A Theoretical Review of Lower Body Plyometric Training and the Appropriateness for Inclusion in Athletic Conditioning Programs

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Specificity of training is considered to be a fundamental component of any detailed goal oriented conditioning program. Whether one is training to improve functional ability, rehabilitate a musculoskeletal injury, or develop sport specific physiological attributes, the specific nature of the prescribed training regimen, and the exercises contained within, will dictate the magnitude of the adaptive response expressed at the myofibril level. When preparing to develop and enhance an athlete's capacity to execute movement skills and physical attributes positively correlated to successful athletic performance, the athlete must participate in a conditioning program that is specific to the demands of their particular athletic event.

It is widely accepted that jumping ability constitutes an integral component of explosive performance (2). It has also been stated that as competition and performance enhancement motivation levels increase, activity and sport specific movement patterns require increased power, agility and speed (6). Potteiger et al report that explosive leg power and vertical jump height are critical components of successful performance in many different athletic events (8).

A substantial volume of critically reviewed published research support the relationship between lower body strength and power and the successful execution of sport specific movement patterns and performance success. As this relationship becomes increasingly understood in the lab and on the field, the question most commonly asked by athletes and strength coaches is, how does one improve their ability to develop enhanced lower body strength and power capabilities?

Plyometric training has been advocated for athletes participating in sports that require explosiveness, high power outputs, and increased vertical jumping ability (2,4). It is reported that the neuromuscular adaptations generated through this type of training are specific to the force producing characteristics of the eccentric / concentric muscle action (3). More specifically, a review of the literature reveals that lower body plyometric exercises are appropriate for virtually any athlete participating in any sport that includes throwing, or sprinting; track and field, soccer, volleyball, basketball, hockey, football, and baseball (7).

The purpose of this investigation is to present a thorough review of the published literature concerning lower body plyometric exercise. This review will attempt to provide a widely accepted definition of plyometric exercise, a review of the reported neuromuscular response within the, and contributions of, the Stretch Shortening Cycle, a biomechanical analysis identifying, isolating, and justifying ideal joint / limb segment positioning associated with proper technique and lower extremity injury prevention, a review of the suggested progressions to be applied in a conditioning program following the overload principle, and a brief discussion regarding the practical applications. In efforts of limiting the length of this review, the biomechanical analysis will be inclusive to lower body plyometric exercises.

A Common Definition of Plyometric Exercise

A review of the published literature produces a common definition of plyometric exercise. Fatouros et al report plyometric exercises as those that are characterized by a rapid deceleration of the body followed almost immediately by a rapid acceleration of the body in the opposite direction. It is this eccentric / concentric contraction pattern which is reported to evoke the elastic properties of the muscle fibres and connective tissue in a way that allows the muscle to store more elastic energy during the deceleration phase and release it during the acceleration period (2,4,9). The goal of plyometric training is to minimize the time between the eccentric and concentric muscle contractions, also known as the amortization, or the foot with floor coupling or contact, time (4). Stated more concisely, it can be summed that plyometric exercise involves any upper or lower body movement that incorporates controlled quick eccentric and concentric muscle contractions where the focus of the movement is to generate power (as measured by force exerted over a distance) while minimizing hand or foot support contact time. This method of training is theoretically supported, as it is reported to develop an athlete's proprioceptive reflexes, neuromuscular capabilities essential for speed-strength activities and producing a rapid rate of force development. Lower body plyometrics encompass all movements that include bounding, hopping, and single or double leg jumping movement patterns (9). Refer to table 1.0 for the various types of lower body plyometric exercises and a brief rationale for their inclusion in a sport-specific training program.

The Stretch Shortening Cycle

The physiological adaptations expressed as changes in muscle fibre composition, associated with goal oriented plyometric training programs, are reportedly generated through a neuromuscular response referred to as the Stretch-Shortening-Cycle (SSC) (1,2,3,4,5,6,7,8,9). The SSC involves the combination of eccentric/ concentric muscle action, and is characterized by a rapid eccentric muscle action, followed by an immediate and forceful concentric contraction (2,4,9). The concept of this rate of change in muscle action lies in the premise that when the muscle is stretched while active a greater force capability is created in the subsequent concentric contraction than what would be created from a static, non-prestretched position (9).

