Drop Jump: a technical model for scientific application

Abstract

Plyometric training has numerous benefits to athletic development and the drop jump is a cornerstone exercise for developing fast stretch-shortening cycle function. The drop jump can also be used as a readiness-to-train marker in practical settings. To assist coaches with athlete development, a technical model for the drop jump is proposed. Verbal instructions provided by the coach have an effect upon the kinetics and kinematics of a task performed by an athlete. To assist coaches in fostering effective performance adaptations, example external cues and analogies are provided to help with optimising performance development whilst minimizing injury risk.

Introduction

Plyometric training is a commonly used method for developing a variety of athletic qualities including speed-strength, sprinting speed, explosive power and running economy (10,26–29,38,80,91). Such training seeks to exploit the force potentiating capabilities of the stretch-shortening cycle (SSC) to improve athletic performance (47). The SSC consists of (i) a rapid eccentric muscle action followed by (ii) an isometric amortization phase, and (iii) a concentric muscle action (12). This sequence results in an enhanced concentric force output through a number of mechanisms including utilization of elastic energy, and reflex muscle activity (47). The majority of lower limb plyometric exercises involve jumping, often incorporating the need to rebound against the floor in an attempt to ensure short ground contact times (<250ms) (76). The drop jump is a commonly utilized fast SSC plyometric exercise among strength and conditioning coaches (13,54). In addition to enhancing performance, the drop jump is also used as a readiness-to-train monitoring tool (56) and for injury-risk screening purposes (64,72,77).

There is a large body of research available on plyometric training (6,7,23) and a growing volume of evidence investigating effective cueing strategies for athletic training (24,53,94,95). However, despite widespread use of the drop jump in strength and conditioning programs, there remains a lack of consensus regarding the correct technical model and effective coaching strategies to improve an athlete's execution of the exercise. A sound technical model will assist in coaching athletes to perform drop jumps in a safe and proficient manner. The likely outcomes of such practise should be a reduction in injury frequency and enhanced physical performance. Two drop jump techniques are defined in peer reviewed literature; the bounce drop jump and the countermovement drop jump (13). The countermovement drop jump involves a large downward movement during the ground contact phase. In contrast, the bounce drop jump seeks to immediately reverse downward velocity upon landing to minimize ground contact time. The origins of the first of these two derivatives can be traced back to the work of Verkhoshansky (87), who describes a "depth jump" exercise where the athlete steps off a box and then performs a vertical jump for maximal height upon landing. No rigid restrictions are placed on the magnitude of leg flexion or ground contact time, though the exercise should be performed quickly. The target outcome of this training method was the development of explosive and maximum strength through stimulation of the central nervous system as a result of the impact.

The second variant originates from the work of Komi and Bosco (48) who describe a "drop jump" where the athlete drops from a platform and immediately executes a vertical jump upon ground contact. Emphasis is placed upon a short ground contact time with low magnitudes of leg flexion. The target outcome of this exercise is fast SSC development from the muscle-tendon units of the leg extensors. However, through the passage of time these two exercises have become confused and now many textbooks, authors and coaches use the terms "depth jump" and "drop jump" synonymously (16,28,51,53,108), to indicate different exercises (22) or to indicate a single exercise with variations in execution (78). It is proposed that nomenclature should be henceforth standardized with a 'drop jump' being an exercise involving restricted amplitude of leg flexion during ground contact and a 'depth jump' having unrestricted levels of leg flexion and subsequently less emphasis placed upon short ground contact times as demonstrated in Figure 1.

This paper will propose a technical model for the drop jump that allows athletes to maximize potential training adaptations. Example cues are provided to assist coaches with providing effective correction of common technical errors and augmentation of performance outcome variables. Finally, effective practical applications of the drop jump are reviewed for suitability within an athletic training program.

