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Plyometric Training and the High Jump

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Introduction

Plyometric training is an important element of the training programme of most top-level jumpers, including high jumpers. Although it has developed over more than half a century and been reported in the literature, its proper utilisation is still not fully understood by many coaches. Some apply plyometrics incorrectly, which can reduce the positive training effects or even lead to injuries, while others avoid the means, and thus compromise the potential performances of their athletes.

The aim of this article is to address this situation by providing a summary of the main aspects of plyometric training, drawn from the current literature, as a general guide and as a starting point for further study and discussion. Special emphasis is given to the use of plyometrics in training for the high jump.

The main points to be covered are:

- The history of plyometric training,
- The scientific basis of plyometric training,
- Plyometric training compared to traditional resistance training and ballistic training,
- Integration of plyometric training in the athlete's training programme,
- Practical aspects of plyometric training,
- Plyometrics and resistance training,
- Plyometrics and circuit training,
- Plyometric drills,
- Plyometrics and the high jump.

The History of Plyometric Training

Although western training scientists became aware of plyometrics in the mid-1970s, this form of training was developed in the Soviet Union in the 1950s and early 1960s (DUKE, 1990). The term was initially synonymous with triple jumpers and triple jump training (see, for example, YOUNG & MARINO, 1985). To develop the type of loads that the plant leg had to withstand in the hop and step phases, athletes trained by jumping down from one box onto the plant leg and instantly jumping up onto another box. The terms "stretch-shortening" training, "depth jump" training, "reactive" training, "drop jump" training and "eccentric-concentric" training started appearing in the literature more and more in the 1960s.

A particularly important piece of literature at the time was a study by Verhoshanski (1967), where he advocated depth-jump heights between 0.75 and 1.15m. According to REID (1989), many coaches took this to mean athletes could develop the stretch reflex by jumping down from boxes higher and higher, land on pre-stretched plant leg and bound back up onto another box. Such training was not substantiated by scientific research and the injury score increased. However, over-zealous coaches often rationalised that athletes who could not complete the drill were simply too weak.

Valeriy Borzov's (URS) double victory in the sprints at the 1972 Olympic Games in Munich 1972 made everyone aware of how plyometrics can be incorporated into a sprint training programme. Borzov made extensive use of various jumping exercises in his training but was by no means the first sprinter to utilise plyometric training. Armin Hary (FRG), the 100m gold medallist in the 1960 Olympics, made use of various jumping exercises throughout his training programme. Many sprinters have also participated in the long jump, the training for which serves a similar purpose. A good example is Irena Szewinska (POL), the multiple Olympic medallist, who incorporated extensive jump training into her programme (GAMBETTA, 1987).

However, plyometric training has by no means been the exclusive domain of the sprinters/jumpers. Throwers, too, have used plyometrics, both for the upper and lower body. Upper body plyometrics has mainly taken the form of medicine ball exercises using 3-6kg balls. Janis Lusis (URS), former javelin world record holder and Olympic champion, made extensive use of jump training in the form of hurdle jumps, hopping, and bounding to develop the explosive power in his legs.

Plyometric type training has also been utilised in the realm of middle distance and distance training. Hill bounding, advocated by Arthur Lydiard in the late 1950s, was designed to yield a powerful stride but is nothing more than bounding with the added resistance of the hill. Pekka Vasala (FIN), the 1972 Olympic champion over 1500m, used a six-week period of a 'bounding endurance phase' in his training. This was performed up a 400m slope of 5-15° gradient.

All these examples show that plyometric training in itself is not new, but the proper application as a training method needs further clarification and guidelines (GAMBETTA, 1987).

The Scientific Basis of Plyometric Training

During plyometric, or stretch-shortening, exercises the muscle is rapidly stretched (eccentric contraction) and then shortened to accelerate the body upward, as in a countermovement jump (see Figure 1).

