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Plyometrics and the High Jump

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"The author, a Canadian National Coach for the High Jump, explains how plyometric training acts on the neuromuscular function to develop the desired strength in athletes. In the second part of the article, he discusses in detail how plyometrics can be applied to the specific training requirements of élite high jumpers."

Introduction

In this age of specialization in athletics, the strength requirements of the different events, demand discussion about maximum strength, strength endurance and *elastic strength*. The adjective *"elastic"* is particularly appropriate since muscles possess high elasticity. Muscles are composed of contractile elements (actin and myosine) and elastic elements that are in parallel and in series. The neuromuscular system accepts and expels rapid loading at high velocity through the coordination of both *reflexes* and these *elastic* and *contractile* components of muscle. Due to these facts the definition of "elastic strength" occurred: (the ability of the neuromuscular system to overcome resistance with a high speed of contraction).

Muscles possess elasticity. In stretching the muscle (to a predetermined optimum), it will contract more forcefully and faster if it is under tension. During the stretching of the muscle, there arises a *reflexive* strengthening of its contraction. This is referred to as the *myotatic stretch reflex* or the *myotonic reflex* or as most coaches refer to it, the *stretch reflex*. The two most plausible

explanations I have heard for this reflex are: (a) that during the pre-stretch phase, the heads of the cross-bridges within the muscle are rotated backward to a position in which they are able to exert more force. (Bosco et al., 1981; Bosco et al., 1982) and (b) during the eccentric phase the elastic parts of the musculature are stretched and the proprioceptive feedback mechanisms are activated and utilized during the concentric part of the contraction. (Komi and Bosco, 1982, Asmussen and Bonde-Peterson, 1974; Schmidt-bleicher et al., 1978 and Viitasalo and Bosco, 1982). The key for coaches then becomes how to maximize this "reflex" with training drills.

Using the jumping events as an example, coaches were aware that a pre-stretch state had to precede the muscle work or flexion state of the muscle(s) for the stretch reflex to work, so the idea of pre-tensing the leg muscles of the plant foot just before the foot landed in the plant phase of jumping became the norm.

The leaders in the area of "plyometric" work were the Soviets. The term was initially synonymous with triple jumpers and triple jump training. To develop the type of loads that the plant leg had to withstand in the hop and step phase, 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-concentic" training started appearing in the literature more and more in the 1960's.

One particularly misleading (misinterpreted) piece of literature at the time was a study by Verchoshanski (1969) which supported the hypothesis that the *greater* the sustained loading at the prestretching, the *greater* the jumping results. Many coaches took this to mean athletes could develop the stretch reflex by jumping down from boxes higher and higher in height, land on pre-stretched plant leg and bound back up onto another box. Such training went on unsubstantiated by scientific research. Fantastic results were reported in the literature, stating abilities of some elite athletes able to jump down from the top of a (gymnastics) box horse, land on one pre-tensed leg and bound back up onto another box horse, countless times in one training session. Very little scientific work was done in this area and the mounting injury score was often rationalized by the over-zealous coach that, the athlete who could not complete the drill was simply too weak.

What coaches didn't realize was that the myotonic stretch reflex could simply be activated by training on flat ground (bounding) or at the most, low boxes, meaning relatively little height was required to "pre-tense" the muscles. By increasing the heights of the boxes from which athletes jumped down, the loading on the muscles in the eccentric (drop down) phase would be so great that a second reflex, called the *golgi tendon reflex* would actually kick in. This reflex actually inhibits the muscles' ability to switch from eccentric (drop down) work to concentric (jump up) work, subsequently limiting muscular power.

Clearly, coaches were not sure what they were training when they turned to classic "plyometric" drills. The strength and gymnastic ability of many athletes saved them from serious injury, but countless others never realized

their potential due to knee (mainly) ankle and hip injuries sustained from ridiculous training sessions that were thought to be training the infamous stretch reflex, the panacea that was going to produce the elite jumpers of the future.

In the 1970's and 1980's, interest by sport medicine and biomechanics researchers led to considerable research work in the area of "reactive training". It became clear that jumping down from boxes was a ballistic method of power training that required strict supervision and careful testing to find the optimum height for the individual athlete's strength, skeletal structure, age and development at the time of training. However, the stretch reflex aspect remained something trained at low heights, while true power eccentric-concentric training continued but for different strength training reasons.

