An Analysis of the Volleyball Jump Serve

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The Volleyball Jump Serve

Introduction

One of the most dramatic skills in modern volleyball is the spike serve, or the jump serve, which provides an exciting and dynamic skill that is captivating for players and spectators alike. The player starts about five meters behind the end line of the court, uses a fast and explosive run up, a dynamic spike takeoff and an exciting spike action at the peak of their jump that sends the ball across the net at speeds of over 27 $m.s^{-1}$ with heavy topspin and at a sharp downward angle. The spike serve has become a dangerous offensive weapon for the top volleyball teams of today, as a great spike server can produce a number of aces over the course of a match. The spike serve is somewhat similar to the spike at the net, except the velocities after impact are somewhat lower for the serve when compared to the spike (Tant, Greene et al. 1993). A study of the spike vs. the serve for collegiate volleyball players revealed similar speeds for the male athletes but slower speeds for the female serve when compared to the spike (male jump serve 19.7 $m.s^{-1}$, male spike 22.4 $m.s^{-1}$, female jump serve 13.2 $m.s^{-1}$, female spike 17.8 $m.s^{-1}$). A study of the front row spikes of elite international volleyball spikers reported mean impact ball speeds of 27 $m.s^{-}1$ (Coleman 1993).

It is generally agreed that the top jump servers of modern volleyball are the players who play for Cuba, the top men's team in the world over the past decade. These players are generally very tall, often up to 2.10 m and have very high vertical jumps that allow them to produce a downward angle on the ball: a fact exacerbated by the heavy topspin usually applied. Their strength and athleticism also allow them to produce very high hand velocities at impact that produce high ball velocities that are very difficult for the opposition to return. There are few detailed descriptions of the techniques of the spike serve in elite volleyball players, so little is known regarding the optimal joint angles and body positions to maximize ball speed. An examination of the serves of the top players in the world may provide some useful information regarding optimal technique, so that other skilled players will be able to emulate this skill and improve their own ball speed and accuracy. This analysis was conducted on the players of the 2005 NORSECA Championships, which included the National teams of Cuba, United States, Canada, Puerto Rico, Dominican Republic and Mexico. Over 300 jump serves were filmed during the course of the championships, held in Winnipeg in September 2005. The top servers were analyzed and compared to the less skilled servers participating in the championships, resulting in the following analysis.

The spike serve has many similarities to the spike itself. The player strikes the ball with maximum force at the peak of his jump, and tries to place it so that the opposing player cannot receive it cleanly. It has been suggested that a successful spike is determined by three factors, which are likely similar to those of the jump serve: the position of the ball at impact, the speed of the ball after impact, and the direction of movement of the ball after impact (Chung, Choi et al. 1990). In the jump serve the ball position at impact is determined by the toss of the server - an effective serve requires a perfectly placed toss and a perfectly timed run up. The higher the point of impact, the sharper the downward angle of the serve, and the more margin for error there is for the server to utilize a higher ball velocity. This makes it faster to arrive on the other side of the net and thus there is less time for the receiver to interpret the path of the ball and move into position to play it, increasing the chance of an error or an inaccurate pass.

Figure 1. Sequence photos of the spike serve by top International player.

Ready Position and Ball Toss

The following description describes the jump serve for a right handed server - foot and hand positions would be on the opposite side for a left handed player. In the ready position for the spike serve, the server stands about 5 m behind the end line and holds the ball in the serving hand. The feet are side by side or the left foot is slightly behind the right and they are pointing toward the net. As the step is taken onto the right foot, the right arm supporting the ball is raised in front of the body for the toss by a combination of shoulder flexion and elbow flexion. An alternative method of footwork for the toss is to release the ball as the right foot is leaving the ground for the toss and the left foot is being planted. Volleyball jump servers most often use the hitting arm as the arm used to toss the ball for the serve, so a right handed server will use the right hand to toss the ball. A study of the toss using either hand concluded that tossing with the serving hand utilized increased range of motion of the hitting arm and the trunk in the toss (Tant and Witte 1991). These actions produce a longer lever arm and greater mass to create optimum velocity in the hand. There may also be benefits in terms of coordination and rhythm by using the hitting arm to toss the ball.

The ball is carried to a position in front of or just above the right shoulder and is then released in a forward and upward pathway. The ball travels to a significant height of up to 10 m, then drops to the position of contact about 2 m inside the court. An accurate toss is an important aspect of the skilled spike serve, and takes many years of practice to perfect the exact timing, direction and height required for a reliable serve.

