What is the most direct means to achieve strength gains specific to the demands of jumping events?

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Introduction

In an on-going effort to improve training methods for the athletes I coach, I have come across a number of articles regarding strength training for the jumping events. Much of what I find is the same basic information with a slightly different twist, often personalized with some applications or references specific to the author's experience. However this past year I have come across some very interesting articles that represent a fresh look at jumps-specific strength training. Independently, the articles suggest that the eccentric contraction that occurs at the plant, and strength training designed to improve this phase of a jumping action, might deserve greater consideration in the search for improvements in event performance. Intrigued with this new look at strength training for the jumps, I began the search for supporting information. With a little effort, I was able to obtain a wealth of information. In order to facilitate the presentation of information, it is assumed that an athlete is at an advanced level of training in areas of general strength, (isometric contractions / stabilization) as well as in the mechanics of jumping, performance of drills, etc. Event specific technique and neural considerations will not be addressed in this discussion.

Rate of Force Development

Traditional jumps-specific strength training has long been centered on weight lifting and plyometrics. Clearly, much success has been achieved through the use of these two mainstays of training. But a specific look at the demands of the jumping events creates the question, "Is there a more specific way to strength train for jumps?" For starters, ground contact times of the plant/takeoff foot in the jumping events; range between an average low around 120 ms (LJ) to less than 200 ms average (HJ).
Yet the application time to reach maximum strength is far longer.

"… In most athletic events there is seldom enough time to develop maximum strength, which takes .5 to .7 sec. Most explosive/ballistic movements do not take that long. Therefore the premium is on generating the highest possible force in the shortest period of time…" 1

So accepting that maximum strength can't be generated within the time constraints of a jump effort, the original question may now be re-stated as, "What is the most specific way to strength train for jumps?" The following quotes speak to a distinction to be considered, between jumping events:

"The period during which the muscle changes from an eccentric to a concentric contraction is called the coupling time and the greater force developed is associated with the shortest coupling time…Bosco et al (1982) proposed that individuals with a high percentage of fast twitch fibres in the leg muscles exhibit a maximum plyometric effect when the eccentric phase is short, movement range is small, and coupling time is brief" 2

"…subjects with a high percentage of slow twitch fibres produce their best jumping performance when the eccentric phase is longer, movement range is greater and the coupling time is longer. Also the degree of flexion of the limb (e.g. knee when doing single leg hops) should not be too excessive because the larger the eccentric movement the greater the loss of elastic tension. The rate of stretch rather than the magnitude of stretch determines the extent of elastic energy boosting that the muscle receives following an eccentric contraction. (Hennessy)." 2

In the first quote the example is most descriptive of the long jump at plant/takeoff, which deals with a near maximal horizontal velocity initially, a slight lowering of CM, a small movement angle as measured at the knee joint, and a resulting compromise between vertical height development and conservation of horizontal momentum in order to achieve the best possible resulting performance. The second quote is more descriptive of the high jump, which needs to be as close to a pure conversion of horizontal kinetic energy to vertical lift. This is achieved through longer ground contact times and longer coupling times over a greater range of motion. To achieve maximum power there has to be a conversion of force to velocity, yet the jumper is trying to achieve maximum vertical velocity in the shortest amount of time. While heavy-resistance strength training ultimately produces a greater maximum force, the greater force production comes at a cost in time of application. Rate of Force Development (RFD) is of prime importance in the efficient conversion of horizontal kinetic energy to vertical impulse. With allowances for the specific nature of individual jumps (LJ, TJ, HJ, PV) there is still much commonality. Although some mechanics and angles may differ, each jumping event requires the conversion and / or conservation of energy at takeoff. While all competitive-effort jumps lose energy, the vertical velocity at takeoff/ground release, (assuming proper takeoff angle for the specific jumping event) is a determining or limiting factor in the maximum height that the jumper's center of mass (CM) will reach in a given attempt. As shown in Figure 1, the optimal rate of force development initially, (RFD up to 200 ms) is generated from the application of explosive-ballistic, strength training.