The key to the proper utilization of the various reactive or eccentric-concentric or depth jumping drills is to first analyze the strength requirements of the event you are training an athlete for and then decide whether you are training the stretch reflex or whether you are trying to develop maximal strength using eccentric-concentric drills (i.e. boxes increasing in height). If the latter, the coach must be aware that to avoid injury and to properly sequence such work in the life of the training athlete, the prerequisite of a very high level of eccentric strength is required before you start increasing the height of the boxes in reactive training (depth jumping, drop jumping, etc.) For instance, East German and Soviet coaches recommend establishing a capability of performing back squats with a load of 2 x body weight before being able to handle depth jumping safely and effectively from heights approximating "navel" height. (Schmidtbleicher, 1985).

Finally, the coach must return to the specific requirements of the event the athlete is training for and not confuse the training requirements required of the athlete preparing for that event. Training for the Triple Jump is very unique and the *requirements* are quite different from those of the High Jump (as well as other events; however, this paper is in terms of high jumping and stretch-reflex training). In the Triple Jump the athlete is required to perform three consecutive take-offs, two of which must be executed immediately after landing from a previous phase, and all must take place from one leg. As expected, maximum take-off forces are great and occur during the initial impact with the take-off surface when the leg extensor muscles are contracting eccentrically or stretching. Peak forces have been reported to be as high as 10.12, 12.62 and 12.17 times the jumper's body weight for the hop, step and jump take-offs, respectively for university level athletes (Ramey & Williams, 1985). The equivalent values for the long jump take-off have been recorded as 10.9 times body weight for national level athletes (Luhtanen & Komi, 1979) but only 4 to 5 times body weight for the high jumper. (Dessureault, 1978). Besides the key observation that it takes *years* to develop high level triple jumpers because of the strength requirements, the mechanics of preparation for the plant and take-off in the Triple Jump and the High Jump are so very different, that training specificity becomes critical.

Training the elastic elements of muscles in athletes involved in the "explosive" athletic events, (particularly the jumps and throws), has been an area of major interest to coaches and athletic scientists for the past ten years. The following discussion centres on training these elastic elements for the elite high jumper.

Plyometrics and high jumping

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 *strength* or *power flopper*. (Reid, 1984).

Jumpers have a combination of the two (just as they have a combination of fast and slow twitch fibres).

The reason this is important is that the approach speed, the gather, the mechanics leading up to and observed in the plant and the take-off time differ between the *speed* and *strength* flopper.

Table 1 illustrates this.

The key component of high level high jumping training, is the plant phase, trying to spend as little time in contact with the ground on take-off. The approach velocity is in the approximate range of 7.0 to 8.0m./sec. Yet in the flight phase, the speed of the jumper is only about 4.5 m./sec. The flight speed will decrease the longer the high jumper is in contact with the ground. As we know, speed floppers spend a

Table 1

	Speed flop	Strength flop
1. Approach velocity (approx)	7.8-8.4 m/sec.	6.5-7.5 m/sec.
2. Unusual arm action preparing	single arm lead into double arm overhead extension	double arm wide sweep and powerful pump up to overhead extension
3. Relative speed over the last two steps in the approach.	little deceleration	more deceleration
4. Location of centre of gravity in terms of loading on the plant leg.	almost on top of the plant leg	more behind the plant leg
5. Location of the centre of gravity in the plant & take-off.	stays relatively forward and high	sinks more and is back of the plant leg
6. Approx. take-off time	.13-.18/sec.	.17-.21/sec
7. Body typing	ectomorph key	mesomorph key
8. Muscle fibre typing	higher percentage fast twitch	higher percentage slow twitch