Figure 2. Ball toss occurs off the right foot, ball is tossed with the right arm, elbow extended, body leans forward.

Figure 3. Ball toss can also occur from the left foot, but this technique leaves only the final two steps of the run-up to build up horizontal velocity so is not recommended.

Figure 4. Ball being released for the serve from the left foot, note high point of release above the server's head, since longer ball contact gives better control over the toss.

The key to a reliable toss is the upward arm swing in which the ball must remain on the palm of the hand and the lower arm must remain in supination to support the ball squarely. The arm swing upwards is produced primarily by shoulder flexion and some elbow flexion during release of the ball, as well as some trunk extension. The elbow should remain close to extension to improve accuracy in the path of the ball to release. The ball should roll off the finger tips rotating forward with topspin, to stabilize the ball's flight and possibly help the generation of topspin at impact. The ball should be released as high as possible for greater accuracy, preferably above the head with full shoulder flexion (Figure 4).

The ball is usually released during the forward shifting of the body weight over the right foot (Figure 2). However, some elite servers are seen to release the ball as the weight is taken on the left foot (Figure 3). This technique is less desirable because the server then only has the final two steps in which to build up the horizontal velocity for the serve. The body has little horizontal velocity as the ball is tossed for the serve, but following release the body starts to move forward toward the court with increasing speed. The speed of this first step, as well as the speed of the run up is determined by the skill of the server - the more skilled the athlete the faster he can move into the hit. When the ball is released for the toss, it is no longer affected by the movements of the server but it will continue its parabolic path toward the court until it is struck by the server in mid air on the serve.

Run up

The run up consists of 4 steps into the takeoff, during which the server builds up forward momentum that he will use to load the legs for the jump. Loading the legs is the mechanism by which the run up velocity is slowed by an eccentric contraction of the hip, knee and ankle extensors, and this lowering of the body weight will increase the flexion of the hips and knees and stretch the muscles prior to the contraction for the jump. It has been reported that a longer run up is related to a higher jump in spiking with skilled volleyball players, so those servers using a 4 step approach to the serve have the potential to jump higher (Khayambashi 1977; Maxwell, Bratton et al. 1980). The velocity of the body's center of gravity forward into the serve will be added to the velocity imparted to the ball from the arm and trunk movements. The faster the run up, the faster the horizontal velocity of the CG at impact and the faster the ball will leave the hand (Figure 5). Horizontal CG velocities of 2.85 $m.s^{-1}$ have been reported for the jump serve of male collegiate volleyball players (Tant and Witte 1991).

Figure 5. Long step onto the left foot to start the run up. A longer step is related to a faster run up, a faster run up is related to a higher jump and a faster serve.

The weight is maintained over the right foot during the toss, and it is followed by a longer step onto the left foot following release. The step onto the left foot is critical in attaining a high horizontal speed at takeoff and should be a long and explosive step. The step from the left foot back onto the right foot is the longest step of the run up, and often covers a distance of up to 80% of the server's standing height. This long step onto the right foot is known as the plant step, and the purpose of this step is to provide the braking forces for the run up and allow the athlete to gather and prepare for takeoff. The longer this step, the more skilled the server and the greater time and distance the server has to decelerate his forward velocity and prepare to takeoff upwards (Alexander and Seaborn 1980). The right foot lands on the heel first, and then the weight is taken over the whole foot as the knee and hip are flexed. The right foot plant is followed by deep flexion on this support leg, in preparation for the jump to follow. During this step the left foot is brought through to a position in front of the planted right foot, often up to 50 cm in front of the right foot. As the left foot is planted, it is rotated toward the midline using hip medial rotation so that the toe is pointing to the sideline, or the foot is almost parallel to the end line of the court. This position allows the left foot and leg to act as an effective brake for the forward momentum of the run up, as well it positions the trunk at an angle to the net to prepare for trunk rotation into the serve. It has been reported that the right leg is the dominant leg for most right-handed spikers, and provides a greater amount of the total force for the takeoff in the spike jump (Wielki and Dangre 1985). This is also the case for jump serving.