Figure 1: Countermovement jump (Hoffman, 2002)

This stretch-shortening cycle has been demonstrated to enhance power performance to a greater extent than concentric training only (e. g. by performing squat jumps) (BOSCO, VIITASALO, KOMI & LUHTANEN, 1982). The improved performance seen in the countermovement jump is attributed to a greater amount of stored elastic energy acquired during the eccentric phase that is able to be recruited during the upward movement of the jump (BOSCO & KOMI, 1979). In addition, the pre-stretch during the countermovement results in a greater neural stimulation (SCHMIDTBLEICHER, GOLLHOFER & FRICK, 1988) as well as an increase in the joint moment (a turning effect of an eccentric force, also referred to as torque at the start of the upward movement (KRAEMER & NEWTON, 2000)). The greater joint moment results in a greater force exerted against the ground with a subsequent increase in impulse (greater force applied over time) and acceleration of the body upward. BOBBERT et al. (1996) have suggested that this latter mechanism may be the primary reason for the greater jump height observed during a countermovement jump, whereas the other mechanisms may play more of a secondary role.

The performance of a stretch-shortening cycle requires a finely coordinated action of agonist, antagonist, and synergistic muscle groups. During the rapid action of the stretch-shortening cycle, the agonist and synergistic muscle groups must apply a great deal of force in a relatively short period of time. To maximise this action, the antagonist muscle groups must be relaxed during the time the agonists and synergists are active. However, a novice to stretch-shortening movements needs some training to coordinate these movements. Through training, contraction of the antagonist muscle muscle groups is reduced, which allows for a greater coordination of these muscle groups and produces a more powerful and effective vertical jump. In addition, during the initial workouts, the EMG (electrical activity of the exercising muscles, indicating extent of activation) of the agonist muscle groups appears to be reduced. This is likely the result of activation of the golgi tendon organ (a muscle proprioceptor) to protect the muscle from excessive stretch. As the training programme continues, these inhibitory effects exhibited by the muscle proprioceptors may be reduced, allowing for improved stretch-shortening perform-ance (SCHMIDTBLEICHER et al, 1988).

The primary question when discussing plyometric training is whether plyometric drills should be considered a supplement to the normal training regimen or an alternative way of training. Specifically, will plyometric training itself be as effective in improving power and strength performance as resistance training? Will including these drills as part of the overall training programme provide any additional benefit for the athlete?

Plyometric Training Compared to Traditional Resistance Training and Ballistic Training

Three methods of training are generally used to improve the power of athletes who participate in dynamic, explosive sports:

1. The primary training method has used traditional resistance training programmes with a relatively high intensity of training (4-6 RM) performed at a relatively slow velocity of movement.

2. Plyometric training is another training method that is used to enhance power performance. Most plyometric exercises require the athletes to rapidly accelerate and decelerate their body weight during a dynamic movement. The athletes' body weight is most often used as the overload, but the use of external objects such as medicine balls also provides a good training stimulus for certain plyometric exercises.

3. The final method of training to enhance muscular power and explosive sports performance is a combination of traditional resistance training and plyometric training. This form of resistance training is referred to as ballistic training. Ballistic movements (see Figure 2) are forced movements initiated by muscle actions but continued by the momentum of the limbs (KENT, 2006). Ballistic movements are performed at a much lower intensity of training (approximately 30% of 1 RM) using a much higher velocity of movement (WILSON, NEWTON, MURPHY & HUMPHRIES, 1993). The have three main phases: 1) an initial phase of concentric action that starts the movement, 2) a coasting phase that relies on the momentum generated in the initial phase, and 3) a deceleration phase accompanied by eccentric actions (KENT, 2006).

