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VERTICAL JUMPING PERFORMANCE:
ONE - FOOT VS. TWO- FOOT TAKEOFF TECHNIQUES

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Introduction

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A considerable amount of literature documents investigations of jumping mechanics and the factors which determine jumping performance. While several researchers have examined biomechanical aspects of either one-foot vertical jumping or two-foot vertical jumping, few have specifically investigated the differences between the two styles. As the one-foot slide attack gains popularity, coaches, athletes and trainers should understand the inherent strengths and weaknesses of each technique. This article reviews the biomechanical factors which contribute to vertical jumping performance, emphasizing the differences between one-foot and two-foot jumping techniques.

Factors in Vertical Jumping Performance

In a maximum vertical jump, the goal is simply jumping and reaching as high as possible. In volleyball, the height to which an athlete can jump and reach is often critically important. In the absence of air resistance and other external forces, the upward projection of the whole body center of mass (CM) is completely determined by the vertical velocity at the instant of takeoff and the acceleration due to gravity. However, this quantity does not completely describe the overall jump and reach height which is observed.

A simple model shows that on individual's maximum jump and reach height, may be described by the sum of four lesser heights: takeoff height, flight height, reach height and loss height (see Figure 1). Takeoff height may be defined as the height of the CM at the instant the individual leaves the ground. Flight height refers to the actual height to which the CM is elevated during the in-flight phase of the jump. Reach height describes the vertical distance from the CM to the fingertips at the instant the maximum jump and reach height is evaluated. Loss height refers to the difference between the peak height of the CM and the height of the CM at the instant the maximum jump and reach height is evaluated. This last factor can usually be attributed to mistiming the final reach (usually by contacting the ball on the way down from the peak of the jump).

In standing two-foot vertical jumps (similar to block jumps), takeoff height, flight height and reach height account for 41, 17, and 42 percent, respectively, of the overall jump

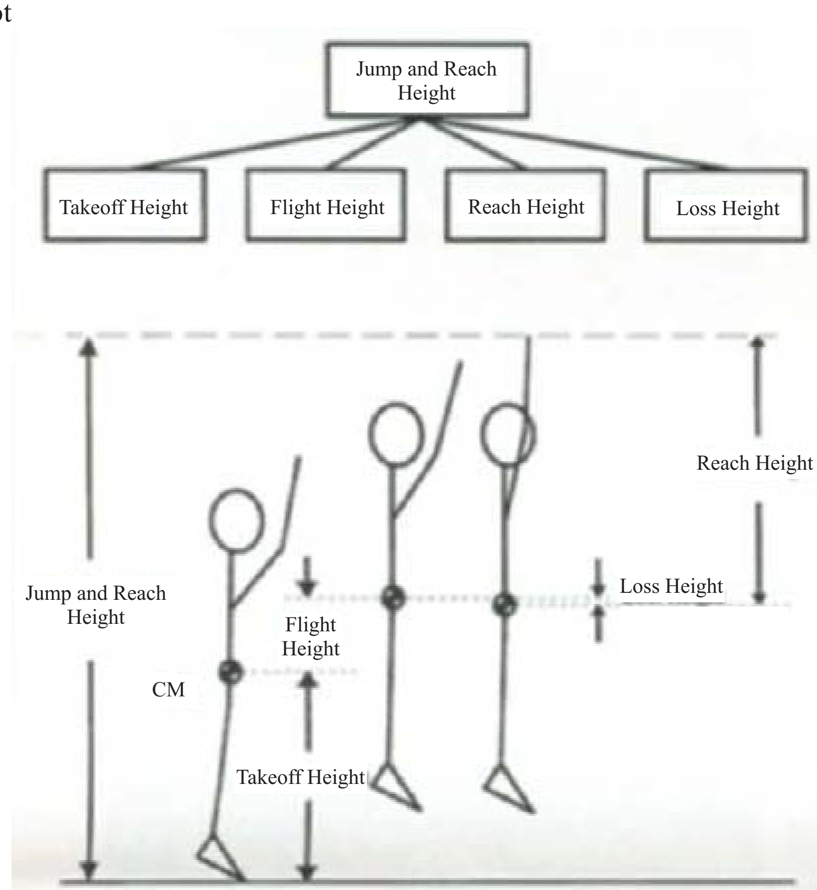

***Figure 1 -** Deterministic model and illustration of simple factors which determine overall jump and reach height. Note: relative proportions of the four sub-heights are drawn approximately to scale.*

and reach height. Loss height was negligible, accounting for about 0.2 percent of the overall jump and reach height. It may be surprising (and perhaps somewhat discouraging!) to note that the contribution of flight height is much smaller than that of takeoff height and reach height. Regardless, it is clear that an overwhelming percentage of the overall jump and reach height is determined not by the vigorous muscular effort required to propel the body upward, but simply by the physique of the jumper and the position and orientation of the body about the CM at the instant of takeoff and again when the maximum height is evaluated.