As the athlete steps onto the right foot, the arms are left behind the body in extreme shoulder hyperextension- the arms should be horizontal or even past the horizontal to attain the maximum position for the arm swing forward (Figure 6). The athlete in the attached photo has the arms hyperextended to an angle of 30º above the horizontal (Figure 6). First contact with the heel of the right foot should correspond with the position of maximum shoulder hyperextension. Maximum shoulder hyperextension is accompanied by trunk flexion that increases the range of shoulder extension. The optimal range of trunk flexion during the arm swing is in the range of 20º from the vertical. Decreased ranges of motion in the trunk flexion or shoulder hyperextension may lead to timing problems with the arm swing during takeoff. The arm swing may then be completed too soon in the jump takeoff, and provides little force to increase ground reaction forces during takeoff.

Figure 6. Plant step onto the right leg, heel strikes first and shoulders in maximum hyperextension above the horizontal, trunk leaning forward.

From this hyperextended position, the arms are swung forward, downward and upward in front of the body in order to provide increased vertical ground reaction forces for the jump. As well, the trunk moves from flexion to extension, and this forceful trunk extension will also increase the ground reaction forces. As the arms and trunk are accelerated upwards, they push down on the proximal joints, which increase the downward forces on the floor and the upward ground reaction forces acting on the athlete. The arms should reach near-maximum angular velocity as they reach the vertical position beside the body (Figure 7), they are then accelerated upward to a position in which the upper arms are pointing forward or slightly upward at takeoff. The speed and range of motion of the arm swing during takeoff is an important factor in increased jumping skill, and top jump servers have a longer and faster double arm swing during takeoff. A longer arm back swing is often accompanied by increased trunk flexion, as both of these movements can help to increase the height of the jump by increasing ground reaction forces during forceful shoulder flexion and trunk extension. It is notable that skilled servers perform the upward swing of the arms while the flexed knees are starting to extend so that the arm swing can contribute to the ground reaction forces acting upward on the server.

Figure 7. Final left foot plant prior to takeoff. Foot planted well ahead of the right foot at an angle to the end line, arm swing nearing completion.

Takeoff

When both feet are planted for the takeoff the extension of the legs and trunk begins in order to drive the body upwards for the serve. The back leg (the right leg) will extend first, as the body is still moving forward over this leg at takeoff. The right leg reaches full extension prior to the left leg, suggesting that the right leg makes a significant contribution to vertical velocity at takeoff in the jump for the spike serve. The arm swing upward is completed prior to extension of the legs, since the arm swing makes a contribution to ground reaction forces early in the takeoff before leg extension has occurred. The end of the upward motion of the arms may also transfer vertical momentum to the rest of the body for take-off. As the leg extension is occurring, the trunk is also extending to maximize the ground forces. The timing of the joint movements during the takeoff consists of shoulder flexion, trunk extension, and hip and knee extension. The final movement to increase jump height is ankle plantarflexion, as the contribution of the calf muscles in jump height is significant (Figure 8). The more extended the body at takeoff, the higher the server will jump, as the height of the CG at takeoff contributes to maximum jump height. The CG at takeoff is raised in the body by full trunk and leg extension, and having the arms raised to a near-vertical position at takeoff. A skilled jumper can attain 60% of their total jump height by the increasing the height of the CG at takeoff.

The mean vertical velocity of the center of gravity at takeoff for back row spikers was reported to be 3.59 $m.s^{-1}$ and the height of the jump was 0.62 m (Coleman 1993; Huang, Liu et al. 2005). The mean horizontal velocity at takeoff was found to be 3.23 $m.s^{-1}$. In a related study of the jump serve the mean horizontal and vertical velocities for the center of mass at takeoff were reported to be somewhat less at 2.76 and 2.77 $m.s^{-1}$ respectively (Coleman 2005). The mean values for the top servers in the present study were horizontal velocities of 4.20 $m.s^{-1}$ at right foot plant, and 3.65 $m.s^{-1}$ vertical velocity at takeoff. The center of mass velocity values at ball impact ranged from -0.33 to 2.76 $m.s^{-1}$, indicating that some servers hit the ball on the way down and others on the way up, fact also noted by Coleman (1993) in front row spiking.