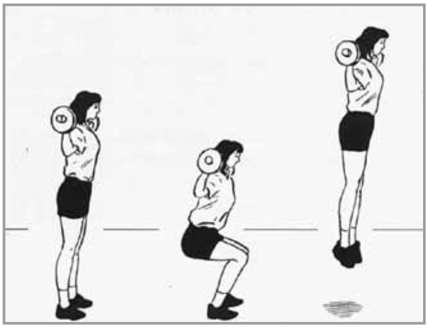

Figure 2: Ballistic training (HOFFMAN, 2002)

Studies have demonstrated the effectiveness of plyometric training for improving power, generally expressed as increases in vertical jump height (e. g. BROWN, MAYHEW & BOLEACH, 1986). Traditional resistance training has been shown to improve vertical jump performance as well (ADAMS et al., 1992). However, these improvements may be limited in experienced strength-trained individuals (HAKKINEN & KOMI, 1985) or in athletes who have a high pre-training vertical jump ability (HOFFMAN et al., 1991). When plyometric drills are combined with a traditional resistance training programme, vertical jump performance appears to be enhanced to a significantly greater extent than if performing either resistance training or plyometric training alone (ADAMS et al., 1992). Neither of these methods may be as effective in improving vertical jump performance as ballistic training.

WILSON et al. (1993) compared all three methods of training (traditional resistance training, ballistic resistance training, and plyometric training) in recreational athletes with at least one year of resistance training experience. After 10 weeks of training, the ballistic resistance group showed improvements in a greater number of variables tested – jump height, isokinetic leg extensions, 30m sprint time, and peak power on a 6 sec cycle test – than either the traditional resistance training or plyometric training groups.

All three training programmes resulted in significant improvements in countermovement jump performance. However, the subjects that performed ballistic training improved to a significantly greater extent than the subjects that performed traditional resistance training but not plyometric training. In the squat jump, significant pre- to post-training improvements were only realised by the subjects in the traditional resistance training and ballistic training groups but not the plyometric group. In addition, the ballistic training group improved significantly more than the subjects in the two other groups. The results of this study suggest that ballistic training might be more effective for improving power performance than either traditional resistance training or plyometric training performed separately.

Integration of Plyometric Training in the Athlete's Training Programme

The use of traditional resistance training programmes that require lifting a heavy load at a slow velocity of movement has generally been considered the primary method of increasing power production. This has been based on the notion that because power is equal to force multiplied by velocity, increasing maximal strength enhances the ability to improve power production. However, to maximise power production, it is imperative to train both the force and velocity components.

In novice resistance-trained athletes, large increases in strength are common during the beginning stages of training. Improvements in various power components of athletic performance, such as vertical jump height and sprint speed, may also be evident. This is primarily the result of the athlete being able to generate a greater amount of force. As the athlete becomes stronger and more experienced, the rate of strength development decreases and eventually reaches a plateau. At this stage of an athlete's career, not only are strength improvements harder to achieve, but improving maximal strength does not provide the same stimulus to power performance as it did during the earlier stages of training. In addition, training for maximum force development may have its limitations on improving power performance. An important factor for maximising power production is exerting as much force as possible in a short period of time. By training for maximal strength through heavy resistance training, the rate of force development does not appear to be enhanced (KRAEMER & NEWTON, 2000). This is supported by a number of studies that showed improvements in vertical jump performance in novice or recreationally-trained individuals after heavy resistance training programmes but limited improvements in individuals or athletes with substantial resistance training experience.

However, if plyometric exercises or a combination of plyometric and resistance training (using a light resistance such as might be used with ballistic training) is added to the training programme, the athlete's ability to increase the rate of force development may be enhanced. This has also been demonstrated by a number of studies showing that the incorporation of ballistic training does provide a positive stimulus for improving power production even in the trained athlete, especially resistance-trained athletes (NEWTON, KRAEMER & HAKKINEN, 1999; WILSON et al., 1993).