Moore and Schilling suggest that the cause of this increase in force production may be related to the series elastic components of the muscle, and enhanced neuromuscular reflex activity (4). The concept of the muscle containing ‘series elastic’ components refers to the fact that a muscle can be stretched, and if recoiled shortly after stretching, can exert a volume of stored potential energy created and held within the increased number of actin-myosin cross-bridge formations held throughout the eccentrically contracted muscle. It is this mechanical actin-myosin disruption during eccentric muscle contraction, and the subsequent reciprocal detachment that is responsible for the increases in muscular force, and favorable structural adaptations in muscle tissue (4).

Shilling and Moore further suggest that as the rate of muscle lengthening increases through increased eccentric loading, a brief storage of additional elastic energy takes place, which can then be utilized during the concentric portion of the jump increasing mechanical force and power (4). Fatouros et al reported in their evaluation of plyometric exercise training and vertical jumping performance that part of the positive work (expressed as the force exerted across a distance) created by the stored elastic energy derives from the recoil of the tense elastic elements of the contractile proteins (2). They further suggest that the increase in efficiency of plyometric movements and the SSC is due to the fact that the previous muscle stretching decreases the time in which positive work is done during the subsequent shortening (2). It is this rapid deceleration phase of the eccentric contraction which leads to larger force production, as it is this movement which eccentrically lengthens the muscle (3). It is this large amount of potential energy within the stretched muscle that is used to reach peak vertical jump velocity and jump height, and thus an increased ability to generate lateral, change of direction, and explosive movement.

It is reported however, that this energy can be lost as heat (expressed as an increase in intramuscle temperature) if the concentric contraction phase of the movement is not initiated quickly (4). This is the key aspect of effective initiation and execution of the SSC, as it is only effective in increasing force and power output if the movement activating it is produced quickly; a function of the decreased amortization or coupling time between eccentric and concentric movement (4).

Biomechanical Analysis of Injury Preventative Lower Body Plyometric Technique

When involved in a goal oriented training program, the effectiveness of the training movement; biomechanical positioning, is dependant on the technique employed. Specific joint angles, limb segment position, and the co-contraction of agonist, antagonist and synergist muscle groups influence the limb segment moment arm lengths, and the resultant moment, shear and compression forces expressed throughout the joints and musculoskeletal system. It is the magnitude and distribution of these forces that contribute to the volume of training adaptations that result as a product of that training; enhanced rate of force development, myofibril hypertrophy, fibre type composition etc.

It can be considered that the principle movement pattern of all lower body plyometric exercises is some form of jump action (7). To ensure that the resultant force vectors are expressed as contributors to quantifiable goal specific training adaptations, and not destructive injury precursors, a biomechanical analysis of the specific movement pattern needs to be taken so that the key limb segment and joint angles can be identified, isolated, and instructed.

The work of Escamilla et al in investigating the biomechanical differences in the back squat with varying width stances, yielded many key biomechanical points that can be applied to generating a biomechanical profile and framework for executing effective lower body plyometric training. The conclusions stated in this work, and the biomechanical points identified, can be applied to understanding the biomechanics of lower body plyometrics, as the primary movement pattern of lower body plyometric training is the multi-jointed squat position; an action that utilizes the triple flexion / extension of the ankles, knees and hips to generate force production and high power outputs (2,7). Figure 1 represents the 'athletic position'. This position is achieved when there is lower extremity bilateral symmetry, and equal body weight distribution across all joints and limb segments. Mastery of this position is granted only when it can be maintained in static and lateral movement patterns. It is this position which acts as the basic start and landing position for all two legged jumps.