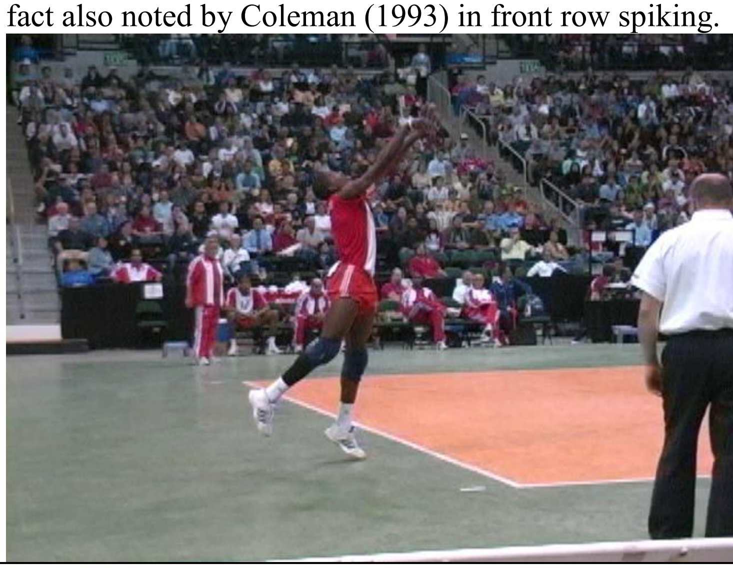

Figure 8. Instant of takeoff for the serve- the left foot is last to leave the floor, both legs are extended, arms are extended upward, body almost vertical.

Airborne Phase-Backswing

At takeoff the server will begin the backswing movements in order to place the hitting arm in an optimal position for striking the ball. The hitting arm will move from a position elevated in front of the athlete to a position behind the athlete in the backswing position. The hitting arm is moved back in one of two ways (Oka, Okamoto et al. 1975): it can either drop down to a position below the shoulder joint and move backward in a low position with the hand at about hip level; or it can remain in a position with the upper arm parallel to the floor as it is moved backward. The backward movement of the hitting arm is accompanied by rotation of the trunk from a position facing the net to a position sideways to the net. In a skilled server, the trunk must move as a two segment model, so that the shoulder girdle and the pelvic girdle (hips) move as separate segments. In the volleyball serve, as the upper body is rotated sideways on the backswing, the hips are rotated further forward in order to take up the torques around the longitudinal axis produced by the shoulders.

Figure 9. Serving arm is moved back behind the body in a low position with the upper arm adducted closer to the trunk, leads to greater shoulder medial rotation in this phase.

Figure 10. Serving arm is moved back behind the body in a high position with the upper arm abducted past 90 degrees to the trunk and less medial rotation.

It is important here to review Newton's Third Law of Angular Motion (Hay 1993) which states that in an airborne body the sum of the torques must remain constant. When body parts move in one direction while airborne, other body parts must move in the opposite direction to ensure the sum of the action and reaction torques around any axis remain constant. As the shoulders are rotated backwards to a position sideways to the net (clockwise torque), the hips (and the attached legs) are rotated further forward to face the net (counterclockwise torque) to ensure the sum of the torques around the longitudinal axis is constant. Top servers commonly exhibit this rotation of the pelvis forward to the left to squarely face the net while the shoulders are moving backward to the right for the arm backswing (Figure 9).

Figure 11. Shoulder girdle rotation to the right is accompanied by pelvic (hip) rotation to the left; both shoulders are medially rotated, R. wrist flexed and lower arm pronated.

The trunk is not only rotating around the longitudinal axis, it is also rotating around the transverse (left to right) axis as it undergoes trunk flexion-extension during the serve. As the trunk is rotated sideways to the right, it is also extended, and even hyperextended during the backswing. This hyperextension of the trunk is accompanied by hyperextension of the hips as the trunk and legs undergo action reaction movements around the left right axis. As the hitter approaches peak height of the jump, the legs assume a position of maximal hip hyperextension and knee flexion (Figure 12). During the forward movements of the hitting arm, the legs are forcefully flexed at the hip and the knees are extended. This forceful leg movement may assist in the forceful flexion of the trunk, again using the action reaction in the air principle. The trunk hyperextension and rotation stretches the abdominal muscles of the trunk, preparing them for the strong contraction producing the flexion and rotation to the left of the trunk during the serve. At the point of maximum knee flexion the trunk is maximally rotated back to the right, and the serving arm is abducted and medially rotated in preparation for the lateral rotation of the backswing. The ability of some players to assume this position of shoulder medial rotation (Figure 12) may be limited by rotator cuff injury which could restrict this range of motion.