shorter time on the ground than do strength floppers, due mainly to the fact that they approach the bar more quickly and slow down less in the gather phase and are quicker in the take-off portion of the jump. Since these traits of speed and quickness of movement are more successful and *produce higher vertical displacement*, all things being equal in technique training, speed floppers will be masters of world High Jump records. So how do we train to improve these mechanics? To discuss this we must look at the mechanics of the final stages of the approach, leading into the plant. (This used to be referred to as the "gather" phase with the old straddle technique and again in the initial phases of the back-layout technique when straddlers-tunrned-floppers tried to employ more strength jumping characteristics, before jumpers employing more of the speed floppers traits started to dominate the event). The gather phase of these strength floppers was characterized by the big, wide double arm sweep, with the centre of gravity back, the trail leg dragging on the ground and a bent plant leg used to generate a muscular, powerful upward drive with the double arm pump. With the speed flopper, there is no specific gather phase. The key is to keep the jumper running through the end of the curve, coordinating the arms so that they do not produce a breaking action, instead they recover just slightly and extend upwards slightly before the leg plant (with an almost straight leg) with the concerted effort of the jumper being on the driving up of the free leg, *not* trying to jump off the blocking plant leg. This is a simplistic overall description of the *difference* between the speed floppers and the strength flopper. (I am getting away from the term power flopper, since *both* the speed and strength flopper generate power on the take-off and the description lies on a continuum with jumpers on one end using more speed while jumpers on the other end employ less speed and more strength.

In the penultimate stride, the shoulders of the approaching high jumper are turned or "cocked". In an anatomical sense, the pervic girdle tries to stay aligned with the plant foot (produces torque) while the twisting shoulders produce a counter torque in the lumbar-thoracic spine in the gather or preparatory phase. This twisted or cocked position for a jumper who plants lets say with his right foot, would see the left external obliques and right internal obliques on stretch with right external obliques and left internal obliques contracted. This produces the characteristic *"serape effect"* of the upper body (lumbar thoracic spine) vs. hips (pelvic girdle) (Reid, 1986).

The plant foot is in a specially designed jumping shoe with heel and sole spikes that keep it from twisting as the upper body torque occurs. However, as the plant foot extends forward in anticipation of the forceful final plant for take-off, the muscles of the thigh specifically and the leg in general, are pre-flexed or stretched. This initiates the myotonic reflex just at the moment when the plant foot strikes the ground. The plant down, causes considerable jarring in the body. Since the body is a series of "links" or as biomechanicians call them "kinematic chain drive systems", the level of strength and technique training of the athlete will decide if the stress/shock of the impact will have a detrimental effect on the jumper and

thus on the final vertical height attained. The key is training and pre-preparation. Since the most important "drive system" is the *knee drive system* (Tsarouchas et al., 1987), the key is to have a strong enough knee muscle girdle to avoid excess flexion (or bending) when touching down in the plant.

Speed floppers spend a lot of training time 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, the emphasis is not on the straight leg plant any longer, but changes to 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.

According to scientific sport research, 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) activation of the muscle spindles during stretching improves reflexly the muscular activity during the stance phase (Dietz, Schmidtbleicher & Noth, 1979) and (b) energy is transferred by the elastic elements from the eccentric to the concentric phase (Cavagna et al., 1971).

It has been proposed that muscular pre-activation is pre-programmed and dispatched from higher centers of the nervous system (Melvill-Jones & Watt, 1971). More recent work by Viitasalo and Aura, 1986, suggests that the pre-contact muscular activity is related to the intensity of the following eccentric stretch of the musculature. If so, this means that the central nervous system must have some intimations before ground contact, about the quality and quantity of the following stretch (Viitasalo & Aura, 1986). This means the high jumper 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 open 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). Interesting work by Dietz et al., 1981 states 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 the high jump. 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.

So what drills are recommended for training the myotonic reflex and to what extent are depth jumps useful for the developing high jumper? We must again look at the event mechanics. If a straight leg means a knee angle of 180 degrees, then the most flexion we want in the plant leg at touch down is about 160 degrees maximum (170 degrees would be even better). This can be accomplished with boxes no higher than 15 to 20 cm. with the jumper standing on the edge of box 1 on the toes with both feet together. A little forward momentum and as the jumper leaves the box, the legs are prestretched and

the jumper lands on the toes, knees held tightly at about 170 or 160 degrees. 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 3, repeating for box number 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 — you don't see it in competition, you don't need to overtrain by doing it. You can start at 5 rounds of 5 boxes and work up from there. (I have seen Ulrike Meyfarth do 100 in a one night training session). A very applied training exercise for the high jumper.

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); it teaches the stiff leg plant and the quick trail leg pull through; it teaches staying vertical and not leaning in with the head or inside arm; it teaches 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 referenced earlier by Dietz et al., 1981. 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 second last 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 centre of gravity providing the plant and take-off technique is flawless.

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