To maximise power development, a number of components of power need to be trained and emphasized at various stages of the athlete's career. KRAEMER & NEWTON (2000) have described each of these components as a window of adaptation. Each window refers to the magnitude of potential for adaptation. For example, as the athlete's strength level increases, the window of opportunity to improve maximal power production from slow-velocity strength training is reduced. Training must then be aimed at improving performance in the athlete's weakest component, because it is in these components that the athlete has the largest window of opportunity for improvement. This could, for example, be the window of adaptation for using ballistic training, which now can prove to be especially effective in increasing jumping performance. A traditional resistance training programme would in this case probably not lead to any changes in jump performance.

HOFFMAN's (2002) explanation is more general. He holds that in order to maximise power performance in an athlete, a number of different methods of training need to be integrated over the course of the athlete's career. As the athlete becomes more highly trained, the relationship between strength and power lessens and a reliance on other methods of power development are needed. It is during this period that the inclusion of plyometric training may have its most profound effect.

Practical Aspects of Plyometric Training

Injury prevention

A primary concern when beginning a plyometric training programme is the increased potential for injury, because the drills place high forces on the musculoskeletal system. The risk of injury can be minimised by heeding the following recommendations:

- Make sure that the athlete has developed a reasonable strength base through a prolonged (>1 yr) resistance training programme.
- Use footwear and landing surfaces with good shock-absorbing qualities.
- Allow for proper warm-up before beginning the exercise session.
- Use proper progression drills; master lower-intensity drills before beginning more complex plyometric exercises.
- All boxes used for drills should be stable and have a nonslip top surface.
- Make sure that there is sufficient space for the desired drill. For most bounding and running drills 30-40m of straightway are required, whereas for some of the vertical and depth jumps, only 3-4m of space are enough. For jumping drills, ceiling height should be approximately 4m.
- Select exercises that have a high degree of specificity within the athlete's sport to enhance performance gains.
- Ensure that all drills are performed with proper technique.
- Allow for sufficient recovery between exercise sessions, and do not perform plyometric drills when fatigued.

Similar to the development of a resistance training programme, the exercise prescription for plyometric training involves the control of a number of programme variables (HOFFMAN, 2002).

Exercise variables

<u>Intensity</u>

In plyometrics, intensity is controlled by the type of exercise performed. Plyometrics ranges from simple tasks to highly complex and stressful exercises. Starting out with skipping is much less stressful than alternate bounding. Double-leg hops are less intense than single-leg bounds.

The intensity of plyometric exercises can be increased by adding light weights in certain cases, by raising the platform height for depth jumps, or simply by aiming at covering a greater distance in longitudinal jumps. As far as exercises are concerned, jumps-in-place are the lowest-intensity plyometric exercises while depth jumps represent the highest intensity. Between these extremes there are standing jumps, multiple hops and jumps, and box drills (see Figure 3).

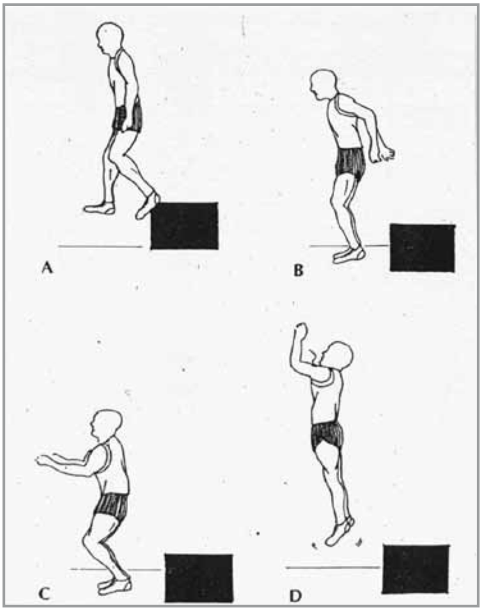

Figure 3: Box drill (DUKE, 1990)

<u>Volume</u>

In plyometric training, volume is often measured by counting foot contacts. For example, an activity like the standing triple jump, comprised of three parts, counts as three foot contacts.

