups trained for 12 weeks. The training included 36 units with identical loads of 600 repetitions of strength exercises and 1,300 repetitions of speed-strength exercises. Group C used shock training or DJ over the 12-week period, which included 21 training units. Each unit consisted of approximately 40 takeoffs from heights of 0.5 to 0.7 meter.

Analysis of the results demonstrated a significantly greater change in speed-strength levels of athletes in Group C than those in Groups A and B. No differences were noted in speed-strength levels between Groups A and B. The investigators concluded that DJ training was more effective in the development of speed-strength abilities than the other variants, but they cautioned that such a finding does not warrant the elimination of weight training with other traditional speed-strength activities. The investigators recommended a strictly regulated DJ program in combination with traditional strength training methods.

Adams attempted to determine whether significant gains in muscular leg strength and power could be achieved via DJ from heights of 0.6 to 1.5 meters (1). A group of 177 males and females ages 12 to
17 was randomly divided into six groups. DJ treatments consisted of 20 takeoffs three times a week over seven weeks. Four groups participated, each at a different DJ height: 0.61, 0.75, 1.22 and 1.5 meters. A fifth group participated in vigorous activities requiring running, jumping and warm-up exercises. The sixth group (control) participated in activities requiring minimal jumping. All groups were pre- and post-tested in VJ, standing long jump (SLJ) and isometric leg strength measured with cable tensiometer at knee joint angles of 90 degrees and 150 degrees.

The results showed no significant differences in VJ and SLJ performance. With a few exceptions, however, significant gains in isometric muscular leg strength were indicated by the DJ group, which received the greatest training stimulus through rebound jumps from 1.5 meters, a height in excess of that recommended for mature athletes (42).

Although Adams found DJ in the 1.5-meter range more effective in increasing isometric leg strength (1), Katschalov et al. found a 0.8-meter drop height produced the best results (28). In an investigation of muscle elasticity, Asmussen and Bonde-Peterson found that maximum vertical height was made from a height of 0.4 meter by 19 young male and female subjects (2). In a similar study, Komi and Bosco found maximum rebound jumps for male and female university students to be from heights of 0.62 and 0.5 meters, respectively (30). The question of an optimal elevation for DJ is complicated by the fact that it is not known whether DJ heights that allow maximal elevation of the center of gravity during the rebound necessarily bring about an optimal training effect.

Optimal elevation and other DJ procedures also were investigated by Dursenev and Raevsky (23). The translated article included only sketchy details of the methods, experimental design and data, but the results are interesting nonetheless.

Three experiments were performed. The first was conducted to determine whether purely eccentric DJ (no rebound) would facilitate the growth of supermaximum and maximum strength. Supremaximum strength was defined as the amount of force a muscle could accommodate during a yielding or eccentric contraction. Supermaximum strength is 1.2 to 1.6 times greater than maximum strength, the greatest force a muscle can produce during a concentric contraction. All jumps were taken from a height of at least two meters. The subjects were novices, but the number of training units, sets and repetitions were not included. The results indicated that DJ of two meters or more using only an eccentric contraction upon landing definitely facilitated the growth of supremaximum and maximum strength.

The second investigation demonstrated that DJ of two meters with only an eccentric contraction of the leg extensors upon landing was significantly superior to DJ of 0.75 to 1.1 meters with a rebound.

The third experiment showed that supermaximum strength was most effectively developed with DJ from a maximum height. In order to establish the height at which DJ would provide the greatest strength gains, Group A jumped from heights of 2.8 to 3.2 meters and Group B jumped from heights of 2.2 to 2.6 meters. In both groups, the loading or eccentric contraction phase was not followed by a rebound. It was demonstrated that DJ from the maximum heights were more effective than DJ from 2.2 to 2.6 meters. Not surprisingly, the investigators found that Group A subjects required pressure from the investigators to complete DJ from heights of 2.8 to 3.2 meters.

