Plyometric Exercise

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This discussion attempts to provide an objective review of plyometric exercises in terms of their definition, contribution to normal movement and sport, potential scope and diversity, efficacy as a training modality, current controversy, and potential risk/benefit ratio. Much of this discussion is based on chap. 27 in The Theory and Practice of Strength Development (LaChance, 1993, Personal Fitness Publ., New Windsor, NY).

The Stretch-Shorten Cycle

Movement of the body and of implements (e.g., weights, balls, bats, racquets) used by the body occur as a result of volitional and reflexive recruitment of skeletal muscle. These movements are classified as being eccentric (lengthening), isometric (static), or concentric (shortening) muscular actions, or a combination of these. A stretch-shorten cycle (SSC) can occur when an activated muscle is eccentrically stretched and immediately performs a concentric action (26).

SSCs are an integral component of nearly all natural and athletic movements. From another perspective, the explosive and ballistic movements performed during sprinting, countermovement jumps, hurdling, throwing, acrobatics, gymnastics, weightlifting, trampolining, diving, and most other sports could not be performed to the same level without incorporating SSCs (24).

SSCs enhance both movement efficiency and performance levels, primarily by utilizing stored elastic energy and, to a much lesser extent, by increasing muscle activation (8).

Use of Stored Elastic Energy

The magnitude of the "potential to kinetic" energy transferred between the stretch and the shorten phase decreases as the time interval and magnitude of the stretch increases (4). That is, rapid, short-range prestretches tend to produce more efficient movement and greater energy transfer. However, the actual interval that is best for an individual appears to be influenced by age, gender, fiber type, and surface contact stiffness (i.e., footwear and contact surface).

The elastic nature and reflex potentiation of muscle are influenced by maturation and the aging process (6). Basic differences in reflex control between fast and slow fibers (postural muscles) may also account for differences in neural versus elastic potentiation (3). Differences in sarcomere cross-bridge life of slow oxidative fibers enable them to both retain attachments longer and utilize elastic energy better during slow versus long stretches (9).

Persons with a higher percentage of fast anaerobic fibers benefit more from stretches performed at high speeds over short angular displacements (10). Women utilize elastic energy more efficiently during low prestretch levels while men show greater potentiation during high prestretch levels (3). This may be due to differences in absolute strength and stiffness regulation or to fiber type composition. Stored elastic energy is wasted, in the form of heat, as coupling time is increased with soft shoes and landing surfaces.
(7). These findings support the significance of the exercise cadence and rapid rates of movement to maximize work and power output. However, the question remains as to what is too stiff a surface. Clearly, jumping on a thawed tundra in April is less appropriate than the same packed down, dried-up field in late summer. If the goal is to use a training surface that minimizes the loss of potential energy, the best surface would seem to be one that does not yield at all, such as concrete. However, training on a parquet wooden basketball court or a tuned track would be less stressful, and probably more specific, than training on a tiled concrete floor. In addition, the training surface and implement may actually absorb and transfer energy to facilitate the performance.

Definition of Plyometrics

Plyometrics describes an extremely wide range of physical conditioning exercises that emphasize SSCs. Stated another way, plyometrics are a subset of SSCs that emphasize rapid short-range-of-motion prestretching and the maximal ballistic activation of muscle. Traditionally, however, plyometrics have been limited to and synonymous with depth or drop jumps as described in the Eastern European literature.

Traditional Plyometrics

Traditional plyometric training exercises include the popular ground based low to moderate intensity horizontal bounding, skipping, hopping, and jumping drills. These exercises have been used by nearly all coaches for leg/sprint speed improvement. It must be emphasized, however, that only those exercises involving rapid prestretching and maximal efforts can be considered truly plyometric.

All other activities are considered regular jumping or SSC exercises. That is, rapid prestretches and maximal efforts are prerequisites of plyometrics.

Controversial Plyometrics

More controversial high-risk, higher intensity plyometrics include vertical weighted countermovement, box jumps, and depth jumps. Countermovement jumps with additional loads ranging up to 120% of body weight and depth jumps from heights of 10 to 110 cm have been prescribed to enhance the force component of power.