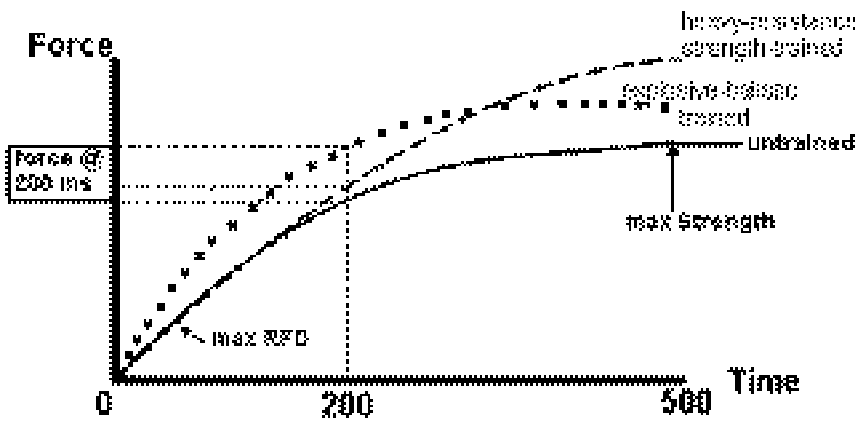


Figure 1. Force expressed in Rate of Force Development
Kraemer, William J. & Newton, Robert U. ***Training For Improved Vertical Jump***
Sports Science Exchange #53 – Vol 7 (1994) No 6, Gatorade Sports Science Institute

Plyometrics

"Siff and Verkhoshansky (1993) have characterized the 5 phases of action involved in a plyometric event. The first phase is an initial momentum phase during which the body is moving because of the kinetic energy it has accumulated form a preceding action. In our case, this would be the energy developed in the approach of the high jump. The second phase is the termination of momentum phase when contact with a surface prevents the body from moving further. This is the high jump plant. The third phase is the amortization phase when the kinetic energy produces a powerful myotatic stretch reflex that leads to eccentric muscle action accompanied by explosive isometric contractions and stretching of the series elastic component (SEC). Fourth is the rebound phase that involves the release of elastic energy from the SEC together with the involuntary concentric muscle action evoked by the myotatic stretch reflex. Last is the final momentum phase that occurs after the concentric contraction is complete, and the body continues to move by means of the kinetic energy imparted by the involuntary concentric contraction and the release of energy form the SEC." 3

Vertical jump performance has been shown to respond to training, which involves the athlete performing SSC movements with a stretch load greater and more rapid than to which they are accustomed. These activities have been termed plyometrics and have been found, in a number of studies, to be effective for increasing jumping ability (Adams, et al.,1992; Clutch, et al., 1983; Schmidtbleicher, et al., 1988; Wilson, et al., 1993). Plyometric training results in an increase in the overall neural stimulation of the muscle and thus force output, however, qualitative changes are also apparent. In subjects unaccustomed to intense SSC loads, there is a reduction in EMG activity starting 50-100 ms before ground contact and lasting for 100-200 ms (Schmidtbleicher, et al., 1988). Gollhofer (1987) has attributed this to a protective mechanism by the golgi tendon organ reflex acting during sudden, intense stretch loads to reduce the tension in the tendomuscular unit during the force peak of the SSC. After a period of plyometric training the inhibitory effects are reduced, termed disinhibition, and increased SSC performance results (Schmidtbleicher, et al., 1988). 4

Plyometrics have long been considered to provide event-specific training, both in the mechanics of performance as well as in addressing the need to improve RFD. With the application of the stretch shortening cycle (SSC) providing elastic energy stored in the Series Elastic Components (or SEC in the above quote) it is common belief that the athlete improves the potential for force production. The improvement comes from a counter movement prior to concentric contraction. However, a standard counter-movement jump (CMJ), drop/depth jump, bounding, or other traditional plyometric exercise, creates contact times of around 300 ms or more. While better than the .5 to .7 seconds it takes to apply maximum strength, this still leaves the athlete short of a training component that creates maximum force within the time constraints mirroring an event-specific effort. The simple solution for this is to achieve event-specific strength training, through competitive effort jumps in competition or practice. But this is problematic if viewed as the only source of specific conditioning.

The Stretch Shortening Cycle (SSC) and Counter Movement Jumps (CMJ)

For years, the trickle-down of information from the field of science has led to a practical interpretation at the coaching level that a periodized, progressive, strength-training plan incorporating general strength training, stabilization, weight training using Olympic lifts, and plyometrics, would achieve optimal results. Additionally, the common belief has been that the accessing of stored elastic energy through SSC's, trained through the dosage of plyometrics, is the advanced approach to jumps training. But taking into consideration RFD, no modality in the preceding list reaches true event-specific training for strength development like full effort jumps.