The recommended volume of specific jumps in any one session will vary with intensity and progression goals. A beginner in a single workout in an off-season cycle could do 60-100 foot contacts of low-intensity exercises. The intermediate exerciser might be able to do 100-150 foot contacts of low-intensity exercises and another 100 of moderate-intensity exercises in the same cycle. Advanced exercisers might be capable of 150-250 foot contacts of low- to moderate-intensity exercises in this cycle.

The volume of bounding (exaggerated running) activities is best measured by distance. In the early phases of conditioning, a reasonable distance is 30m per repetition. As the season progresses and the athletes' abilities improve, the distance may be progressively increased to 100m per repetition.

Low-intensity exercises used during warm-up are generally not included in the number of foot contacts when computing volume. Thus warm-ups should stay low in intensity and progressive in nature so they do not overtax the athlete.

<u>Frequency</u>

Frequency is the number of times an exercise is performed (repetitions) as well as the number of times exercise sessions take place during a training cycle.

Beginners should have at least 48 hours of recovery between plyometric sessions. If the athlete does not get enough recovery, muscle fatigue will make him or her unable to respond to the exercise stimuli (ground contact, distance, height) with maximal, quality efforts. The overall result is less efficient training for athletic development.

There are varied methods for establishing frequency in plyometric training. Some coaches prefer to use a Monday and Thursday schedule during the preparation cycle. Using the principle of 48-72 hours of recovery for lower extremity training many programme variations can be developed. Running programmes can also be integrated into the training cycle along with or replacing weight training on certain days, although it is recommended that weight training be a priority in developing and maintaining the strength base necessary to carry out a successful plyometric training programme.

Because of the stressful nature of plyometrics and the emphasis on quality of work, plyometric exercises should be performed before any other exercise activities. They can be integrated into weight training (this combination is called complex training) in a later cycle in the training year if desired, or they might comprise the entire workout. This is quite conceivable, in fact, if the athlete is involved in athletics, where the plyometric training might be very specific to the event or to skill development.

Recovery

Recovery is a key variable in determining whether plyometrics will succeed in developing power or muscular endurance. For power training, longer recovery periods (45-60 sec) between sets or groupings of multiple events, such as a set of 10 rim jumps (=continuous jumps trying to reach the rim of a basketball goal), allow maximum recovery between efforts. A work to rest ratio of 1:5 or 1:10 is required to assure proper execution and intensity of the exercise. Thus, if a single set of exercises takes 10 sec to complete, 50-100 sec of recovery should be allowed.

Less than two seconds of recovery time in a 12 to 20 min workout makes it aerobic. Exercise for both strength and endurance is usually achieved through circuit training, where the athlete continues from one exercise to another without stopping between sets.

Plyometrics and Resistance Training

Resistance training is the ideal counterpart of plyometric training as it helps prepare the muscles for the rapid impact loading of plyometric exercises. In resistance training one works to develop the eccentric phase of muscle contraction by first lowering the body or weight and then overcoming the weight using a concentric contraction.

Open-chain resistance training (using machines that isolate a single joint) is useful for developing strength in specific muscle groups. However, the user of plyometrics also needs to perform closed-chain exercises that involve multi-joint activities such as free-weight exercises. These exercises, which are generally performed with the feet fixed to the ground as in squatting, are more functional for athletes, allowing them to assume positions specific to their events when they exercise. Closed-chain exercises have proven themselves to have much higher carryover value than isolated joint exercises in developing athletic ability.

Plyometric training can be successfully integrated with resistance training by imposing a speed-strength task immediately on muscles that have been subjected to pure strength movements like those in weightlifting.

The more intense plyometric exercises become, the more crucial the need for strength. Poor strength in the lower extremities results in loss of stability when landing, and high-impact forces are excessively absorbed by the soft tissues of the body.

Early fatigue also becomes a problem without adequate leg strength. Together, these will result in the deterioration of performance during exercise and an increased chance for injury (CHU, 1998).