Countermovement jumps are also used to assess the load/velocity relationship, or the load at which jump height produces the greatest power outputs. Longitudinally, these tests can be used to assess improvements in jump height (based on flight time) under specific stretch loads. This is significant since the ability to tolerate stretch loads is directly related to one's performance potential.

Training has been successful under those conditions in which power output is maximal (36). Box jumps provide an opportunity for maximal-effort takeoffs without the stress of landing other than on top of an elevated platform. Depending on the surface of the platform, however, missed box jumps may result in abrasions and bruises to the lower leg, unless the landing is attempted on a stack of mattresses.

Stretch Loads

Biomechanical analysis of squat jumps, countermovement jumps (with no load), and drop jumps illustrates the significance of countermovements on the magnitude of the preload and ultimate takeoff force. While these values range from 2, 3, and 6 × BW, they are only a fraction of those observed during simulated basketball drills and contact sports. Cavanaugh et al. (13) observed peak forces ranging from 1.7 ± 0.52 BW under one foot in the lay-up takeoff to 8.9 ± 2.8 BW under two feet in the lay-up landing. The greatest values of 14 × BW recorded during a two-footed landing are only exceeded in the literature by Panzer’s analysis of landing from a gymnastics high bar (cited in Ref. 13).

Alternative Approaches

Although the amount and rate of prestretch exerted is significant from a mechanical standpoint, it may not be important how the prestretch is actually applied. Stretch loads may be applied from either a horizontal run-up or a vertical drop.

Considering that most sports involve vertical jumps following horizontal transitions, drop jumps (in which the magnitude of the prestretch load can easily be regulated and measured) may provide less specific preparation than normal sport movements. Thus, coaches interested in applying stretch loads of increasing magnitude could utilize run-up approaches at progressive speeds versus drop jumps from increasing heights.

On the other hand, if kinetics are more important than conditions, weightlifting (e.g., associated pulls, racks, push presses, and jerks) may also provide an acceptable overload of the musculature supporting the triple extension movements characteristic of sport. (Note that the triple extension refers to the coordinated bi- and unilateral extension of the ankle, knee, and hip.) From a safety standpoint, it is reassuring to note that Burkhardt et al.’s (12) analysis of forces during power cleans
Midsection and Upper Body Plyometrics

Until recently most of the plyometrics research has focused on the leg/jumping musculature. Less attention has been given to the use and design of SSC flexion, extension, and rotation exercises for the midsection muscles, and to pulls, presses, swings, and throws of implements by the upper body muscles (35). Ironically, movements and exercises typical to many sports and conditioning drills are often overlooked for their plyometric and SSC potential. The gymnastics snap down, cartwheel, and roundoff are examples of upper body exercises that could easily be integrated into many conditioning programs.

Why have plyometrics been used? There are a number of reasons. SSCs and specific plyometric exercises expose and probably prepare the trainable muscles, ligaments, and bones for the rigors of physical activity and sport (32).

When appropriately prescribed, these exercises specifically overload the trainable neuromuscular mechanisms involved during SSCs and, more important, during sport. Another benefit is not so much to increase absolute strength but rather to increase the rate at which force can be produced. Rehabilitation, enhanced coordination, agility, and anaerobic and general conditioning are the potentially obtainable but often overlooked benefits of many traditional and less obvious SSC/plyometric exercises.

Potential Training Effects

Plyometric exercise appears to improve both efficiency and the rate of muscular activation. This has been supported by cross-sectional studies that have reported differences in both mechanical efficiency and activation between trained and untrained subjects.

Mechanical efficiency. Increases in mechanical efficiency have been supported by a cross-sectional study comparing trained female gymnasts to female controls. The gymnasts were able to outjump (at 20 to 50 cm) the controls and maintain greater jump heights (from 60 to 80 cm) as drop jump height increased (26). This finding supports the notion of improved stiffness regulation, particularly at higher stretch loads, as an important training effect. In another study reported by Komi (26), male volleyball players were able to outjump controls during a 60-cm drop jump, suggesting a neural adaptation to specific stretch loads.