Figure 1 – The Athletic Position in Triple Flexion

The athlete in Figure 1 is attempting to highlight the key biomechanical points outlined in the literature associated with force production and power output. These key points include the feet being shoulder or slightly greater than shoulder width apart, the knees remaining posterior to the distal aspect of the feet, where the feet are oriented in the sagittal plane, in line with the patella, where the centre of the patella does not drift past the lateral aspect of the foot. Feet must remain forward with an angular displacement from the midline of the shank no greater than 10^o-15^o, with hip flexion at approx 90^o (1).

The stated biomechanical limb positions are suggested based on the following collection of reported findings related to force production, power output, and decreased risk of injury.

While active in bounding, hopping, or jumping movements, either single or double legged, deep knee flexion during the eccentric phase of the movement, and complete triple extension of the ankles, knees and hip should be encouraged during the concentric phase of the movement, as illustrated in Figure 2. These joint position recommendations are given as the factors established as being major determinants of vertical jump performance; force developed from the hip, knee and ankle joints, and the rate of force development produced by these muscles (3), and the neural control of the movement (2).

However, before the particulars of the concentric, explosive phase of the movement is discussed, the eccentric, force and power producing flexion aspect of the jump must be analyzed.

Figure 2 – Concentric phase of a Medicine Ball jump squat.

Escamilla et al reported that, greater forward knee movements during the descent (eccentric) phase of the squat are shown to increase knee shear forces (1). This is important biomechanical error to consider in relation to performing plyometric exercises, as the speed at which the movements take place are purposefully quick, and as such creates an element of instability. Further, several studies have reported significant greater tibiofemoral shear and compressive forces during a fast squat cadence (1). Escamilla et al report that the fast decent rate of a squat movement requires greater deceleration forces from the knee and hip extensors in order to slow down and stop the body system (body plus added resistance) at the bottom of the decent (1). If the athlete is in poor biomechanical alignment, the unequal distribution of these forces has the potential to increase the magnitude of the compressive forces to the stabilizing structures of the knee joint; namely the bursa, medial and lateral meniscuses, or collateral and cruciate ligaments. It is the unequal distribution of these compressive forces which have the strength to create myotendinous or joint capsule injury.

The dynamic nature of plyometric training places a large emphasis on controlled movement and joint stability. It is this stability which produces the capacity to effectively absorb and release the high energy outputs generated during the quick explosive movements.

Results presented by Myer et al demonstrate that neuromuscular (plyometric) training emphasizing deep knee flexion landings significantly alter knee biomechanics, specifically knee flexion during the landing phase of the jump (6). Myer et al further demonstrate that dynamic neuromuscular training has been shown to reduce gender-related differences in force absorption, active joint stabilization, muscle imbalances, and functional biomechanics while increasing strength of structural tissues (bone, tendon, ligament etc.) (6).

Griffin reports that the work of Henning identified three potential dangerous manoeuvres in sport that should be modified through training to prevent Anterior Cruciate Ligament (ACL) injury. He suggests that athletes need to land in a more bent-knee position and decelerate before initiating a cutting movement (the bent knee position is depicted in Figure 1, and exists at approx 80^o-110^o of flexion). Boden et al (9) support Henning's work with a biomechanical analysis of knee injuries in which they reported a majority of ACL injuries occur when landing and cutting with the knee near extension. There is evidence that neuromuscular training not only decreases ACL injury risk, but that it alters biomechanical risk factors for ACL injury (5).

This is supported by Myer et al as they report Plyometric training significantly improves centre of pressure (COP) measures along the medial lateral axis of the knee (5). The improvement in medial lateral COP decreases the imbalances in side to side muscle strength and balance capabilities. It is this improvement which acts to decrease the risk of injury in both lower extremity limbs. As over reliance on the dominant limb becomes minimized, the stress and torque forces o displaced on the dominant knee become decreased. This enhanced balance of force distribution increases the force absorption capabilities of the weaker knee's musculature (5), producing greater bilateral force absorption symmetry between limbs allowing for an enhanced limb to limb segment equal load absorption and force production capabilities. It is the enhanced capacity to develop these capabilities which are required for executing quick change in direction and explosive movement patterns.