Plyometrics and Circuit Training

Plyometric training can easily be organised into circuits. By moving from station to station, the athlete can do a variety of exercises that stress either the vertical or linear components of various movement patterns, or both.

By using circuits, athletes can perform activities of even greater duration than with anaerobic, sprint, and interval training. This may move the level of cardiovascular stress toward improvement in aerobic conditioning, resulting in increased stamina (CHU, 1998).

Plyometric Drills

The following drills are proposed by HOFFMAN (2002):

Drill	Intensity	Starting position	Action
Standing long jumps	Low	Stand in semi-squat position with feet shoulder-width apart.	With a double arm-swing and countermovement with the legs, jump as far as possible.
Squat jumps	Low	Stand in squat position with thighs parallel-to floor and interlocked fingers behind head.	Jump to maximum height without moving hands. On landing, return to starting position.
Front cone hops	Low	Stand with feet shoulder-width apart at the beginning of a line of cones.	Keeping feet shoulder-width apart, jump over each cone, landing on both feet at the same time. Use a double arm-swing and attempt to stay on the ground for as little time as possible.
Tuck jumps with knees up	Moderate	Stand with slightly bent knees and feet shoulder-width apart.	Jump vertically as high as possible, bringing the knees to the chest and grasping them with the hands before returning to floor. Land in a standing vertical position.
Lateral cone hops	Moderate	Stand with slightly bent knees and feet shoulder-width apart beside a row of 3-5 cones stretched 2-3 ft apart.	Jump sideways down the row of cones, landing on both feet. When the row is complete, jump back to starting position.
Double-leg or single-leg zig-zag hops	Moderate	Place 6-10 cones 50-75cm apart in a zigzag pattern. Begin with slightly bent knees and feet shoulder-width apart.	Jump diagonally over the first cone. On landing, change direction and jump diagonally over each of the remaining cones.
Standing triple jumps	Moderate	Stand with feet shoulder-width apart, bending at the knee with a slight forward lean.	Begin with rapid countermovement and jump as far up and forward as possible with both feet, as in the long jump. On landing, make contact with only one foot and immediately jump off. Get maximal distance and land with the opposite foot and take off again. Landing after this jump is with both feet.
Pike jumps	Moderate-high	Stand with slightly bent knees and feet shoulder-width apart.	Jump up and bring the legs together in front of the body. Flexion should occur only at the hips. Attempt to touch the toes at the peak of the jump. Return to starting position.

Drill	Intensity	Starting position	Action
Split squats with cycle	High	Stand upright with feet split front to back as far as possible. The front leg is 90° At the hip and 90° at the knee.	Perform a maximal vertical jump while switching leg positions. As the legs switch, attempt to flex the knee so that the heel of the back foot comes close to the buttocks. Land in the split squat position and jump again.
Single-leg hops	High	Stand with one foot slightly ahead of the other, as in initiating a step, with the arms at the sides.	Using a rocker step or jogging into the starting position, drive the knee of the front leg up and out as far as possible while using a double-arm action. The non-jumping leg is held in a stationary position with the knee flexed during the exercise. The goal is to hang in the air as long as possible. Land with the same leg and repeat.
Single-leg push-offs with box	Low	Stand in front of a box 15-30cm high. Place heel of one foot on the box near the closest edge.	Push off the top foot to gain as much height as possible by extending through entire leg and foot. Use double-arm action for gaining height and maintaining balance.
Front box jumps	Low-moderate	Stand in front of a box 30-100cm high (depending on ability) with feet shoulder-width apart and hands behind head.	Jump up and land with both feet on the box and step down. For a more advanced exercise, hop down and immediately hop back on top. Use a variety of box heights.
Multiple box-to-box jumps	Moderate	Stand in front of 3-5 boxes 30-100cm high (depending on ability) with feet shoulder-width apart.	Jump onto the first box then off and jump onto the next box. Continue to the end of the line, using a double-arm action for gaining height and maintaining balance.
Multiple box-to-box squat jumps	High	Stand in front of 3-5 boxes 30-100cm high (depending on ability) in parallel squat position with feet shoulder-width apart and hands behind head or on hips.	Jump onto the first box, maintaining squat position, then jump off and onto the next box. Continue to the end of the line. Keep the hands behind the head or at the hips.
Depth jumps	Low-moderate	Stand on a box 30-100cm high (the higher the box height, the greater the intensity of the exercise) with toes close to edge and feet shoulder-width apart.	Step from box and drop to ground with both feet. As soon as there is foot contact, jump explosively as high as possible. Try to have as little ground contact as possible.