Scoles randomly allotted college-age men into three groups: DJ, flexibility (F) and control (C) (40). The DJ group participated in two training units per week over eight weeks, with each unit consisting of 20 takeoffs from a height of 0.75 meter. The F group engaged in the same number of training units and participated in a program of stretching the hamstring, quadriceps and lower back muscles. The C group was inactive and participated only in the pre- and post-testing sessions.

Although no statistical difference was found among the groups, the DJ group showed the greatest gains in VJ (two centimeters) and SLJ (eight centimeters). The F group showed gains of approximately one centimeter in both VJ and SLJ; the C group showed no change. The author concluded that the number of subjects per group (n = 9) and the brief training period (16 units over eight weeks) led to failure of the DJ group to demonstrate any statistical significance.

Herman investigated the effects of DJ training on the VJ performance of college men (27). The subjects performed 12 DJ per twice-weekly session for the first week; the number of DJ was increased by two per week over the five-week training program. DJ were performed from heights of 0.75 and 1.1 meters, as recommended (43). Statistical analysis indicated no significance between pre- and post-test VJ performance. As with Scoles (40), the investigator stated that the experimental design could have been a limiting factor in the light of no significance being shown in VJ performance.

Brown et al. investigated the effect of plyometric training on VJ performance by 26 freshman and sophomore high school basketball
players. Subjects were placed into a training group (P) or a control group (C). A pre-test of VJ ability with the use of the arms (VJA) and without (VJNA) was conducted for both groups. On alternate days over 12 weeks, Group P participated in DJ training: three sets of 10 repetitions from a 45-centimeter bench with one minute of rest between sets. Group C participated solely in regular basketball training. Post-test results revealed no significant difference between Groups P and C on VJNA; however, Group P performed significantly better on VJA. Comparing the relative increases in VJNA and VJA between the groups, the authors concluded that approximately 57 percent of VJ gain in Group P was due to skill improvement, and the rest was due to strength increases. Bosco and Komi suggest that the arms can increase jumping performance by 10 percent or more (10).

Parcells studied the effects of DJ and weight training on VJ performance among 45 college-age men (36). The subjects were randomly assigned to either of two experimental groups or a control group. Group A participated in a six-week weight-training program twice a week. During the first week, subjects performed three sets of eight repetitions of half squats into heel raises with a 50-pound barbell. Two repetitions were performed each week. Group B underwent DJ training twice a week for six weeks, performing DJ from a height of 0.8 meter for the first three weeks and 1.1 meters for the last three weeks. Initially, two sets of 10 takeoffs were performed, with two additional jumps added each week thereafter. The control group was inactive.

All subjects were tested on VJ performance after six weeks. Results showed that DJ training improved VJ performance, whereas weight training did not. The investigator noted that a longer training period and a more intense, individualized weight-training program may have resulted in different findings.

Blattner and Noble compared DJ with isokinetic training and studied their effects on VJ performance (7). A group of 48 college-age men was divided randomly into one of three groups. Group I performed isokinetic training on a Model 16 KX leaper by Mini-Gym Inc. All subjects performed three sets of 10 repetitions of leg presses three times a week over the eight-week program. Group II engaged in DJ training, performing three sets of 10 repetitions three times per week over eight weeks from a height of approximately 0.86 meter. During the first two weeks of training, Group II subjects performed all DJ with only body weight as resistance. Additional weight was attached to each subject by a weighted vest during the last six weeks. Ten pounds were added during weeks three and four, with an additional five pounds added every two weeks thereafter. In all areas, a rest period of two minutes was allowed between sets. Group III was the control.

Results showed that both training groups significantly improved VJ performance. There was no significant difference between Groups I and II. Mean gains of 4.9 and 5.2 centimeters for the isokinetic and DJ programs, respectively, represented statistically significant improvement in VJ performance.

Polhemus and Burkhardt examined the effects of plyometric exercises on strength gains of collegiate football players (38). The purpose of the study was to determine whether greater physical strength gains could be demonstrated on performance in bench press, power clean, half squat and military press using plyometric drills with conventional weight training as opposed to weight training alone.

Group A performed only conventional weight-training exercises. The program consisted of three training units per week over a six-week period, with five sets of five repetitions from 65 percent to 75 percent of one-repetition maximum (1 RM) for the four weight-training exercises. Every fourth workout was devoted to testing of 1 RM efforts for the four exercises.