Myer et al also report that plyometric training significantly decreases the risk of ACL injury as hamstring strength relative to quadriceps strength (H/Q ratio) is noted to be improved through plyometric training. The increased motor-unit activation of the co-contraction relationship of the quadriceps and hamstring muscle groups leads to favourable neuromuscular and muscle fibre adaptations. It is these adaptations generated through the biomechanical points identified on the lower limb segments which increase one's H/Q ratio effectively decreasing their risk of (ACL) injury (5).

The potential injury prevention and improved movement mechanics substantiate the concept that deep knee flexion exercises be incorporated into an athlete's conditioning program (6). It is recommended that plyometric exercises incorporate the same controlled knee flexion during the triple flexion deceleration phase of the movement.

While participating in the dynamic phase of the movement, body control is to be maintained through soft landings (6), the effect of coordinated triple flexion control of the ankles, knees and hips (Figure 1).

Muscle activity EMG readings reveal that peak quadriceps and gastrocnemius activity occurs at near maximum knee flexion (1), this suggests, in conjunction with the strength ratio improvement of the quadriceps / hamstring relationship, that there is a large force capacity produced during the eccentric muscle action (knee flexion) which provides the muscle with the capability to control movement, and possibly enhance it's protective influence over the less compliant structures of the neuromuscular system (meniscus, bursa, ligaments etc.) from being damaged resulting from the high impact forces, or the repeated low force activity (4) as already discussed.

Justification for the feet being shoulder or slightly greater than shoulder width apart is supported through the work of Escamilla et al who reported that Gastrocnemius activity is 10-15% greater in a squat stance of 87-118% of shoulder width (1).

Escamilla et al also reported that knee and hip moments and moment arms generated by the system decrease during the movement ascent (concentric phase) as the knees and hips extend (1). Escamilla et al further report that the net hip extensor moment, which acts to increase the force generated by the system, produced by the gluteus maximus, hamstrings, and ishial fibres of the adductor magnus have been shown to be greatest at a hip angle of 90^o.

As the above findings suggest, the deceleration of the landing phase should be achieved through soft landings, where deep knee flexion is emphasized to an angle approx. 90^{o}, and trunk or hip flexion is also near 90^{o} so that gastrocnemius, quadriceps, and hip flexor muscle action contributing to control and stabilize the body is maximized. The afferent neural feedback and golgi tendon body excitatory action of the SSC contribute to decelerate the body, and provide it with a volume of energy that can be used to quickly accelerate it in the opposite direction.

Review of Plyometric Training Induced Quantitative Performance Measures

There is a large volume of published work supporting the benefits of including lower body plyometric training into a sport-specific conditioning program. Some of the reported findings suggest plyometric training elicits improvements in force production, power output, an enhanced ability to produce force in a shorter period of time (7), increases in vertical jump velocity, jump height (1,2,3,4,5,6,7,8,9), and an increase in muscle fibre size (1).

The work of Myer et al. reported that after a 6 week comprehensive neuromuscular training program, subjects were able to improve 1RM back squat by 92%, single leg hop distances by 10.4 cm (right) and 8.5 cm (left), and double leg vertical jump height by 3.3cm. (6).

Potteiger et al reported that 8 weeks of plyometric training produced significant increases in myofibril cross sectional area. More specifically they showed that subjects who completed 8 weeks of just jumping and bounding exercises increased type I fibres by 4.4%, and type II fibres by 7.8%, whereas when 20 minutes of aerobic exercise was performed in addition to jumping and bounding exercises, there was an increase in type I fibre area by 6.1% and 6.8 and for type II fibres (1).