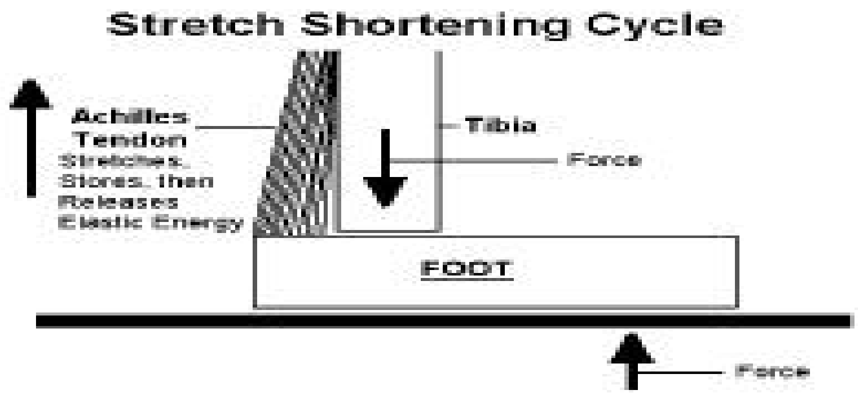


Figure 2. An example of the application of force and the Stretch Shortening Cycle Adapted from: Challis, John H. ***Advanced Biomechanics/Series Elasticity Influences, Lecture Notes*** Pennsylvania State University Website (2001)

Recently, there have been an increasing number of articles that challenge the role of the SSC in jumping. For example, a recent article by Robert Newton, Ph.D. poses the question, "Why is CMJ (counter-movement jump) height greater than SJ (squat jump) height? It addresses the popular belief that the recovery of elastic energy and increased muscle activation from SSC movements improves the resulting jump. Use the image of a concentric contraction only jump, initiated from a squat start position as the SJ. The CMJ would be a jump where the athlete drops the CM prior to the jump, invoking an SSC.

One study by Bosco et al. (1982) found differences between squat jump (SJ) and counter movement jump (CMJ) heights of 18%-20%. The CMJ jump is higher because as the jumper approaches the end of the decent, the muscle begins to act eccentrically to slow the body and initiate the upwards movement. As the muscle is activated, force is increased in the tendomuscular complex increasing its stiffness or resistance to stretching. The result is a storage of elastic energy in the muscle and tendon which is recovered during the subseqent concentric phase making it more powerful (Bosco & Komi, 1979). Also contributing to the potentiation of the concentric muscle action is a reflex increase in neural stimulation to the muscle, brought about by the sudden stretch stimulus (Gollhofer & Kyrolainen, 1991; Schmidtbleicher, et al., 1988). 4

Newton's article first offers six potential (traditional) explanations as to why CMJ height is greater than SJ height, but discounts them all. It then leads to an interesting conclusion.

"… it would appear that the difference in CMJ and SJ height is primarily due to the fact that the countermovement allows the subject to attain greater joint movements at the start of the upward movement. This results in greater forces exerted against the ground and subsequently an increase in impulse (F x t) and thus acceleration of the whole body upward. The other mechanisms proposed appear to play at best a secondary role in the enhancement of performance by the SSC." 4

Newton implies that the emphasis is on the "counter-movement" or eccentric phase, over the concentric and "other mechanisms". Imagine a hypothetical example of adding runway speed to a jumper's approach. Lacking sufficient eccentric strength and given the corresponding potential for buckling of the knee, the addition of approach speed would require limiting the range of motion or "joint movements" from the Newton quote, that would otherwise be utilized to generate greater vertical velocity at takeoff. It is of paramount importance that the jumper applies force as quickly as possible while doing so over the greatest possible range of motion. So while Newton doesn't mention eccentric strength, the implication is clear.

"…the current findings indicate that power output was most enhanced by rebound motion in those individuals with greater strength. The enhancement was confined to the initial part of the concentric phase of motion, and had no influence on peak power measured across the entire concentric phase, though time to peak power was decreased." 6

"Speed strength is the ability of the neuromuscular system to produce the greatest possible impulse in the shortest possible time…Starting strength is the force developed in 30ms from the start of a concentric contraction." 2

"…The stretch reflex responds to the rate at which a muscle is stretched and is faster than other reflexes. A voluntary response to muscle stretch would be too late…" 2

"…The results of this study indicate enhancement of concentric motion by prior eccentric muscle action (200-780% enhancement in the first 100 ms)." 18

Again, these quotes speak to the preceding eccentric contraction as facilitator. Time to peak power improves with the addition of a counter-movement. However the counter-movement doesn't improve the entire concentric phase, only the initial part. As well, the concentric contraction is involuntary at the RFD of an SSC, dependant on the eccentric phase.