These findings are not too surprising since gymnastics and volleyball success is directly related to leg power and jumping ability. Yet it must be emphasized that other traditional methods such as resistance exercise and conditioning drills can be used to increase stiffness regulation.

Increases in EMG. An increase in EMG following training can result from an increase in the number of motor units recruited, an increase in reflexive/neural potentiation (via the short- and long-loop stretch-reflex), and a decrease of inhibitory responses to high stretch loads (18). Analysis of trained and untrained jumpers also illustrates differences in apparent adaptation. Untrained jumpers respond with a period of inhibition while trained jumpers demonstrate a facilitation during periods of high eccentric stretch loads from 1.1 m (31).

These cross-sectional studies suggest there may be a self-selection phenomenon or a generalized (rather than specific) training effect in response to all forms of plyometrics exercise.
Training Studies Involving Explosive Exercise

One primary goal of sport conditioning programs is to be time efficient, safe, and effective in terms of enhancing the rate of tension development and power output. The results of a few training studies (25, 36) support the use of training loads permitting maximal power output (i.e., between 30 to 60% of the 1-RM). One of the best studies illustrating the significance of the rate of tension developed during training was conducted by Hakkinen et al. (20).

Hakkinen et al's (20) study contrasting the effects of heavy resistance training versus explosive jump training clearly illustrates the potential of plyometric exercise to enhance the rate of EMG and tension development during isometric force-time analysis and depth jump performances. Heavy resistance training increased max EMG by 0.3% and force by 27%, but it had little if any effect on the rate of EMG (0%), rate of tension development (0.4%), or drop jump performance (0%). Conversely, jump training increased max EMG by 8% and force by 11%; and it had a much greater effect of the rate of EMG (38%), rate of tension development (24%), and drop jump performance (19%).

On the other hand, a few studies have found that the use or addition of plyometric exercises produces gains that are merely equivalent, not superior, to traditional methods of strength/power training in the gym. Table 1 summarizes selected training studies that assessed the effects of stretch-shorten exercises on performance. Perhaps the diversity of results is due to limitations in the design of the studies and the fact that trained athletes either do not benefit from additional jump training or there is a wash-out effect from their traditional sport training.

Other Support for Plyometric Exercise

The majority of SSC/plyometric exercises evaluated (via EMG and force-plate analysis) and promoted have involved weighted and unweighted countermovement jumps and depth jumps from various heights. Although most of the research on SSCs has been cross-sectional in nature, there have been many testimonials, training manuals, and peer reviewed journal articles about the effectiveness of plyometrics.

The amount of testimonials and training programs or manuals on the market far exceeds the number of athlete-based training studies that have adequate design, sample sizes, and duration either (a) demonstrating the overwhelming effectiveness of plyometrics or (b) delineating the appropriateness of prescriptions for specific plyometric exercises. That is, many of the current recommendations for plyometric exercise are based on a limited number of research observations.

Accordingly, there remains a great deal of confusion and controversy about the definition, scope of potential exercises, and relative risks and benefits. This uncertainty has opened the door for unlimited advertising and promotion of gadgets (e.g., strength shoes, speed chutes, training devices), books, videos, etc. Predictably, some organizations and individuals indiscriminately regard all forms of plyometric and ballistic SSC exercises as dangerous. This overly conservative approach is illogical, since the essential elements of sports and conditioning drills involve SSCs (preloading and rapid changes in direction) and can be classified as plyometric in nature.

Current Questions

While most sports are plyometric in nature and just about every conditioning program incorporates some form of plyometrics, a number of important questions remain:

1. How important is movement and temporal specificity for either horizontal or vertical based plyometrics to the transfer of training effects to other activities?
2. Would training time be better spent with more traditional gym-based strength/power and field-based speed/skill development exercises?
3. Can the actual sport and practice period provide enough of a plyometric training stimulus?
4. What are the actual risk/benefit ratios for SSC/plyometric exercises?
5. What is the best way to prescribe plyometric exercise?
Table 1
Results of Selected Plyometric/Stretch-Shorten Training Studies