One-Foot and Two-Foot Vertical Jumping

There are some interesting differences between one-foot and two-foot jumping performances. A recent study from the biomechanics laboratory at Arizona State University shows that, on the average, there was virtually no difference (< 1 cm) in the overall height which could be attained between one-foot and two-foot jumps. All jumps were initiated from a running, four-step, self-paced approach. Using a procedure identical to that used for vertical jump testing in volleyball, subjects were asked to jump and reach as high as possible and to contact the slats of a Vertec at the highest point of the jump. The results of this experiment indicated that while overall jump and reach heights were virtually identical between jump styles, the manner in which these results were achieved were different.

One-foot jumps benefited from an increased takeoff height, largely attributable to the elevation of the free swinging leg. That is, simply by having the non-support leg elevated at the instant of takeoff, one-foot jumps to achieved a 10 cm (about 4 inches) increase in takeoff height (Figure 2). The important thing to consider is that compared to the upward propulsion of the body, elevation of the free swinging leg requires virtually no effort and results in a significant increase in takeoff height. This is "free" height. Further, the actions of this free swinging leg may have helped develop higher muscular tensions and therefore greater flight heights than would have otherwise been expected. Swinging the non-support leg seems to have about the same effect as swinging the arms during the approach. However, one-foot jumps probably derive more benefit from this action than do two-foot jumps because the non-support leg is far more massive than the arms alone. This relative increase in mass helps the support leg develop greater force and therefore provides one-foot jumps with an additional advantage.

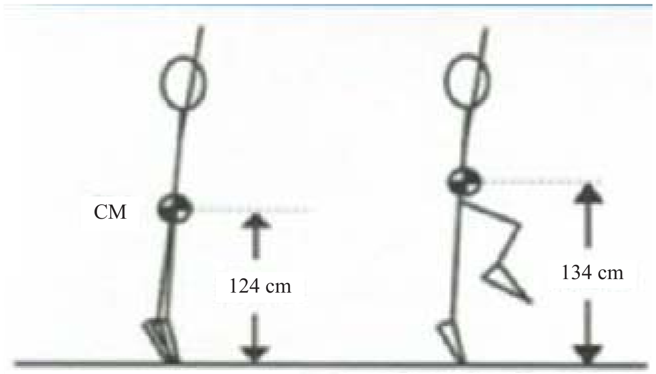

Figure 2 - *One-foot jumps benefit from an increased takeoff height. This is largely attributable to the elevation of the free swinging leg at the instant of takeoff.*

Two-foot jumps, with about twice the available leg musculature to produce vertical impulses against the ground, were expected to produce greater vertical velocities at takeoff and greater elevations of the CM during the flight phase. Although significantly greater flight heights were achieved during two-foot jumps, the magnitude of this difference was only about 9 cm (Figure 3).

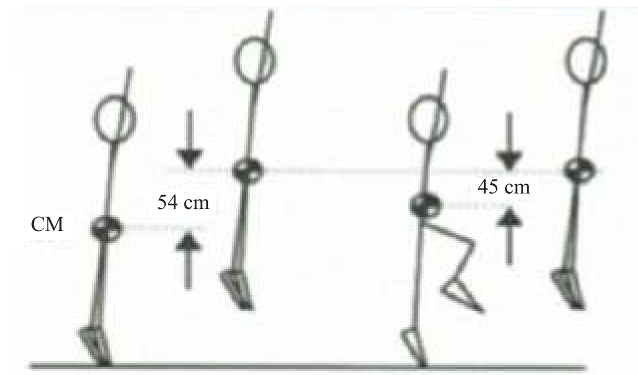

Figure 3 - *Two-foot jumps produce greater vertical impulses against the ground, thereby increasing the vertical velocity of the CM at takeoff which results in increased flight height.*

This result was somewhat surprising considering that the difference in flight height between jump styles was so small. With two "motors" (i.e., twice the available leg musculature) which could be used to propel the body upwards, why were two-foot jumps able to generate only a 17 percent increase in flight height (a parameter which is ultimately dependent upon vigorous muscular effort).