Group B followed the same weight-training program, with the addition of three plyometric drills that followed each weight-training unit. Exercise 1 consisted of running in place with emphasis on high knee lift; five repetitions of 30 seconds were done, with repetitions four and five at maximal effort. Recovery between repetitions was limited to 30 seconds. Exercise 2 used DJ from a bench height of approximately 0.45 meter. Subjects jumped down facing the bench, with an immediate rebound onto the bench. The exercise consisted of three sets of 10 repetitions, with one minute of recovery between sets. Exercise 3 consisted of bounding 10 meters at maximal effort three times per workout.

Group C followed the same program as Group B, with additional loads during the plyometric drills. Exercise 1 was done with 2.5 ankle weights. Exercises 2 and 3 were performed with a vest that weighed 10 percent to 20 percent of each subject's body weight.

Analysis of the pre- and post-test performances on the bench press, power clean, half squat and military press indicated that Group C, which used plyometric drills with additional loading and conventional weight training, was statistically significant when compared to Groups
A and B in all weight-training exercises except the military press, where no significance was found between groups. The mean increase in half-squat performance of Group C was 130.63 pounds versus 65.18 and 71.12 pounds for Groups A and B, respectively. The percentage increases in strength gains of Group C over Groups A and B were 50 percent and 30 percent, respectively.

In a study of similar design, Polhemus and Burkhardt investigated the effects of weight training and weight training plus plyometrics with ankle and vest weights on performance in VJ, SLJ, and the 40-yard dash. Groups A and B both participated in a weight-training program consisting of bench press, half squat, power clean and military press, all with five sets of five repetitions from 65 percent to 75 percent of 1 RM. Group B also included two plyometric drills. Drill 1 consisted of running in place with high knee lift for five 30-second bouts. Ankle weights of 2.5 pounds were used, and 30 seconds of recovery was allowed between repetitions. Repetitions four and five were done at maximal effort. Drill 2 consisted of repeated DJ with an immediate rebound jump. Three sets of 10 repetitions were performed, with a one-minute recovery period between sets. The subjects performed the drills at maximal intensity with a weighted vest of 10 percent to 20 percent of body weight. The bench height was not cited, but in the previous study using the same drill, the height was 0.45 meter. The program consisted of 18 training units over a six-week period. Twenty-seven college-age men were assigned randomly to Group A or B.

A comparison of pre- and post-test results indicated that plyometric drills can enhance weight training. Although both groups demonstrated improvement in VJ, SLJ, and 40-yard dash performance, only Group B showed statistically significant improvement.

Clutch et al. investigated the effectiveness of plyometrics in two experiments (21). The first consisted of 12 college-age men performing three jump programs: maximal VJ from a stationary position; DJ from a height of 0.3 meter; and DJ from heights of 0.75 and 1.1 meters. All jumping was done in four sets of 10 repetitions with a 220-yard jog recovery between sets. All subjects also engaged in a weight-training routine of three sets of four to six repetitions of half squats. When a subject could complete six repetitions of the exercise over the three sets, more weight was added. Only eight training units over a four-week period were included in the program, with pre- and post-tests examining VJ 1 RM of the half squat, and maximal isometric knee extension at an angle of 125 degrees.

Results indicated that DJ, when combined with weight training, is no more effective than a program of regular maximum VJ. Also, DJ from a height of 0.3 meter versus 0.75 and 1.1 meters results in comparable gains. Although no significance was demonstrated, subjects made an average gain in VJ performance of 8.4 centimeters. This improvement led the authors to conclude that any jump training, combined with weight training, can increase VJ.

The second experiment involved competitive athletes in a DJ program. Sixteen members of a men's collegiate volleyball team and 16 men in a college weight-training class were assigned randomly to one of two groups. Group A trained with weights and incorporated DJ into its routine, while Group B trained with weights only. Weight training consisted of deadlift, bench press and half squat. Three sets of four to six repetitions were performed with a load of 80 percent of 1 RM. DJ consisted of four sets of 10 repetitions from heights of 0.75 and 1.1 meters, with a 200-meter jog recovery between sets. Weight training was performed three times per week, and DJ training twice per week over the 16-week training period. All subjects were pre- and post-tested on VJ performance.