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<thead>
<tr>
<th>Reference</th>
<th>Method</th>
<th>Results</th>
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<tr>
<td>Adams (1)</td>
<td>Evaluated 177 M &amp; F ages 12-17 in 6 groups (jumping, control, active) to identify the DJ height (0.61, 0.75, 1.22, 1.5 m) that elicited the greatest gains in strength &amp; power.</td>
<td>No differences observed in SLJ or VJ, but DJ increased isometric leg strength.</td>
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<tr>
<td>Anderst et al. (2)</td>
<td>Compared the effects of plyometric (n = 5) &amp; explosive resistance (n = 7) training on bounce drop jumps &amp; countermovement jumps.</td>
<td>Both improved takeoff velocity, takeoff power, &amp; jump height, but there were no statistical differences.</td>
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<tr>
<td>Blattner &amp; Noble (5)</td>
<td>Evaluated the effects of 6 wks of 3 x 10 reps of either isokinetic leaper or plyometric DJ training on VJ performance.</td>
<td>Both groups improved VJ performance (no difference, 4.9 &amp; 5.2 cm, respectively).</td>
</tr>
<tr>
<td>Brown et al. (11)</td>
<td>High school basketball players added depth jumps to traditional practice for 12 wks.</td>
<td>Improvements in VJ only found for jumps w/arm assistance (not w/o arm assistance), suggesting importance of skill vs. drop jumps.</td>
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<tr>
<td>Clutch et al. (14)</td>
<td>Intercollegiate volleyball players did 16 wks of countermovement jumps in addition to weight training &amp; daily volleyball practices.</td>
<td>No benefit was found, suggesting that any combination jump &amp; weight training can increase VJ.</td>
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<tr>
<td>Cook et al. (15)</td>
<td>Evaluated the Strength Shoe™, a modified 4-cm thick rubber sole on the front half of a sneaker, using an 8-wk training regimen recommended by the manufacturer.</td>
<td>No improvement observed in strength, flexibility, or performance.</td>
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<tr>
<td>Crowder et al. (16)</td>
<td>34 Ss were tested for upper body medicine ball push power (throw) &amp; assigned to 1 of 2 groups training w/either traditional push-ups or hand-clap plyometric push-ups each session following a strength training session. No pretest or normative data given for push-ups or medicine ball throw.</td>
<td>The plyometric group outperformed the traditional group on upper body power.</td>
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<tr>
<td>Ford et al. (17)</td>
<td>Contrasted the effects of 3 combinations of plyometric &amp; weight training programs for 10 wks on 5 selected physical fitness test items (N = 50).</td>
<td>No significant effects observed.</td>
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<tr>
<td>Hakkinen et al. (19, 20)</td>
<td>Compared explosive jump training &amp; heavy resistance training on drop jump performance, max rate of IEMG, &amp; rate &amp; amount of force development.</td>
<td>Demonstrated differences between types of training.</td>
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<td>Herman (21)</td>
<td>Compared twice a wk depth jumps (12 reps/sess), increased 2 reps/wk for 5 wks from 0.75 &amp; 1.1 m DJ on VJ performance.</td>
<td>No significant difference observed; improvement in pre/posttest vertical jump.</td>
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<td>Hortobagyi et al. (23)</td>
<td>16 yr-olds trained 12 wks on skilled execution of either the long jump or bounding.</td>
<td>Similar improvements in performance, emphasizing the importance of skill development in preparation of young athletes.</td>
</tr>
<tr>
<td>Hortobagyi (22)</td>
<td>Compared the effects of 2 stretch-shorten programs emphasizing either horizontal or vertical jump performance in 13-yr-olds.</td>
<td>No significant differences between groups on either test.</td>
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<tr>
<td>Kraemer et al. (27)</td>
<td>24 female rowers trained 9 wks w/(n = 13) or w/o (n = 11) plyometric exercises 3 times a wk.</td>
<td>Jump exercises offer no advantages to oarswomen.</td>
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<td>Parcells (28)</td>
<td>Evaluated the effects of DJ &amp; weight training on VJ performance. Twice/wk for 6 wks, 45 college males did either 3 sets x 8 reps half-squats w/heel raises w/50 lbs (+2 reps per wk) or DJ from 0.8 m progressing to 1.1 m the last 3 wks.</td>
<td>Only depth jumps improved vertical jump performance.</td>
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<td>Polhemus (29)</td>
<td>College football players trained 6 wks by weightlifting, jogging, &amp; flexibility exercise, w/o added jump exercise, w/ or w/o added ankle &amp; vest weights.</td>
<td>The only significant gain was in the group w/weighted jumps; Note small sample w/no report of significant difference between groups.</td>
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<tr>
<td>Polhemus &amp; Burkhardt (30)</td>
<td>Contrasted the effects of traditional weight training &amp; plyometric training w/ &amp; w/o added ankle &amp; vest weights.</td>
<td>The weight training group using loaded plyometric exercises was superior.</td>
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<td>Taylor et al. (34)</td>
<td>High school sprinters used speed chutes 2 days/wk for 6 wks.</td>
<td>No greater improvement in flying 55-m sprint performance than w/ traditional training.</td>
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<tr>
<td>Wilson et al. (36)</td>
<td>64 untrained Ss were randomized to contrast the effects of 10 wks of traditional weight training (heavy squats), plyometric (DJ training, &amp; explosive weight training (weighted squat jumps) at the load that maximized power output.</td>
<td>The group that did explosive weighted squat jumps at the load that maximized mechanical power output recorded statistically significant improvements.</td>
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Note: Only activities involving a short range, rapid prestretch followed by a maximal effort shortening phase are plyometric. Use of additional weights during depth jumping & other plyometrics not recommended, due to increased likelihood of protracted ground contact times. Likewise, any technique or skill that flexes joints excessively during loading (e.g., Strength Shoes™, heavy medicine or plyo balls, weighted jump ropes & vests) are not recommended because increased loading increases contact time. The further one is from his/her genetic potential for elastic power (e.g., teens, untrained persons), the more likely he/she will improve with any program. Also, it may be better for some less trained individuals to emphasize either strength, speed, or skill training, depending on need, rather than plyometrics.