Potteiger et al continued to report in their evaluation of muscle fibre power characteristics that changes in power in relation to changes in muscle fibre size, suggest that hypertrophy training, in addition to the neuromuscular adaptations produced through plyometric training, act to improve force production and power capabilities. The correlation coefficients that they determined are listed in Table 1. The statistical significance of these correlations are not reflective of a strong positive relationship, however, they do suggest that there is a relationship between the two physiological adaptations. There is no doubt, that the cross-sectional area of the myofibril has strength development properties, and when it is enhanced through hypertrophy based training, acts to positively increase strength, force and power output.

These findings are in accordance with the conclusions of Fatouros et al, and Adams et al who found that weight training programs that focus on incorporating dynamic and explosive movements aimed at improving power development have been found to be very effective in improving mechanical power in movements requiring explosiveness (2,5).

Correlation Coefficients for Power Output and Muscle Fibre Size

Fibre Type	*Peak Power*	*Average Power*
I	0.4768 (p<0.004)	0.4709 (p<0.005)
II	0.5793 (p<0.001)	0.6185 (p<0.001)

Table 1

By taking advantage of stored elastic energy and stretch reflex the muscle is capable of performing more work in the concentric phase. Potteiger et al states their findings support the results of others who have demonstrated that improvements in the ability to produce leg power increase jump performance, in reporting that improvements in vertical jump height and peak and average power production were observed following 8 weeks of plyometric training (1,9).

Plyometric Training Progressions

The ability to notice continued positive neuro-muscular adaptations during a training program is dependant on the principle of progressive overload and its appropriate application. The progressive overload principle is widely accredited with developing positive gains, as it suggests for a muscle fibre’s composition to change, it must be placed under progressively stressful conditions, so that the adaptive response does not reach a point of plateau. Progression can be based on manipulating any one, or combination of the multiple variables included in a typical training program; weight of resistance, number of repetitions, the speed at which the repetitions are completed, the rest period allowed between sets etc. As with traditional resistance training, progressive overload progressions also exist in plyometric training. Figures 3a through 6c represent varying progressions of lower body plyometric exercises.

In determining an appropriate selection of exercises for an athlete wanting to improve quickness and jumping capabilities, the strength and conditioning coach must understand the sport-specific movement patterns associated with successful performance of that event and assess whether the athlete is physically and neurologically capable of performing beginner (low), intermediate (medium), or advanced (high) intensity (9).

Myer et al support Wathan, by reporting in their investigation concerning the performance and biomechanics of neuromuscular training in female athletes that the progressive nature of neuromuscular training was important in achieving successful training outcomes (5).

A review of the literature suggests that before an athlete can begin a double or single leg based lower body plyometric program, they need to be significantly weight trained to enjoy the positive adaptations associated with plyometric training (2). It is recommended that before an athlete begins a plyometric program they must have a high level of upper and lower body muscular strength; a strength capacity required to withstand the stress of the high force and power outputs created, through the execution of the movement. It is widely accepted that before one begins a lower body plyometric training regimen, they are capable of performing a free bar back squat of one and a half to two and a half times their body weight (7,9).

Wathan, in his review of plyometric based literature reports another lower body strength criterion for assessing physical preparedness of lower body plyometrics; the ability to perform five back squat repetitions of 60% body weight in five seconds. Wathan suggests that successful completion of this performance evaluation is an indication of the athlete's neuromuscular conditioning and joint stability capacities are tolerant to the stresses of a beginner level training program (9).

The direction of the overload should be based on initial exercises involving both legs to safely introduce the subjects to the movement patterns, with emphasis being made on athletic positioning (as outlined in Figure 1) to help create dynamic control of the body's centre of gravity (6). Fatouros et al state that training intensity, volume, and exercise selection follow the principle of progressive overload; starting with lower intensity and less complex exercise techniques, progressing to higher intensities, multi-joint and more complex techniques (1). The training program should begin with an emphasis on double leg, progressing to single leg movements, once balance, and propriocetive control is achieved and maintained (5).