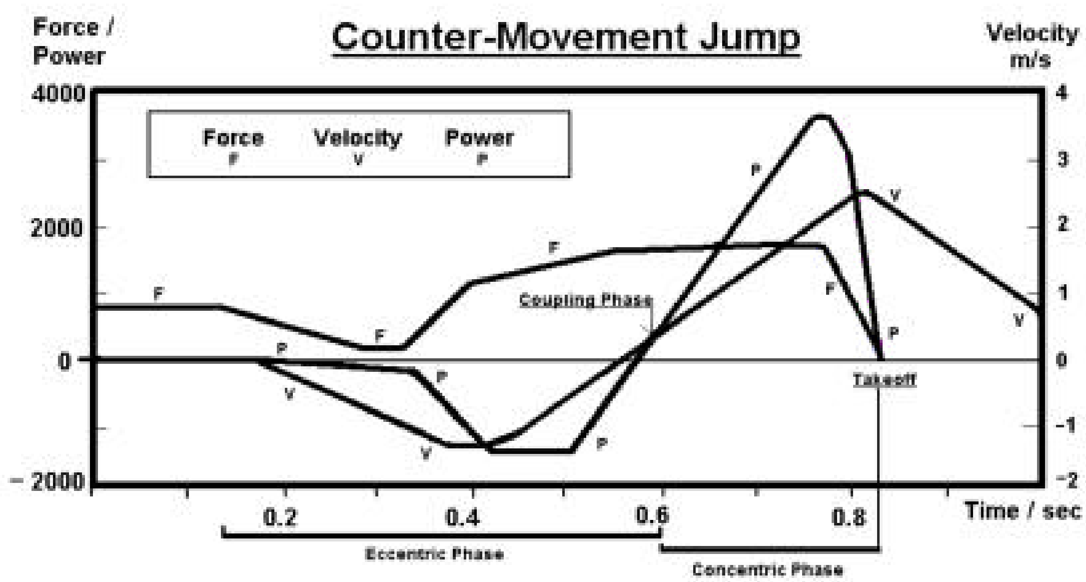


Figure 3. Adapted from Newton, ***Expression and Development of Maximum Power*** Innervations Website (2001)

"Power has been defined as the optimal combination of speed and strength to produce movement (Chu 1996). More specifically, power represents the ability of the athlete to produce high levels of work through a given distance. The more power an athlete possesses the greater the level of work performed (Wilson 1992). Power is a combination of strength and speed: POWER = STRENGTH (force application) x SPEED (velocity). Therefore, an analysis of the components of strength and speed should help to define the fundamental mechanisms controlling the expression of power." 21

Imagine a firing order with force coming first. In much the same way that producing force facilitates the production of power, the success of the concentric contraction is similarly dependant on the efficiency of the eccentric contraction. The fact that the concentric contraction is involuntary and therefore dependant on that which precedes it, also supports this suggestion. Impulse = Force x time and can be increased by improving RFD. Again, quoting from Newton:

"…This results in greater forces exerted against the ground and subsequently an increase in impulse

(F x t) and thus acceleration of the whole body upward. The other mechanisms proposed appear to play at best a secondary role in the enhancement of performance by the SSC." 4

Impulse precedes power and therefore a progression could read, Force → Impulse → Power. The position of impulse in the progression is not unlike eccentric coming after isometric and facilitating concentric.

"…The results of this study clearly indicated the enhancement of concentric motion by prior eccentric muscle action (336–1332% enhancement in the first 20 ms)." 17

The commonalities of impulse and eccentric could be a topic worthy of further research.

Eccentric Strength

"***Eccentric strength is the limiting factor especially in more complex high volume and high intensity plyometric training. Without adequate levels of eccentric strength rapid switching from eccentric to concentric work becomes very inefficient…If on observation you see an excessively long amortization phase and a slow switching from eccentric to concentric work then eccentric strength levels are not adequate...The specific goal before any emphasis on plyometric training should be to raise the level of eccentric strength to an acceptable level…It seems that increasing the athlete's eccentric strength of the knee extensors is indicated to not only allow for greater speed in the approach but also to increase the efficiency of the elastic energy storage…Improvements in advanced jumpers will come primarily from increasing the vertical velocity achieved at takeoff, which is a direct result of increasing the horizontal velocity of the approach…The primary limiting factor in preventing the use of faster approach speeds is the eccentric strength of the takeoff leg. Increasing the eccentric strength of the leg extensors will allow the athlete to effectively transfer the increased speed developed in the approach to a vertical direction at takeoff with a minimal loss of energy… Another effective method for developing eccentric strength may be depth landings, which are essentially depth jumps without the rebound. Dursenev and Raevsky found that the effects of depth landings from heights of 2m or more were effective in developing super-maximal strength...lower heights may offer appropriate lead up activities while offering the same advantages of depth jumps without the complexity of a rebound jump."*** 3