Clearly, additional research is needed to definitively answer such questions about plyometric exercise. Meanwhile, following are some guidelines for exercise prescription.

**Safety and Training Principles**

Most of the low to moderate intensity plyometric exercises that have been used, those not dependent on equipment, can be integrated into many conditioning programs to provide a safe, effective, and efficient form of sport-specific conditioning. However, when plyometrics (except weighted, box, and depth jumps) are used to complement training, a number of basic safety principles must be considered:

- Assuring prerequisite biological/skeletal maturity in terms of adequate strength, speed, skill, and flexibility levels;
- Use of a general and specific warm-up;
- Monitoring of total hand/foot contacts/reps or distance covered in a training diary;
- Following a slow rate of progression for both volume and intensity;
- Use of repetition ranges that are inverse to the intensity of exercise;
• Use of appropriate repetition ranges and rest intervals to assure neuromuscular recovery;
• Limited frequency of use (once a week heavy, twice a week light);
• Individualizing or periodizing training plans based on the athlete’s strengths and weaknesses, training history, and genetic potential;
• Ongoing orthopedic and trainer-coach evaluation.

Clearly, moderate to high intensity plyometric activity should not be performed by pubescent persons with a history of orthopedic problems (e.g., knee instability), or overfat athletes. A strength base of 1.5 to 2 times body weight for the squat and a high strength-to-weight ratio for the midsection and upper body are also prerequisites for intense plyometrics. Jumping should not occur from any height or at any time the heels are forced to make contact upon landing.

More restrictive guidelines limit drop jump heights to levels equal to one’s maximal box jump height. The use of additional weights in the form of vests, dumbbells, or Olympic bars require advanced conditioning. Regardless of the form of exercise performed, the risk of injury increases with (a) the use of more complex movements, (b) higher intensity of exercise (relative to fitness level and biological age), and (c) muscular and central nervous system fatigue, whether acute or chronic. Plyometric exercise should be gradually integrated into conditioning programs using the technique of periodization.

References

20. Hakkinen, K., P.V. Komi, and M. Alen. Effect of explosive type strength training on isometric force and relaxation times, electromyographic, and muscle fibre characteristics of leg extensor muscles.


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