As with other types of training, (resistance, aerobic, anaerobic etc.) the specific training protocols used have a different influence over the results created. Specifically, exercise selection (general {squats} or Olympic), loads used, repetition number, frequency etc. have a different influence on strength development and power production (which contribute to more forceful and rapid movement execution, generation of power output, and increased flight time, and decreased coupling time (1). The National Strength and Conditioning Association and Wathan (7,9) do not recommend resistance and plyometric training (complex training) on the same day because of potential compromised neuromuscular and metabolic system recovery. If complete recovery is not permitted between reps and sets the athlete risks accumulating neuromuscular fatigue, whose accumulation is associated with decreased quality of performance gains and increased risk of injury (9).

It is suggested that the frequency of plyometric training not exceed 3 times per week, and that if executed in back to back days, the same muscle groups not be stressed in succession (ex. lower body exercises two days in a row) (9). If the strength coach prescribes traditional resistance training, metabolic training and plyometric training on the same day, the program's outline should represent a pattern that includes plyometrics first, weights and then metabolic training (2).

Practical Applications

The results of this investigation provide the strength and conditioning professional with a theoretical and practical framework from which they can develop and implement lower body plyometric programs while instructing effective technique. The lower extremity limb segment biomechanical positions that are provided, are reflective of maximizing leg triple flexion and extension, and creating a bilaterally symmetrical balanced position. By concentrating on utilizing soft landings, where deep knee flexion is stressed, the neuromuscular response generated by the SSC and the golgi-tendon body / afferent neural feedback complex, an athlete is able to quantitatively improve their vertical force and power outputs, effectively increasing their ability to jump higher, change direction faster, and be more explosive. As long as the principles of progressive overload are maintained, and appropriate recovery is allotted, lower body plyometric training is an applicable method of training for athletes of all sport.

Types of Lower Body Plyometric Exercises & Their Rationale

Type of Exercise	*Rationale*
Jumps in place *** Figures 3a & 3b**	These drills involve jumping and landing in the same spot. Jumps in place emphasize the vertical component of jumping, and are performed, repeatedly without rest between jumps; the time between jumps is the SSC's coupling time.
Standing jumps *** Figures 4a & 4b**	These emphasize either horizontal or vertical components. Standing jumps are maximal efforts with recovery between reps.
Multiple Hops & Jumps	Multiple hops and jumps involve repeated movements and may be viewed as a combination of jumps in place and standing jumps.
Bounds	Bounding drills involve exaggerated movements with greater horizontal speed than other drills. Volume for bounding is typically measured by distance but may be measured by the number of reps. Bounding drills are normally greater than 30m and include either single or double legged.
Box Drills *** Figures 5a - 5c**	These drills increase the intensity of multiple hops and jumps by using a box. The box may be used to jump on to, or off of. The height of the box depends on the size of the athlete, the landing surface, and the goals of the program. Box drills can use 1 or 2 legged drills
Depth Jumps *** Figure 6a - 6c**	Depth jumps use gravity and the athletes weight to increase exercise intensity. The athlete assumes a position on a box, steps off, lands, and immediately jumps bertically, horizontally, or to another box. The height of the box depends on the size of the athlete, the landing surface, and the goals of the program. May involve 1 or 2 legs.

Table 2

Figure 3a – Start position of a Jump Squat – A low intensity jump.

Figure 3b – Initiation of the landing phase of a Jump Squat.

Figure 4a – Starting position of a Medicine Ball Jump Squat – A high intensity jump

Figure 4b – Peak vertical height and triple extension of a Medicine Ball Jump Squat

Figure 5a – Right side starting position of a Side to Side Push Off Box Jump. A Medium Intensity Jump.

Figure 5b – Peak vertical height (point of full triple extension of ankles, knees and hips) during a Side to Side Push-Off Box Jump.

Figure 5c – Left side landing position of a Side to Side Push Off Box Jump.

Figure 6a – Drop phase of a Depth Jump. A High Intensity Jump.

Figure 6b – Triple extension of the take off phase of a Depth Jump.

Figure 6c – Landing (triple flexion) phase of a Depth Jump.

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