*****Insert Figure 1 near here*****

Technical Model of the Drop Jump

Drop jumps rely upon adequate development of critical biomotor abilities such as maximum strength, rate of force development, SSC function and leg stiffness (47,90). Consequently, it is necessary to develop high levels of strength in foundational movements, alongside a systematic progression of jump-landing based exercises that gradually and progressively increase the eccentric load placed on the athlete. Flanagan and Comyns (34) have provided suitable activities and progressions within their 4-step progression for developing fast SSC performance. However, even with these foundations in place, technical errors may still occur due to faulty movement patterns that can be acutely corrected by practitioners.

The intensity of a drop jump is determined by the eccentric load (70)**,** which is directly influenced by the duration of the exposure to gravitational acceleration. Therefore, the key variable to manipulate as a means of either reducing or increasing the intensity, is drop height. Elevated drop height increases impact velocity, which may subsequently generate greater impact peaks and loading rates if the task exceeds the athlete's eccentric force producing capacities (34,90). To avoid such an eventuality, it is desirable to utilize an optimal drop height to maximize performance adaptations and minimize the risk of injury. Many studies arbitrarily assign a drop height of 40cm for all participants (20,39,83) but this might exceed the eccentric strength capabilities of some athletes or fail to reach a threshold for adaptation for others. Several methods have been employed to determine the appropriate drop height for training, but few have been experimentally validated. Byrne et al. (17) compared drop jump training with a height determined by maximum countermovement jump height against the height that achieves optimum RSI as suggested by Flanagan and Comyns (34). The optimum RSI method produced a drop height approximately 10cm lower than the maximum countermovement jump method. Training with a drop height determined by either method produced significant improvements in countermovement jump height and RSI. Therefore, since the RSI method produces a lower drop height but the same training adaptation this might be the best option as there will be lower impact forces due to the lower drop height. However, the coach's assessment of technical competency should remain as the primary determining factor for the selection of an appropriate drop height. An athlete must demonstrate technical mastery of the exercise at the prescribed drop height, otherwise the intensity should be regressed to avoid unnecessary risk of injury.

*****Insert Figure 2 near here*****

In order to assist practitioners with a conceptual target to direct their athletes towards, a technical model for the drop jump has been provided (Figure 2). The drop jump has been broken down into five distinct phases although there are also some technical factors that should remain consistent throughout the exercise. The hips, knees and feet should all remain parallel in the frontal plane and therefore lateral tilt of the pelvis should be minimal. A neutral spine and pelvis position should be maintained throughout the exercise. Finally, a constant fixed gaze should be maintained on a point at head height directly in front of the athlete. It should be noted that there is no arm swing evident in the technical model presented. This is common practice in research studies to try to standardize the height of the center of mass on both landings and to minimise anterior-posterior deviation between the two landings. The use of an arm swing has been demonstrated to enhance jump height (33,50). Thus, when working with athletes for performance outcomes, practitioners should allow athletes to practice this skill since it will be freely available in their sporting context.

Effective Verbal Cueing for the Drop Jump

Good coaching requires accurate instruction, error identification, relevant and well-timed feedback, with the goal of improving technical proficiency and performance outcomes (19,25,92). There is a growing body of evidence that instructions and feedback used by strength and conditioning coaches have an impact upon the acute technical execution and the performance outcomes of a task (1,36,44,69,93,96,97,99). *External* cues divert the attention to the environment around the athlete and their impact upon it, while *internal* cues direct the attention towards the athlete's body, body segments or body movements (95). An external focus of attention has been shown to augment performance in a number of skills and performance tasks including vertical jumping (94,97). Analogy learning further reduces the amount of explicable information by providing a biomechanical metaphor for a complex motor skill (9,45,51,58). This approach to cueing has been shown to develop performance characteristics that are associated with implicit learning (51). Therefore, strength and conditioning practitioners should attempt to utilize analogy cues and/or external focus of attention cues when coaching the drop jump, particularly with athletes of a lower training age. Figure 2 provides examples of cues that could be used for the drop jump.