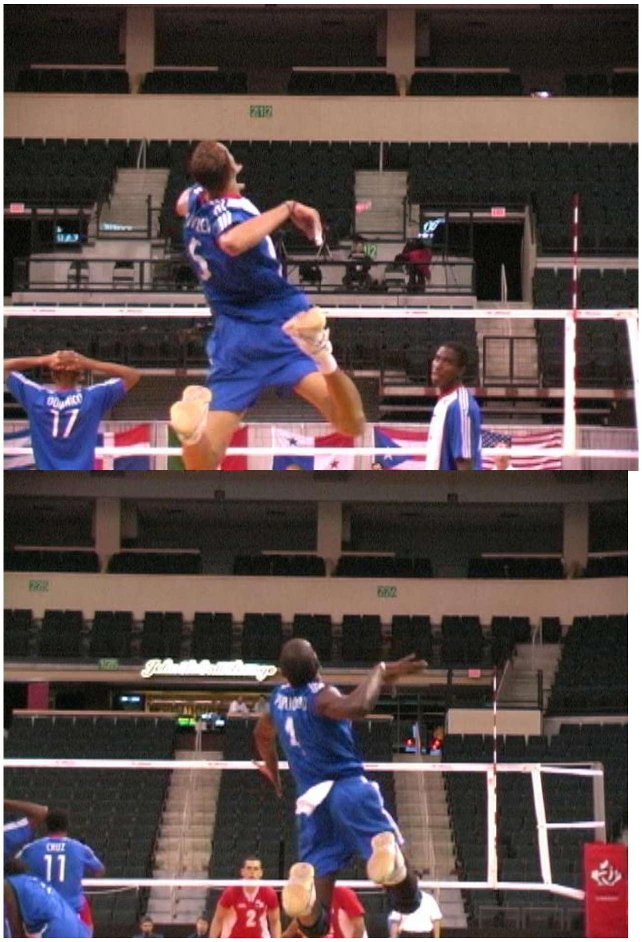

Figure 12. Flexed knees and upper trunk rotation to the right as hips rotate left to face the net squarely as server approaches peak height.

A further advantage of the flexed knees and trunk hyperextension movement is that they help to stabilize the head during the airborne movements of the serve. As the legs are flexed behind the server, and the arms are raised for the hit, the center of gravity (CG) moves upward in the trunk. As the CG is moving up in the trunk, and then moving back down in the trunk during the hit, the head remains in a level position for an extended period of time (Bishop and Hay 1979). This is an advantage for the skilled server, as it allows the head to be stationary for the important phase of tracking and contacting the volleyball. This ability to keep the head still vertically at the top of the jump while the CG moves in the trunk is called "hanging in the air", and has been documented in skilled basketball jump shooters. Close examination of the skilled server reveals that the head does indeed remain stationary in the vertical plane during the phase just before, and during contact with the ball.

As the shoulders are rotated sideways to the right, the hitting shoulder undergoes medial rotation in order to stretch the lateral rotators for the backswing. Skilled servers will attain a position of shoulder medial rotation in which the palm of the hand is facing downward during the trunk rotation and backswing of the hitting arm. As the shoulder girdle begins to rotate forward, the hitting shoulder moves into a position of maximal lateral rotation in which the palm and the upper arm face upwards. The more forceful the trunk rotation forwards, the greater the range of lateral rotation the hitting shoulder moves into prior to the hit. The shoulder girdle literally moves out from under the hitting arm, and leaves the hitting arm and hand behind the trunk in a position of maximal lateral rotation. Maximal lateral rotation is characterized by the forearm in a position parallel to the floor, or in extreme cases even past parallel to the floor. This position of maximal shoulder lateral rotation places the medial rotators and the elbow extensors on a stretch prior to their important contribution to hand speed (Figure 13).

Figure 13. Position of maximal lateral rotation places the shoulder medial rotators on a stretch, trunk is tilted to the left and hyperextended while it is squarely facing forward.