Drill	Intensity	Starting position	Action
Depth jumps to prescribed height	Moderate	Stand on a box 30-100cm high (the higher the box height, the greater the intensity of the exercise) with toes close to edge and feet shoulder-width apart in front of a box of similar height.	Step from box and drop to ground with both feet. As soon as there is foot contact, jump explosively as high as possible onto the second box. Try to have as little ground contact as possible.
Single-leg depth jumps	High	Stand on a box 30-45cm high with toes close to edge and feet shoulder-width apart.	Step from box and drop to ground with both feet. As soon as there is foot contact, jump explosively as high as possible with that single foot. Try to have as little ground contact as possible.
Skipping	Low	Stand comfortably.	Lift one leg with knee bent to 90° while lifting the opposite arm with elbow also bent to 90°. Alternate between both sides. For added difficulty, push off ground for more upward extension.
Power skipping	Moderate	Stand comfortably.	With double-arm action, move forward in a skipping motion, bring the lead leg as high as possible in an attempt to touch the hands. Try to get as much height as possible when pushing off on back leg. Each repetition should be performed with alternate leg.
Alternate leg bounding	Moderate	Begin with one foot slightly in front of the other with arms at the sides.	Using a rocker step or jogging into the starting position, push off the front leg and drive the maximal horizontal and vertical distance with either an alternate or double-arm action. Try to hang in the air for as long possible. On landing, repeat with opposite leg. The goal is to cover maximal distance with each jump. This is not designed to be a race or sprint.
Single leg bounding	High	Stand on one foot.	Bound from the one foot as far foreward as possible, using other leg and arms to cycle in air for balance and increase forward momentum.

Plyometrics and the High Jump

According to REID (1989), the discussion of plyometrics and high jumping has to be preceded by a brief discussion of the relationship of fast-twitch and slow-twitch fibers.

Athletes have a combination of the two and their resultant technique in high jumping terms has led to the descriptive terms *speed flopper* and *power* or *strength flopper* (REID, 1984). The approach speed, the gather, the mechanics leading up to and observed in the plant and the take-off time differ between speed and power/strength floppers. For example, the approach velocity of a speed flopper is 7.8-8.4m/sec, whereas the approach velocity of a power/strength flopper is 6.5-7.5m/sec; the approximate take-off time of a speed flopper is 0.13-0.18m/sec, whereas the approximate take-off time of a power/strength flopper is 0.17-0.21m/sec.

The plant is the crucial phase of high-level high jumping. In principle, high jumpers should try to spend as little time in contact with the ground on take-off as possible. Since speed floppers spend a shorter time on the ground than power/strength floppers (due mainly to the fact that they approach the bar faster, slow down less in the gather phase, and are quicker in the take-off portion of the jump), they are more likely to produce world-class high jumps.

Much of the training time for high jumpers, especially speed floppers, is spent working on the take-off mechanism. As the plant foot is about to touch down, not only are the leg muscles pre-flexed or tensed, but accelerating the free leg is the key to continuing the horizontal velocity into vertical acceleration and displacement, providing, of course, the jumper has planted with an almost perfectly straightened leg and not allowed it to flex any further during the plant.