Results indicated that DJ training was helpful to weightlifters who had no other jumping stimulus. The active volleyball players (2.5 hours per day) who were involved in weight training and DJ made similar gains to those of volleyball players who were involved only in weight training. The authors concluded that DJ training is useful for athletes who do no other jumping, but from this study, DJ appeared to add nothing to training programs that already include a good deal of jumping.

Summary

Although a consensus has not been reached on the effects of plyometric training on muscle strength and jump performance, the technique has become a popular form of speed-strength or special strength development. Conflicts in the literature are possibly due to the variety of experiments and the range of subjects used. When beginning a plyometrics program, some basic facts and questions must be considered, using common sense and experience as well as the limited research available.

A review of the literature shows that Verkoshanski's work on shock or depth jump training has greatly influenced the training programs and studies that have been attempted (42, 43). Many of these investigations have incorporated his guidelines.
Verkhoshanski suggested that depth jumps from heights of 0.8 and 1.1 meters were most effective. The lower height brought about maximal speed in switching from yielding to overcoming work, whereas the greater height emphasized maximal dynamic strength. Studies have indicated that heights from 0.5 to 3.2 meters have been effective in increasing muscular strength and motor performance. One might conclude that heights less than 0.8 meter might be best for children and novices, whereas heights equal to or greater than the 0.8 to 1.1 meter range might be most effective for mature athletes.

According to Verkhoshanski, to exceed 1.1 meters or to apply additional weight to the body to increase resistance in depth jumps lengthens the changeover time from yielding to overcoming contraction, and defeats the purpose of the exercise. Various investigations have shown, however, that the use of ankle weights and weighted vests in hopping and bounding drills and heights of 1.5 to 3.2 meters in depth jumping have been effective in improving leg strength or motor performance. Further research is necessary to clarify what constitutes optimal height, and whether the use of additional weight during plyometric drills is appropriate.

There is little evidence that the twice-weekly sequence of four sets of 10 depth jumps, recommended by Verkhoshanski, can be refuted. Few studies have investigated the variables of sets, repetitions or recovery in depth jumping. Studies that did not include weight training and found no significant improvements in leg strength or motor skills used 10 to 21 training units over five to eight weeks. The total number of takeoffs ranged from 130 to 420, from heights of 0.5 to 1.2 meters. It appears from the limited research available that depth jump training requires a greater training load than the ranges above to improve leg strength or specific motor skill performance.

In reference to horizontal and stationary plyometric drills such as hopping, bounding and leg tuck jumps, optimal training load is still a matter of the coach’s judgment. Research in Germany has indicated that horizontal bounding by mature athletes of approximately four meters, with the center of gravity elevated 0.5 meter, corresponds with the training effects accrued from depth jumps (45).

Verkhoshanski advocated a sound foundation of general strength training as a prerequisite for plyometric training. Although some studies have shown plyometric training to be equal or superior to isokinetic and isotonic resistance training, he recommended that depth jumps be used with traditional strength training and introduced later in the preparation period. This protocol would use the so-called complex training methods that combine heavy weight training with plyometric activities in the same training session. Traditional weight-training programs that incorporate plyometrics have been shown to be superior to those that do not. From the available research, it seems prudent to allow for general strength development through traditional weight training and stationary and horizontal plyometric drills before the undertaking depth jump training. This format takes into consideration the progressions and periodization of sports training. Freeman, McFarlane, Verkhoshanski and Costello, among others, have discussed how such progressions may be used (22, 24, 34, 43).

Plyometric training is widely used in strength training programs even though the effects are not completely understood. Though there are contradictory findings, the use of plyometrics is theoretically sound and is supported by some research. Because of its nature, however, it must be strictly monitored (number of takeoffs, height of descent, etc.) to protect the athlete and allow for adaptation through well designed progressions.

References