Drop jumping is unique from other jumping tasks in that there are two outcome priorities; maximizing jump height and minimizing ground contact time. Practitioners frequently instruct athletes to jump as high as possible whilst minimizing the time spent on the ground. This focus upon ground contact time invariably leads to a reduction in jump height, greater peak VGRF and greater loading rates due to the stiffer landings usually observed (44,98). In one 6-week training study, three participants from a training group with a contact time focus were forced to drop out due to tibial pain (98). It was speculated that these drop outs were injured due to low levels of relative leg strength (62). It may be that these findings are more a reflection of inappropriate programming in terms of the prescribed drop height, which was beyond the capabilities of the athlete rather than a direct effect of the cue *per se*. A focus upon contact time when dropping from a drop height that exceeds the eccentric capabilities of the athlete will result in undesirable stiffening strategies such as landing with a much more extended knee and hip and thus placing greater stress on skeletal structures rather than the muscle-tendon unit.

From a performance perspective, reducing ground contact time whilst maintaining jump height is highly desirable as it is a marker of increased power capabilities in the athlete (44). In order to reduce ground contact time and maintain jump height, greater VGRF is required in a shorter timeframe to maintain the necessary level of vertical impulse to achieve the same take-off velocity. Consequently, it might be prudent to avoid this attentional focus with athletes who do not have a sufficient levels of relative strength (62) since they will be unable to tolerate the loading rates and peak forces effectively, which could elevate their risk of injury. Previous research has observed significant relationships between the volume of landing sound and the magnitude of the VGRF (88). Since large impact forces place greater stress on soft tissue structures, it would be efficacious to use cues that encourage the performer to be quiet in both landings involved in the drop jump to avoid undesirably large impact forces during the eccentric portion of ground contact.

Previous literature discussing training progressions to develop SSC function has recommended a progression from tasks that are characterized by a low eccentric demand with a short contact time focus, towards activities involving higher eccentric loads and a greater focus on increased jump height and reduced ground contact time (34). These guidelines are intuitive but it should be noted that a reduced contact time focus might concomitantly elevate ground reaction forces on impact; therefore, the task provided to the athlete must involve a level of eccentric load that can be tolerated to optimize training adaptations (44). This serves as another important reminder of conservative progression in the use of plyometric training. Regardless of whether the focus is directed towards jump height or ground contact time, the literature is congruent in its' support for maintaining an external focus of attention.

Finally, it should be noted that the effectiveness of all cues will vary between individuals. What works for one athlete may not work for another. It is also important to be aware of the potential negative effects of cues if they are taken too literally or to extremes by the athlete. For example, instructing an athlete to "land quietly" during the initial landing of a drop jump is intended to reduce excessive impact peaks and improve SSC utilisation; however, if taken too literally by the athlete, they may utilise excessive magnitudes of hip and knee flexion and let the heels contact the floor to give themselves more time to absorb force. As a coach, prior awareness of these undesirable outcomes is necessary to allow early detection and implementation of a different cueing strategy that is more easily and accurately interpreted by the athlete. Due to the high degree of individual variability in cueing effectiveness, it is essential that a coach establishes meaning with their athletes and has a battery of different cues for prompting the same movement when working with a wide range of individuals.

Why Use the Drop Jump?

Performance

When selecting appropriate exercises, their ability to transfer adaptations into improved execution of a sporting task should be considered. The magnitude, direction and rate of force production, the nature of muscular contractions and the energy systems utilized are all important factors in determining the degree of training transfer between an exercise and a sports movement (79). The majority of human movements utilize the SSC rather than relying purely on eccentric, concentric or isometric actions (46). This is particularly true of locomotive tasks such as walking, running, skipping, hopping and jumping (63,75). These actions typically involve limited time for force production due to brief ground contact times and some element of rebounding, with the main propulsive action being simultaneous triple extension of the ankle, knee and hip joints. Similarly, drop jumps also involve SSC muscle actions with particular emphasis on eccentric overload during the yielding phase where rapid triple flexion takes place, and this is followed by triple extension to propel the body into the air. This sequence is replicable of the time frames afforded in human locomotive tasks such as jumping and ground contact times during sprinting and change-of-direction tasks (14,57,61).