"The use of plyometric exercises in the training of athletes in explosive sports and events has increased dramatically over the last few decades. This development has no doubt been due primarily to research showing the performance benefits of the SSC in selected motor skills and, in particular, to various forms of vertical jumping. If further work supports the initial indications (a) that the SSC does not play a significant role in the development of vertical velocity during the takeoff to a running long jump (and perhaps also during the takeoff to running jumps in general) and (b) that the characteristics of the stretching of the triceps surae muscles do have an important role in this respect, such findings may have important practical consequences… It may come to be recognized, for example, that plyometric exercises are beneficial training exercises not because they increase the enhancement obtained from the use of SSCs but because they develop an athlete's ability to benefit from the stretching that precedes the shortening phase of an SSC. Or, to put this in a different way, it may be recognized that coaches and athletes have been doing the right thing (that is, using plyometric exercises) for the wrong reason. It may be, then, that the current emphasis on plyometric training shifts to, or is shared with, training in which the emphasis is on the stretching phase of a movement alone and not on the entire SSC and that exercises like drop or depth jumps (in which athletes step or jump down from a platform, land and then immediately jump upward) are replaced by exercises limited to the first two parts of this three-part sequence -- that is, to the initial drop and landing. But this is, of course, mere speculation. What must be established first is whether the initial indications are supported by further research." 7

The article by Schweigert left me to look for supporting information on the suggestion that depth landings may be equal or more beneficial than depth jumps. My search led to the article by Dr. Hay who many will remember from his years at the University of Iowa. The two articles take different paths yet present a common suggestion that eccentric strength is key, and there is potential for gains through depth landings along with or to the exclusion of depth jumps.

Commonality of the articles is found in statements such as:

" …the amortization phase of the plant is critical to successful high jumping and that the strength needed most by the jumper is not for extension but for the prevention of excessive flexion at the plant. This is a function of eccentric strength.." 3

" Another effective method for developing eccentric strength may be depth landings…" 3

" …it may be recognized that coaches and athletes have been doing the right thing (that is, using plyometric exercises) for the wrong reason… and that exercises like drop or depth jumps… are replaced by exercises limited…to the initial drop and landing." 7

A world apart, from different approaches, the two authors present a potential new focus for jumps training. Schweigert's article speaks to the high jump and its demands, making the case for the primacy of the eccentric phase and thus the need to center training on eccentric strength. Hay's article begins with a focus on the Long Jump that continues into all running jumps, concluding with the proposition that plyometrics may be worth reconsidering. Hay states,

"If further work supports initial indications (a) that the SSC (Stretch Shortening Cycle) does not play a significant role in the development of vertical velocity during the takeoff to a running long jump (and perhaps also during the takeoff to running jumps in general)…"

Neither Hay nor Schweigert completely takes a stand for eccentric training and depth landings over drop jumps, hurdle hops and other more traditional plyometric exercises. Yet, existing information lends credibility to the notion that eccentric strength should be viewed as primary. This, along with horizontal velocity from the approach as well as technical competency particular to the given jumping event, will ultimately determine or limit success in the jumping events

Schweigert sites Siff and Verkhoshansky's studies regarding a plyometric event, which state that concentric contractions are involuntary. Without kinetic energy, from the approach (in an event jump) or from the drop (in a training rep.) the resulting purely concentric jump (view as a jump initiated from a squat position) is severely limited. The value of the addition of kinetic energy is derived from the conversion to vertical lift. The efficiency of this conversion is dependant on the level of eccentric strength available.

" Changing the body's direction of movement at high speeds requires a tremendous amount of eccentric strength to minimize the time of the amortization phase and increase the ability to transfer the horizontal kinetic energy developed in the approach, to vertical lift."

Hay's article speaks directly to this topic using analysis results from 11 elite female long jumpers taking six full effort / full approach jumps, using a force platform and high speed cameras to gather his information:

"In total, the significant results for the vasti and the triceps surae muscles suggest ...
1. that the shorter these muscles were at touchdown, the longer was the distance over which they were subsequently stretched;
2. the longer the distance over which they were stretched, the faster they were stretched;
3. the faster they were stretched, the larger the forces they generated (force-velocity relationship);
4. the larger the forces they generated, the larger was the vertical velocity developed,
5. and, finally, that enhancement due to use of the stretch-shorten cycle did not make a significant contribution to the development of vertical velocity via these muscles."

Eccentric Specific Training

If you accept that a greater emphasis in training needs to be placed on improving eccentric strength, then the question is, how best can one achieve eccentric strength gains? The prime directive in this case, is the rule of specificity. It would suggest that the best way to improve upon strength is by event specific application. This is problematic in that an athlete will breakdown over time if all they do is full approach / effort jumps. So if constant, full attempt jumping is not the answer, then the next step would be to break down the event by segment and train for the requirements at the plant. This is where the conservation thru conversion of kinetic energy becomes the focal point.

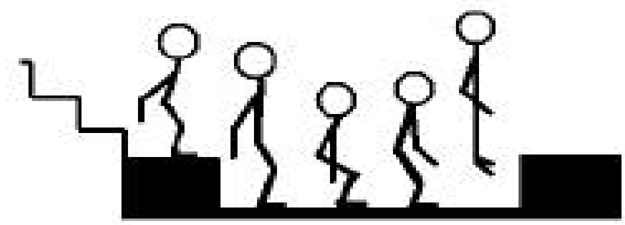
The search for the best way to convert horizontal kinetic energy eliminates the use of "negatives" such as one would find in the weight room.