Airborne Phase-Forward Swing

From the position of trunk hyperextension and rotation to the right, the shoulder girdle will rotate forcefully to the left and move into flexion. These forceful trunk movements make an important contribution to hand speed at impact with the ball. As the trunk and shoulder girdle rotate forward into the hit the hitting arm moves further backward into lateral rotation and stretches the medial rotators (Figure 15). The trunk then starts to rotate forward and as the trunk approaches the forward facing position, the arm begins to make its contribution to the speed of the hand. The first movement that occurs in the hitting arm is shoulder medial rotation and horizontal adduction, followed by elbow extension, lower arm pronation, wrist flexion and wrist adduction. A report on the variables of spiking reported that in a study of spike servers from the UK, mean elbow angular velocity prior to impact was found to be 1363 $deg.s^{-1}$, suggesting the importance of elbow velocity in this skill (Coleman 2005). The ball is contacted with a cupped, relaxed hand just as the elbow completes its extension. The wrist is flexing and the hand is rotating forward due to pronation and wrist adduction (Prsala 1981). The velocity of the hand at contact is one of the most important variables in the jump serve, as the faster the hand velocity the faster the ball velocity (up to a point). The ball will always leave the hand at a faster velocity than that of the hand, due to the transfer of momentum from the heavier hand and arm to the lighter volleyball. A study of the serve of collegiate male volleyball players revealed that the players' hand traveled at 13.6 $m.s^{-1}$ prior to contact, while the ball left the hand at 19.7 $m.s^{-1}$ (Tant, Greene et al. 1993). When compared to the spike in which the player's hand traveled at 15.4 $m.s^{-1}$ and the ball left the hand at 22.4 $m.s^{-1}$, suggesting that the velocity of the hand is close to 70% of the velocity of the ball after impact (Tant, Greene et al. 1993). A more recent study reported that hand speed at impact for the jump serve was 16.1 $m.s^{-1}$ for a group of elite UK players, while post impact ball speed was 23.7 $m.s^{-1}$ (Coleman 2005), a value again close to 70%. In the current study, the ball velocity at impact for a group of nine of the top players averaged 23.48 $m.s^{-1}$ with a peak value of 24.24 $m.s^{-1}$.

Figure 14. As shoulder girdle rotates to the right, the hips rotate forward to the left to retain balance in the air.

The ball is contacted with a cupped, relaxed hand just as the elbow completes its extension. At that time the wrist is flexing and the hand is rotating forward (Prsala 1981). Adequate relaxation of the hand during contact is essential in applying maximum force to the ball. Relaxing the wrist increases the range of motion of the wrist action results in a more powerful hit (Prsala 1981). The hand contacts the ball with the palm directly facing the ball and the fingers extended. The hand moves over the top of the ball during contact, producing topspin on the ball in flight. This topspin is important to stabilize the flight of the ball and keep it on line to the target. As well, topspin will cause the ball to drop more rapidly than normal, increasing the difficulty of a clean return.

Figure 15. Shoulder girdle rotation to the left has occurred, leaving the hitting arm in near-maximal shoulder lateral rotation prior to medial rotation.

The leg position during the spike occurs in order take up the rotations produced by the arm movements. From the position with the legs flexed under the body, the knees are extended and the hips are flexed to take up the trunk flexion during the hit. As the ball is contacted, the trunk should be almost perfectly vertical, with the trunk legs and hitting arm fully extended to maximize the reach at impact. As the legs are extended, the left leg is also abducted at the hip to increase the moment of inertia (I) of the body around the longitudinal axis. Some servers also exhibit abduction of the right hip, which also increases I about the long axis. The greater the moment of inertia around this vertical axis the greater the resistance to rotation around this axis, and the less the reaction of the rest of the body to the arm action that occurs around the vertical axis in the serve.

Airborne Phase-Impact

The ball should be contacted at peak height of the jump, and at the highest possible point of the reach of the athlete (Figure 16). At impact the hitting arm is fully extended above the hitting shoulder. The trunk is also leaning to the left in order to increase the height of reach of the right hand. This trunk lean to the left will also decrease the angle of shoulder abduction and somewhat decrease the chance of shoulder impingement. The greater the abduction angle of the shoulder, the greater the possibility of impinging the subdeltoid bursa and the supraspinatus tendon under the acromion process. Servers should attempt to utilize as much lateral trunk lean as possible in order to increase reach height as well as decrease the possibility of impingement by decreasing the angle of shoulder abduction. As well, trunk tilt away from the ball will increase the length of the lever arm for rotation around the spine, which will increase the velocity of the ball relative to the spine. Greater trunk lean moves the ball further from the spine, and increases the relative speed of the ball due to rotation of the trunk around the spine. However, too large a trunk lean may unbalance the player in mid-air and lead to erratic right hand path and ball impact, or at least to a restriction in the range of directions of the serve.

At impact the ball is given topspin to stabilize flight, although there are also jump serves with backspin and floater serves. The flight path of the ball varies considerably depending on the type of spin and the ball surface roughness (Depra and Brenzikofer 2005).