In practise, drop jumps are rarely used in isolation but rather as a component of an athlete's training program. However, the performance enhancing effects of plyometrics are well documented (6,55,73,81) and drop jumps in isolation have been shown to improve countermovement, squat and drop jump performance (39,59,98), 5m, 20m and 40m linear sprinting ability (20,74), 505 and T-test change of direction ability (83,86) and running economy (5,10). Drop jumping lies at the most intense end of the plyometric training spectrum (34,43,52), and with correct implementation is therefore a suitable exercise in the training programs of well-trained athletes seeking fast SSC development.

Post-activation Potentiation

In addition to providing a chronic training stimulus, drop jumps have also been used in an attempt to acutely improve athletic performance in a variety of tasks. Postactivation potentiation (PAP) is an acute facilitation of enhanced muscle performance through the use of a preceding activity prior to the execution of another task (18,85). The inclusion of low volume (2-6 repetitions) drop jumps at the end of a warm-up protocol has been shown to improve subsequent sprint performance (15,18), vertical jump ability (15) and one-repetition maximum back squat (16). Conversely, other studies have found no beneficial acute vertical jump performance effects following drop jumps used as a potentiating stimulus (31,82). This may be due to strength levels, fibre type distribution and training age, all of which have been postulated as confounding factors (84) impairing the effectiveness of the SSC (47). To this end, a certain level of physical competency in utilization of the fast SSC may be necessary to elicit a PAP response from drop jumps. Furthermore, careful consideration needs to be given to the selection of drop height on an individual basis to allow eccentric loading within athlete's tolerance levels and to maximize the probability of a PAP response.

Training Monitoring Tool

Due to the reliance upon both neurological and muscular mechanisms during drop jumps, the reactive strength index (RSI) has been used to assess the levels of neuromuscular fatigue and quantify readiness to train (12,49,56,68). RSI is the ratio of jump height to ground contact time (34) and has shown to be reliable in numerous studies (32,35,60). A good RSI score is achieved through maximizing jump height, whilst minimizing ground contact time. Executing this effectively requires good SSC function and high levels of leg and ankle stiffness (2).

Drop jump performance is susceptible to fatigue following marathon running (3) and simulated soccer activity (66). In both instances, greater reductions in peak VGRF between the impact peak and the propulsive peak were evident, which suggests a decrement in SSC function due to fatigue. Links between fatigue and injury risk are well documented in team sports (41,65,67), with most injuries occurring towards the end of playing time (30,89) and during periods of the season where fixtures are congested and players experience the most cumulative fatigue (8,37,71). RSI has been shown to be sensitive to increased workloads and fatigue in elite rugby union players and youth soccer players during tournament match play (4,41). Therefore, this metric could be considered a useful assessment tool to monitor neuromuscular fatigue with athletes, provided they are familiar with drop jump training and technique.

Based on the cumulative body of evidence, it appears that the drop jump has many uses for training and monitoring athletes. Drop jumps can be used as an effective fast SSC development exercise in well-trained athletes who possess sufficient levels of strength and are able to tolerate high eccentric forces. The drop jump also offers promise as an injury risk screening tool, with kinematic variables showing good predictive ability; however, further research is warranted to explore the link between injury risk and a range of kinetic variables that assess relevant forces and rates of loading related to the mechanisms of traumatic injury. Finally, the drop jump can be used as an objective daily readiness-to-train measurement tool to optimize training loads, reduce the risk of non-functional overreaching and injury due to athletes training in a fatigued state.

Summary

The drop jump is a cornerstone of plyometric athletic training programs but has other diverse applications including injury risk screening and monitoring of training and neuromuscular readiness. The drop jump requires well developed function of the SSC and provides a unique challenge to the athlete in comparison to other SSC activities such as countermovement jumps due to the greater eccentric load, elevated power output and magnitude of impact forces. Proficient execution of the drop jump requires high levels of strength, in addition to effective and safe movement control. The latter can be developed through effective coaching with an emphasis on external cueing as part of a periodized training programme, and with progression determined by technical competency. This article has also proposed a technical model for the drop jump and guidelines to correct common technical errors through effective cueing, which has the potential to improve performance and reduce the likelihood of musculoskeletal injury.