There are two interconnected ways in which the eccentric phase of muscle contraction during the ground contact of jumping can improve the concentric phase of take-off: (a) the activation of the muscle spindles during stretching improves the muscular activity during the stance phase (DIETZ et al., 1979, quoted by REID, 1989), and (b) energy is transferred by the elastic elements from the eccentric to the concentric phase (CAVAGNA et al., 1971, quoted by REID, 1989).

It has been proposed that muscular pre-activation is pre-programmed and dispatched from higher centres of the nervous system (JONES & WATT, 1971, quoted by REID, 1989). VIITASALO & AURA (1986, quoted by REID, 1989) suggest that the pre-contact muscular activity is related to the intensity of the following eccentric stretch of the muscles. If so, this means that before ground contact the central nervous system must have some intimations about the quality and quantity of the following stretch. This means, high jumpers would consciously know the expected impact and would be trained and conditioned to be able to handle the load and take-off explosively (without further flexing the plant leg).

This leads to the question of whether the quality of the selected pre-programme is connected to the performance itself or whether it is due to learning during several years of sports training (VIITASALO & AURA, 1986, quoted by REID, 1989). DIETZ et al. (1981, quoted by REID, 1989) state that visual information (the bar being raised to record heights in a competition) could have an effect on the quantity of pre-activation, suggesting that learning may modulate the preparatory activity of the neuromuscular system as the bar is raised and the jumper is expected to jump higher and higher in successive attempts. In any case, training to handle the plant and take-off phase of high jumping at higher and higher heights is still the operable activity for the coach and athlete.

REID (1989) holds that when wanting to know what drills are useful for training the myotonic reflex and to what extent depth jumps are useful for the developing high jumper one must again look at the event mechanics. If a straight leg means a knee angle of 180°, then the most flexion in the plant leg at touchdown should be about 160° maximum (170° would be even better). This can be accomplished with boxes no higher than 15 to 20cm with the jumper standing on the edge of box number 1 on the toes with both feet together. A little forward momentum and as the jumper leaves the box, the legs are pre-stretched and the jumper lands on the toes, knees held tightly at about 170 or 160°. The jumper pops (or explodes) up onto box number 2 as quickly as possible, landing on the toes; forward lean, drops down onto the floor and pops back up onto box number 3, repeating for box numbers 4 and 5. The athlete then walks back to the start and repeats. The stress on the pre-tensed legs is considerable. The work, with legs hardly flexed at all, is also considerable. The injury factor is negligible. If more loading is required a weight vest is employed. The key is to jump and rebound as quickly as possible, but not by a deep flex at the knee. The athlete can start at five rounds of five boxes and work up from there.

According to REID (1989), the next best plyometric exercise for high jumpers is actual jumping – particularly the scissors technique in practice. It teaches the jumper:

- the feeling of the proper loading on the plant leg (practising pre-tensing);
- the stiff leg plant and the quick trail leg pull-through;
- staying vertical and not leaning in with the head or inside arm;
- a quick take-off, running off the end of the approach and not sinking or settling.

The quicker the execution, the more characteristics of the speed flopper can be trained/exhibited. Raising the bar can give the jumper's neuromuscular system the "learning" that may modulate the preparatory activity of pre-activation or pre-stretching (DIETZ et al., 1981, quoted by REID, 1989). The key is to teach the high jumper to pre-stretch the plant leg muscles to avoid knee flexion to the point where he/she does this automatically. Then the athlete's concentration is on the penultimate step, which involves the free leg. The push-off and pull-through of the knee of the free leg with maximal knee flexion to produce a short but powerful lever becomes a key technical skill to learn and concentrate on. It is the combination of the strong, pre-tensed leg plant and the simultaneous push-off and pull-through of the free leg that will provide the greatest vertical velocity and vertical displacement of the jumper's center of gravity providing the plant and take-off technique is flawless (REID, 1989).

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