"…While these are essentially eccentric contractions, we must consider the overload principal in assessing the effectiveness of these exercises (negatives) ***in developing sport specific strength. Much***

higher intensities than found in typical negative-type exercises may be needed to adequately overload the eccentric contraction mechanism to the extent required for the intensities found in high jumping" 3
"When comparisons between isometric, concentric and eccentric contractions were normalized to the mean force or time produced, eccentric contractions were found to be more variable. The findings of this study support previous results (Christou & Carlton, 1999) and suggest that eccentric contractions might be more variable due to an alternative recruitment of motor units, as suggested by Nardone et al. (1989). The results of this study, provide further evidence to the hypothesis that eccentric contractions might be uniquely controlled by the CNS (Enoka, 1996)" 8

To provide specific overload; both event-specific and to challenge the "uniqueness" of eccentric contractions, we are left with the following parameters in the search for optimal, eccentric jump-strength training:

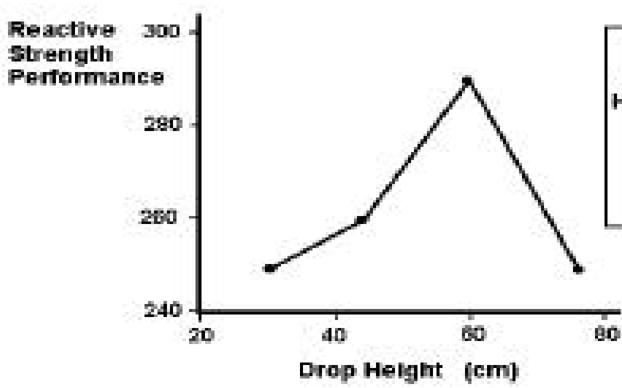
1. Single-leg ground contacts
2. Shortest possible ground contact duration / Highest Rate of Force Development
3. Creation of "Super-Maximal" eccentric load/demand
4. Nearest approximation of event specifics in the exercise performance



Depth Jump

Which leads us to consider depth jumps, or other plyometric exercises vs. depth landings. As normally applied, traditional plyometrics are performed with double leg ground contacts and rebounds, leading to single leg plyometric drills. This is in conflict with the rule of specificity that finds no double leg contacts or takeoffs in the jumping events. Additionally, the loss of stability / proprioception development where there is double leg support as opposed to single leg support is disadvantageous to optimal training. When traditional plyometrics are performed with single leg contacts, the exercise becomes more specific but contact times are too high as the demands to stabilize and create a single or repetitive rebound jump(s) are too much to perform, under 200 ms.

"Studies by Bosco and Komi (1979) demonstrate that jump performance increases with increasing stretch loads applied. For example, during drop jumping, the height of the subsequent jump increases with increases in drop height. This occurs only up to a point. There is a threshold at which the stretch load is too great and the golgi tendon organ reflex causes an inhibition of muscle contraction reducing the jump height attained (Gollhofer & Kyrolainen,1991; Schmidtbleicher et al., 1988)". 4



Drop Jumps

Drop Height (cm)	Jump Height (cm)	Contact Time (sec)	Reactive Str. Perform. (jump height / time)
30	36.2	0.145	250
45	37.3	0.144	259
60	41.2	0.143	288
75	39.4	0.157	251

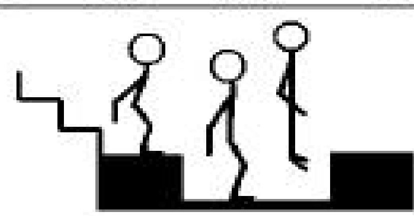


Figure 5. Drop Jumps, shown as a drop to landing, to a rebound jump, with closed angle at the knee at landing. As in depth jumps, the benefit from the drop increases with the height dropped from, to an optimal drop height, then performance benefit decreases beyond the optimal height. Adapted from Young, ***"Specificity Of Strength Development For Improving The Takeoff In Jumping Events"*** The Jumps: Contemporary Theory, Techniques & Training, by Jess Jarver, Tafnews Press (2000)

A potential solution would be to use the double-leg drop jump with a reduction in the amount of knee flexion at landing, prior to rebound.