Understanding the Actions of the Support Leg(s)

This question has yet to be properly answered. Some preliminary results can help explain why the support leg musculature yielded relatively greater output during one-foot jumps compared to two-foot jumps.

Figures 4 and 5 illustrate the general motions of one-foot and two-foot vertical jumping performances, respectively. The path of the CM has been superimposed on the stick figure profiles to demonstrate an interesting difference between the two jump styles. Notice that in one-foot jumps (Figure 4), the CM never lowers during the ground support phase of the jump. Conversely, in two-foot jumps, the CM demonstrates a prominent low-

Figure 4 - *Stick figure representation of a typical one-foot jump. Notice that the trajectory of the CM displays no vertical lowering throughout the jump.*

ering phase prior to the upward propulsion of the body (Figure 5).

This effect is important not only in understanding the difference between one-foot and two-foot jumping performances, but in understanding the general effects of running approaches. Consider the theoretical situations presented in Figures 6 and 7. In the following example, the mass represents the CM of the jumper, the spring represents the musculature of the support leg(s), and the hinge represents the middle of the support leg's foot.

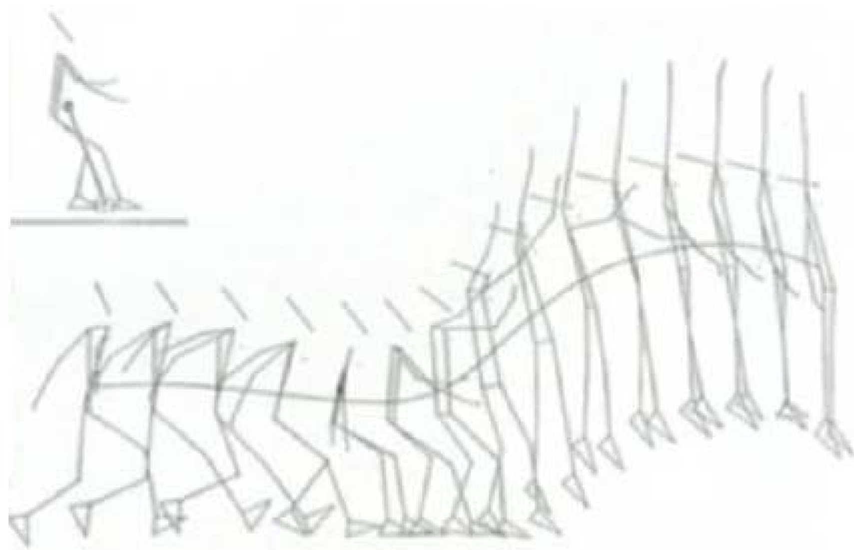

Figure 5 - *Stick figure representation of a typical two-foot jump. The CM shows noticeable vertical lowering throughout the first part of the jump.*

General caption for Figures 4 and 5 - *The representative athlete is left-handed. The horizontal spacing between adjacent stick figures has been exaggerated for clarity. The trajectory of the CM has been overlaid on the stick figure profiles. The inset is provided to illustrate the hinge point over which the CM passes during the ground support phase.*

In Figure 6, a mass moves horizontally over a hinge point (middle of the foot) which is on the ground. Although there is no vertical motion of the mass, there is significant radial motion of the mass during its horizontal progression over the hinge point. Radial motion, in this context, refers specifically to the distance between the mass (i.e., the CM of the jumper) and the hinge (i.e., the middle of the foot). Expressed differently, radial motion is defined by the changes in length of the spring (i.e., support leg). The horizontal motion of the mass compresses the spring toward the hinge throughout the ground contact time. That is, the distance between the mass and the hinge becomes smaller as the mass passes over the hinge. This is analogous to one-foot jumping where, although there is no appreciable vertical lowering of the CM, the support leg is compressed by the radial actions of the body as the CM passes over the foot of the support leg. This compression increases the muscular tension in the support leg and allows the athlete to develop greater propulsive forces during the jump. This, in turn, serves to increase flight height.