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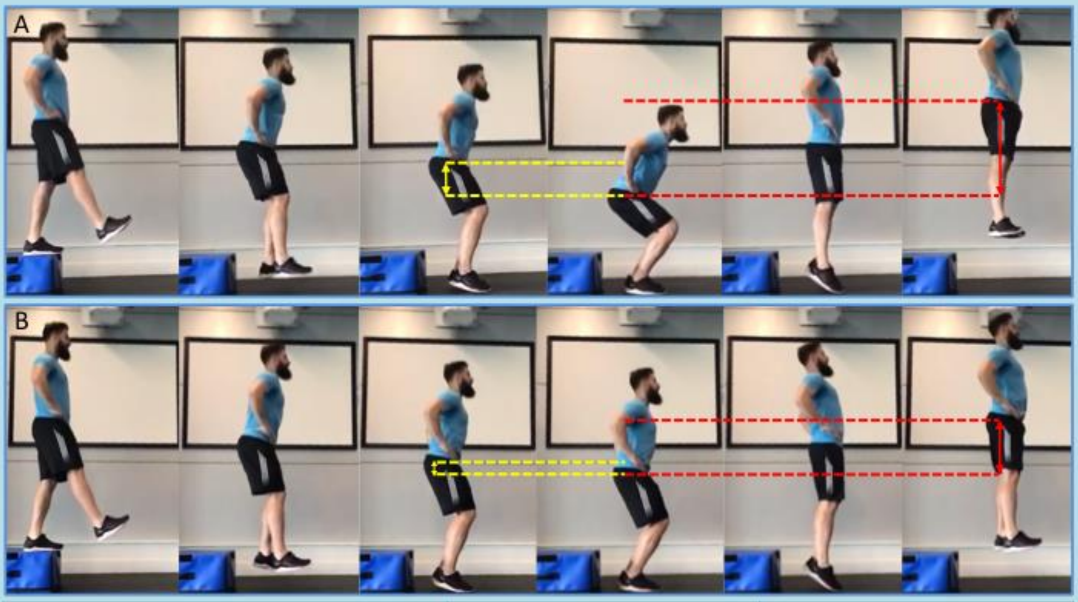
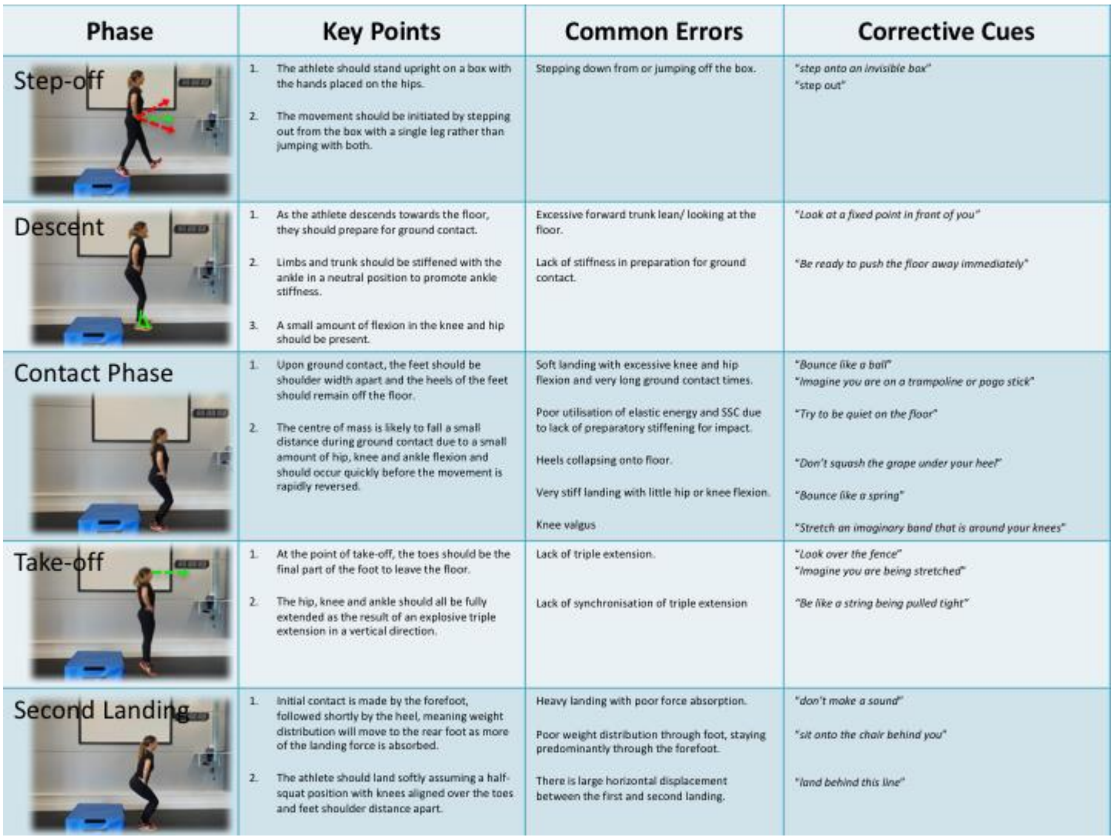
Figure Legend