"The typical range of contact times produced by this method is approximately 125 – 180ms, which is very similar to those used in the jumping events(15). This test also invokes a relatively small knee flexion and high stretch loads, which are similar to the jump take off" 9

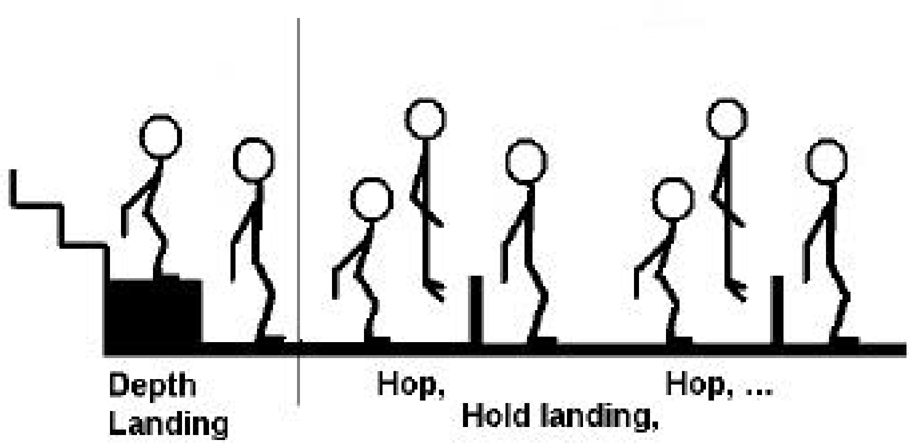
While more event specific than the traditional depth jump, this is performed as a double leg exercise in order to achieve the contact times less than 200 ms. With less range of movement measured at the knee joint, this exercise does a better job isolating the eccentric stretch phase, therefore coming closer to, but still short of true event specific training's single leg requirement.

Depth Landings

Single leg depth landings and single leg hops with a hold or pause (no rebound), provide specific, eccentric strength training, along with the potential to be event-specific through the eccentric contraction phase. The overload is achieved through the application of a drop from height, adjustable to meet specific overload requirements. The elimination of a rebound jump has benefits; intensity and focus is on the eccentric contraction, and the issue of contact times is eliminated. The suggestion of a focus on eccentric work should not be viewed as replacement for work in the area of coupling times and concentric work. A yet to be determined dosage of traditional plyometrics will always have a place in the training protocol. The proposal is a shifting or at least, a sharing of the importance currently held by SSC's and stretch reflex, with specific eccentric work in an overall training program for jumpers.

For a standard depth landing, picture a gymnastics vault landing. "Sticking the landing" entails tremendous stabilization and eccentric strength to prevent collapse at the knee. The forces generated mirror the forces at the plant prior to takeoff in the jumps, providing the overload required to train the eccentric contraction. The force of the eccentric contraction is controlled by drop height, and the exercise can be performed with either single or double leg landings. Maximum overload will come from higher drop heights and the use of single leg landings. The prescription of such intense workloads assumes that there are appropriate levels of general strength, stability, and co-ordination, and that the progression is from double to single leg contacts.

A variation of depth landings is available in the application of lower height, "hop, hold the landing, hop, hold the landing, …" type drills. This variation presents great specificity in that it can be modeled after the specific event, for instance L ,L, R or R, R, L contacts for the triple jumper. Or using alternating contacts (L, R, L, …) while applying arm actions specific to the particular event, as in TJ, PV, or HJ specifically. Additional variability will only be limited by the imagination of the coach. Potential for dynamics within the eccentric specific exercises will come from many sources. Variable drop heights, varying angles of the knee joint at landing, softer/harder landing surfaces, barefoot landings, endurance vs. maximal strength work as controlled by repetitions and/or recovery times, bi-lateral work, Pliates-style equipment to artificially mirror HJ lean at plant, and adaptations similar to those found in traditional plyometric drills. Where these exercises will fit into a comprehensive training program is up to the coach to determine. While this is a growing topic of research and discussion in the scientific community, there is far from a consensus regarding the concept, let alone its application.



It has recently been proposed that the nervous system sends a special signal to start an eccentric contract as opposed to the signaling of other contractions. Along with further defining the uniqueness and importance of the eccentric contraction, this could serve at least in part, in explanation of the occurrence of Delayed Onset Muscle Soreness (DOMS) that follows eccentric training. After a heavy bout of eccentric work, there is typically more soreness and swelling than results from other types of training. The symptoms peak between 2 to 4 days and are usually recovered from in about a weeks time. Thus, DOMS must be taken into consideration when planning eccentric specific work within a training period.