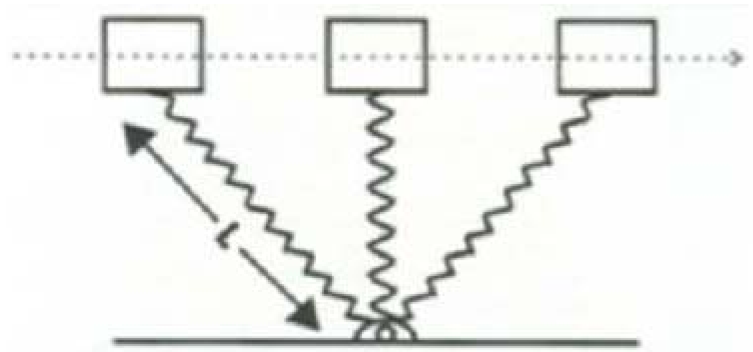

Figure 6 - *During one-foot jumps, the radial motion of the mass (CM) helps compress or load the spring (support leg). Note: there is no appreciable vertical motion of the mass during the ground support phase of one-foot jumps. At the instant of touch-down, the length of the spring is "L". As the mass passes over the hinge (mid-foot), the length of the spring decreases to some value less than "L".*

During two-foot jumps (Figure 7), the CM demonstrates both vertical and radial compression. While these combined effects may load the spring to a greater extent, two-foot jumps also must overcome the downward momentum of the body before efforts could be made to directly increase the vertical velocity upward. This alone may put the two-foot jumps in a less than ideal situation for propelling the body upward.

Therefore, although two-foot jumps have essentially twice the musculature, they are somehow less effective, per leg, in developing propulsive forces against the ground. While one-foot jumps display only radial motions of the CM during the ground support phase, two-foot jumps also demonstrate appreciable vertical lowering. Other possible mechanisms associated with the development of muscular tension during one-foot and two-foot jumps are currently being investigated. For example, two-foot jumps may be subject to a certain neural phenomenon which may somehow inhibit the expression of maximum muscular force.

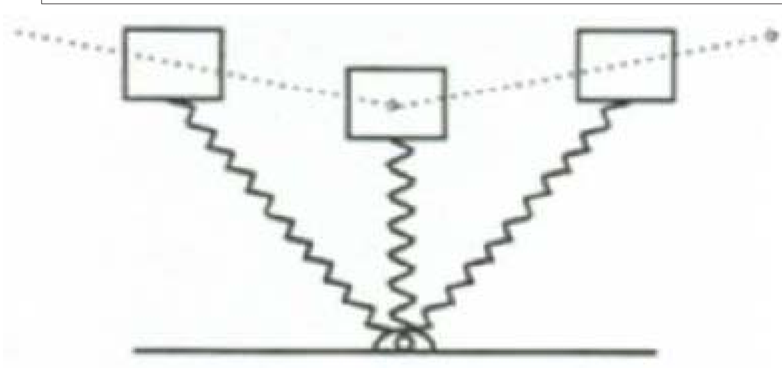

Figure 7 - *During two-foot jumps, the vertical and radial motions of the mass (CM) help compress or load the spring (support leg).*

Implications for Training

While the mass-spring system presents a nice analogy to vertical jumps initiated from a running approach, the idea that the spring develops force as it compresses is actually opposite to what happens to the support leg musculature. Because of the rotational motion of the ankle, knee and hip joints, the radial (and vertical motions) of the body cause the joints to flex (bend) and stretch the muscles which extend these same joints. Therefore, the muscles are actually stretched(not compressed) during the ground support phase of jumping.

This stretching effect is called on eccentric action of the musculature. The muscle is stretched while it is trying to contract. This effect is also evident in block jumps where the athlete's body is lowered before being propelled upward. This concept is important, because eccentric actions develop greater muscular tensions than do concentric, or shortening actions. By first stretching the muscles which eventually shorten and extend the ankle, knee, and hip joints, the muscles start at a higher tension level and are capable of performing more work.

It has been theorized that in addition to improving the force producing capacities of the muscle itself, this pre-stretch mechanism improves jumping performance by utilizing some of the elastic properties of the muscles and tendons. This is accomplished by increasing the distance over which force can be exerted, thereby prolonging the upward propulsion phase; and, by taking some of the muscular "slack" associated with the initial stages of the development of muscular tension. Although the exact mechanisms by which this eccentric action enhances jumping performance have yet to be completely understood, it has been used as the foundation for plyometric training.

As a strong proponent of sport-specific training, I believe that the most effective way to improve vertical jumping performance is simply to jump. Jump training not only strengthens all of the appropriate musculature, it maintains the complex timing and coordination patterns required during jumping performances.