	Depth Jump (A)	Drop Jump (B)
Jump Height (cm)	38.75	31.66
Flight Time (ms)	562	508
Contact Time (ms)	404	212
Reactive Strength Index	1.39	2.39
Leg Stiffness (kN/m)	8.38	26.48

Figure 1. The depth jump involves larger amplitudes of centre of mass displacement during ground contact than the drop jump. Consequently, the drop jump requires much higher levels of leg stiffness. Depth jumps allow greater jump height to be achieved but this is at the expense of ground contact time and therefore, though this exercise might be suitable for promoting some desirable adaptations, it is not suitable for developing fast SSC ability (<250ms).



Phase	Key Points	Common Errors	Corrective Cues
Step-off	1. The athlete should stand upright on a box with the hands placed on the hips. 2. The movement should be initiated by stepping out from the box with a single leg rather than jumping with both.	Stepping down from or jumping off the box.	*"step onto an invisible box"* "step out"
Descent	1. As the athlete descends towards the floor, they should prepare for ground contact. 2. Limbs and trunk should be stiffened with the ankle in a neutral position to promote ankle stiffness. 3. A small amount of flexion in the knee and hip should be present.	Excessive forward trunk lean/ looking at the floor. Lack of stiffness in preparation for ground contact.	*"Look at a fixed point in front of you"* *"Be ready to push the floor away immediately"*
Contact Phase	1. Upon ground contact, the feet should be shoulder width apart and the heels of the feet should remain off the floor. 2. The centre of mass is likely to fall a small distance during ground contact due to a small amount of hip, knee and ankle flexion and should occur quickly before the movement is rapidly reversed.	Soft landing with excessive knee and hip flexion and very long ground contact times. Poor utilisation of elastic energy and SSC due to lack of preparatory stiffening for impact. Heels collapsing onto floor. Very stiff landing with little hip or knee flexion. Knee valgus	*"Bounce like a ball"* *"Imagine you are on a trampoline or pogo stick"* *"Try to be quiet on the floor"* *"Don't squash the grape under your heel"* *"Bounce like a spring"* *"Stretch an imaginary band that is around your knees"*
Take-off	1. At the point of take-off, the toes should be the final part of the foot to leave the floor. 2. The hip, knee and ankle should all be fully extended as the result of an explosive triple extension in a vertical direction.	Lack of triple extension. Lack of synchronisation of triple extension	*"Look over the fence"* *"Imagine you are being stretched"* *"Be like a string being pulled tight"*
Second Landing	1. Initial contact is made by the forefoot, followed shortly by the heel, meaning weight distribution will move to the rear foot as more of the landing force is absorbed. 2. The athlete should land softly assuming a half-squat position with knees aligned over the toes and feet shoulder distance apart.	Heavy landing with poor force absorption. Poor weight distribution through foot, staying predominantly through the forefoot. There is large horizontal displacement between the first and second landing.	*"don't make a sound"* *"sit onto the chair behind you"* *"land behind this line"*

Figure 2. Technical model for the drop jump with common errors and example corrective cues.