Figure 16. Contact for the serve at peak height and full extension of all body parts, trunk leans away from ball.

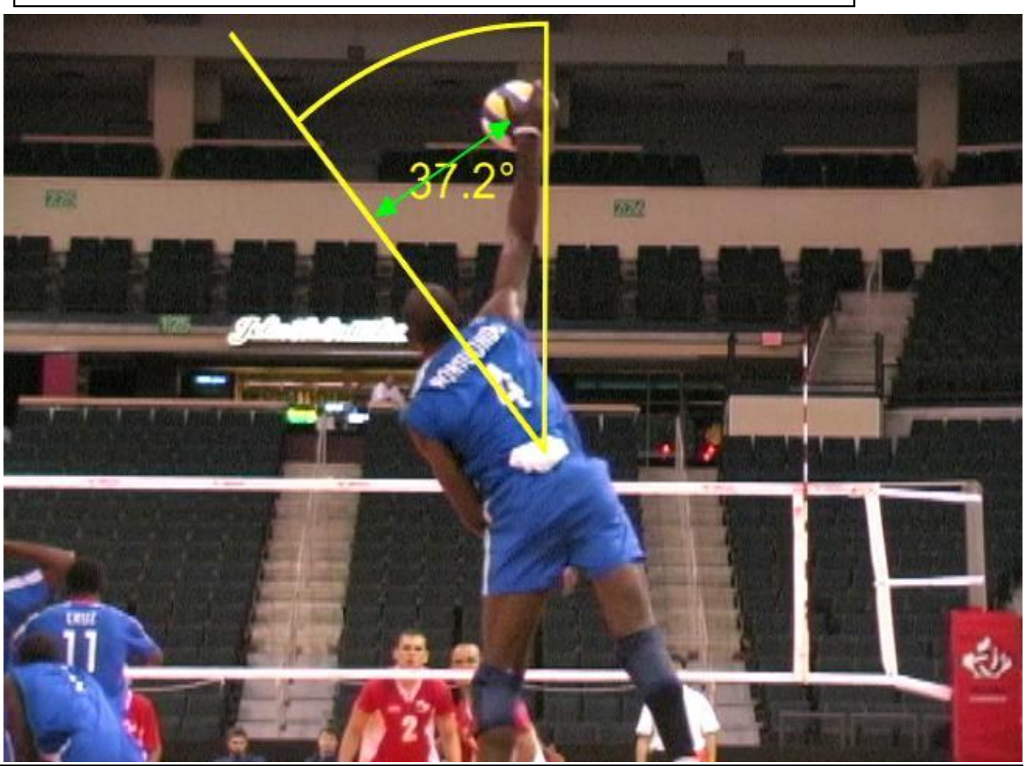

Figure 17. Trunk lean to the left at impact increases height of reach and may reduce shoulder impingement if the abduction angle decreases- here the abduction angle may be too great.

Follow Through and Landing

Following impact with the ball, the hitting arm will continue to move across the body in shoulder extension and adduction, while the trunk continues to flex (Figure 18). The follow through should be as long as possible, so that the high speed of the hitting hand and arm at contact can be decreased over the greatest time and distance possible. This will decrease the force per unit time that has to be applied to the arm to decrease the speed. In terms of angular impulse momentum, the arm has a large angular momentum that is the product of the moment of inertia of the arm and the angular velocity of the arm during the swing. The muscles must apply a large angular impulse in the form of eccentric contractions to decrease this considerable angular momentum to zero following the hit.

Figure 18. Following impact the trunk continues to flex forward and the shoulder continues to extend to decelerate limb gradually.

The server should land on both feet when landing from the jump. Some servers land on one foot (often the non-dominant leg) only, producing very high impact forces on the landing leg, a fact also noted by Coleman (1993) in front row spiking. Landing on both feet will decrease the landing forces by on each leg by half and will also ensure that the server is ready to play defense when the ball is returned from the serve. However, this may be difficult given the amount of trunk lean utilized in the service.

Summary

In summary the jump serve is an exciting and complex skill that is currently performed by almost all highly skilled volleyball players at all levels of play. Adherence to the suggestions included here describing the movements and timing involved in ideal technique will improve the skill of players at all levels. Even if these extreme positions are difficult for players of lower strength and flexibility levels, attempting to increase range of movement, joint movement timing and jump height will improve jump serve effectiveness.

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