When performing two-foot approach jumps players should emphasize horizontal approach speed and the arm swing. For one-foot jumps, the actions of the non-support leg should also be emphasized. In general, one-foot jumps utilize slightly faster approach speeds. This may be related to the fact that contacting the net is not as much of an issue as it is during traditional two-foot attacks because the slide is performed horizontally along the net. However, it also may be easier to use faster approaches during one-foot jumps because the final takeoff phase uses an arm swing action which is in-phase with the running motion.

Two-foot jumps, in comparison, must essentially break the natural running motion near touchdown to properly coordinate the dual-arm swinging motion. Regardless of the difference between jump styles, the faster the approach, the more eccentric loading by the support leg musculature. Up to a point, increases in the rate and extent of the eccentric loading result in better vertical jumping performances. Increases in eccentric loading may be accomplished by increasing the rate and/or depth of lowering of the CM vertically, or radially, or in some combination of the two. The limit to which eccentric loading is beneficial must be understood. Too much eccentric loading may compromise the integrity of the involved musculoskeletal structures (e.g., muscle, tendon, ligament) and potentially result in injury. This has traditionally been one of the concerns about plyometric training (particularly with young and inexperienced athletes). Some evidence suggests, for example, that there is an optimum approach speed which results in optimum jumping performances. Approaches slower than the optimum result in lower jumps than could have been achieved, because the muscles are not pushed to their limit. Conversely, approaches faster than the optimum result in lower jumps than could have been achieved because the support leg(s) may not be strong enough to accommodate the increased eccentric loads. In this case, the support leg(s) may buckle under the strain and be unable to produce the desired upward propulsion. However, since the approach speeds for elite level volleyball players are about two to three times slower than analogous speeds reported for elite level high jumpers (whence the optimum approach speed information was derived), suggest that most volleyball players are still well below their optimum approach speed.

In addition to increases in approach speed to improve jumping performance, considerable emphasis should placed on the arm swing for both jump styles, and on the non-support leg swing during one-foot jumps. While some tactical situations may limit the arm swing, a vigorous and properly coordinated arm swing and/or leg swing enhances jumping performance. As the limbs accelerate upward, they produce a downward force on the torso which develops greater tensions in the support leg musculature. As the limbs slow, they produce a lifting effect on the body. Increasing the vigor with which these actions are performed magnifies this beneficial effect.

Concluding Remarks

On average, while overall jump and reach heights are similar between one-foot and two-foot jumps, the strategies employed to achieve these results are notably different. It is certain that some athletes prefer one style of jumping over the other. Whether this is a reflection of strength, technique or experience, these techniques share common features which can be exploited to improve overall performance. Increases in approach speed and incorporating a more dynamic arm/leg swing result in improved in jumping performance. While these actions have the same effect as plyometric training jumps, they are more sport-specific and should be heavily emphasized during jump training drills and activities. Performing approach and block jumps with hand weights can accentuate the effects of the arm swing, but it is import that the coordination of the arm swing is not compromised in the process.

Each athlete is different with different strengths and weaknesses. A "universal" training program which does not accommodate individuality is ineffective and ill advised. Jump training is effective because it is a natural reflection of the individual's strength. Vertical jumping performance can rapidly improve by requiring athletes to employ faster approaches and more dynamic arm swings. **O**

JUMP Training Principles

Exercise	Beginning	Intermediate	Advanced
Two-foot squat jumps - no arm swing	X	X	X
Two-foot countermovement jumps - no arm swing	X	X	X
Two-foot squat jumps - with arm swing	X	X	X
Two-foot countermovement jumps - with arm swing	X	X	X
Two-foot approach jumps with arm swing	X	X	X
One-foot slide jumps	X	X	X
Two-foot squat jumps - with arm swing with light hand weights		X	X
Two-foot countermovement jumps - arm swing with light hand weights		X	X
Two-foot approach jumps with arm swing with light hand weights			X

- Athletes should warm up and stretch properly before performing any of these exercises. Place particular emphasis on warming up and stretching the calves, quadriceps, hamstrings, gluteals and lower back muscles. If performing jumps with arm swings, the shoulder flexors and extensors also should be warmed and stretched.
- Intensity, approach speed and arm swing vigor should increase as strength and performance increases.
- Number of sets and repetitions per set should increase as strength and performance increases.
- Proper coordination and timing should be maintained at all times.
- The use of hand weights accentuates the beneficial effects of the arm swing. Use only light weight hand weights (~2 lbs) for these jumping exercises.
- To minimize the chance of injury, do not perform an actual spiking action while using the hand weights.