"..."It is now established that unaccustomed eccentric exercise leads to muscle fiber damage and to delayed-onset muscle soreness (DOMS) in the days after exercise. However, a second bout of eccentric exercise, a week after the first, produces much less damage and soreness." 19

"…Adaptation to eccentric exercise can occur in the absence of significant muscle damage. Exposure to a small number of non-damaging eccentric contractions can significantly improve recovery after a subsequent damaging eccentric bout. Furthermore, this adaptation appears to be mode-specific and not applicable to concentric contractions." 20

"… Electromechanical delay is shorter during eccentric contraction in comparison to concentric (Komi, 1973; Komi and Cavanagh, 1977). This can partially be explained by the fact that during eccentric contraction the direction of lengthening of series elastic element is the same with the action of the contractile element. The reverse is the case for concentric contraction. This is also one of the factors for greater tension production with eccentric contraction." 22

What now remains, is for implementation and documentation of eccentric specific training, re: workloads, periodization, and corresponding results observed in individuals and over broad groups. Observation of performance results and their correspondence to the training is of particular interest in the athlete who has been training and competing at a high level prior to the addition of, or more specific, eccentric training. Only time and trial will tell if the current "buzz" about eccentric training, taking place on the scientific level, will have meaningful application on the coaching level and enhanced results on the competitive performance level.

References:

1. Gambetta, Vern, ***Plyometrics: Myths and Misconceptions by Vern Gambetta***
Gambetta Sports Training Systems Website (2001)

2. Knowles, Denis, ***Training for Speed Strength***
Modern Athlete & Coach Vol. 37, No. 2, pgs. 35-38, April 1999

3. Schweigert, Doug, ***Functional Strength Considerations for the Advanced High Jumper***
National Strength & Conditioning Association, Vol 22, No. 5 pages 25-30 (2000)

4. Newton, Robert U. ***Laboratory Exercises using the Kinematic Measuring System***
Innervations Website (2001)

5. Newton, Robert U. ***The Great Stretch Shorten Cycle Debate***
Innervations Website (2001)

6. McNair, Cronin, & Marshall, ***The role of maximal strength and load on initial power production during concentric and stretch shortening cycle activities*** 5th IOC World Congress on Sports Sciences, Sydney Australia (1999)

7. Hay, J.G. ***The Takeoff in the Long jump & Other Running Jumps***
ISBS Coaches Information Service – Field Athletics The University of Edinburgh, Faculty of Education, Dept. of Physical Education, Sport & Leisure Studies (2000)

8. Christou and Carlton ***Eccentric Contractions Of The Quadriceps Muscle Have Greater Motor Output Variability Than Isometric And Concentric Contractions*** Proceedings of the Annual Meeting of the American Society of Biomechanics, October 1999

9. Young, Warren, ***Specificity Of Strength Development For Improving The Takeoff In Jumping Events***
The Jumps: Contemporary Theory, Techniques & Training, by Jess Jarver, Tafnews Press (2000)

10. Plisk, Steven, ***Resistance Training - Part I : Considerations in Maximizing Sport Performance***
ISBS Coaching Information Service website (2001)

11. Challis, John H. ***Advanced Biomechanics/Series Elasticity Influences, Lecture Notes***
Pennsylvania State University Website (2001)

12. Kraemer, William J. & Newton, Robert U. ***Training For Improved Vertical Jump***
Sports Science Exchange #53 – Vol 7 (1994) No 6, Gatorade Sports Science Institute

13. Paxinos, Thrasivoulos, ***Mechanics and Specific Adaptation to Resistance Training***
Athens College of Sport Sciences, as published in: Proceedings of the ITFCA, Date unknown

14. Farthing, Dan ***Vertical jumping and lower extremity joint strength- What is the relationship between these two when measured eccentrically and concentrically at five angular velocities?***
University of Saskatchewan, Canada, Sports Medicine Science - Exercise Physiology Website (2001)

15. Newton, Robert U. ***Expression and Development of Maximum Power***
Innervations Website (2001)

16. Lexell, Jan, ***Eccentric Muscle Contractions***
AgatonFitness Website (2001)

17. Cronin, McNair and Marshall, ***The role of maximal strength and load on initial power production***
Medicine and Science in Sports and Exercise, Vol. 32, No. 10, 2000.

18. Cronin, McNair and Marshall, ***Magnitude and decay of stretch-induced enhancement of power output***
Medicine and Science in Sports and Exercise, Vol 33 No. 7, 2001

19. Brockett, Morgan and Proske ***Human hamstring muscles adapt to eccentric exercise by changing optimum length***
Medicine and Science in Sports and Exercise, Vol. 33, No. 5, 2001

20. Paddon-Jones and Abernethy, ***Acute adaptation to low volume eccentric exercise***
Medicine and Science in Sports and Exercise, Vol. 33, No. 7, 2001

21. Behncke, Luke, ***Is Olympic lifting relevant to developing Athletic Power?***
Faccioni Speed and Conditioning Consultancy Website (2001)

22. Paxinos, Thrasivoulos, M.Sc, Ph.D., ***Muscle Architecture, Mechanics and Specific Adaptation to Resistance Training*** As published in: Proceedings of the International Track & Field Coaches Association, Date Unavailable