# DETERMINISTIC FACTORS OF OVERALL BALL CONTACT HEIGHT DURING HIGH-OUTSIDE FRONT-ROW VOLLEYBALL ATTACKS

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The purpose of this study was to quantify the deterministic factors of overall ball contact height among elite level volleyball attackers. Thirty-two trials collected from nine members of the 1999 USA National A2 Team were subjected to 3D analysis. Results demonstrated that takeoff height (CM height at takeoff) and reach height (vertical distance between the hand and CM at contact) accounted for 86.7% of the overall ball contact height. Flight height (in-flight CM elevation) accounted for only 14% of overall height. Reach height was the only meaningful sub-height that was significantly correlated with overall ball contact height (r=0.70) and appeared to be most sensitive to technique-related differences in performance. Horizontal approach speeds used by the athletes in this study were relatively slow ($3.4 \pm 0.3$ m·s-1) but were positively correlated with flight height (r=0.60).

**KEY WORDS:** volleyball attack, ball contact height, jump.

**INTRODUCTION:** In volleyball, the goal of the attack or spike is to gain a point for the attacking team. And, while the deterministic factors of volleyball attacking have yet to be adequately described, it seems reasonable to suggest that three factors: ball contact height, ball speed, and ball control (i.e., ball placement) are fundamental to the success of the volleyball attack. The purpose of this paper was to quantify the deterministic factors of overall ball contact height during high-outside, front-row volleyball attacks performed by elite level players. 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 height at which the ball is contacted. It can be shown that the height at which an athlete contacts the ball during an attack may be described by the sum of four lesser heights: takeoff height, flight height, reach height, and loss height. Takeoff height may be defined as the height of the CM at the instant the athlete 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 ball is contacted. Loss height, a negative number, refers to the difference between the height of the CM at the instant of ball contact and the peak height of the CM. This last factor is usually attributable to mistiming. In standing two-legged vertical jumps (with arm swing and countermovement), takeoff height, flight height, and reach height have been found to account for 41%, 17%, and 42% of the overall jump and reach height, respectively. Among skilled jumpers, loss height has been found to be negligible, accounting for approximately -0.2% of the overall jump and reach height (Hinrichs & Vint, 1994). Similar results have been observed during one-legged and two-legged maximum effort vertical jumps that were initiated from a running approach (Vint & Hinrichs, 1996).

For the volleyball attacker, it is clear that an overwhelming percentage of the overall jump and reach height is likely determined by the position and orientation of the body about the CM at the instant of takeoff and again when the ball is contacted. Flight height is the only factor that encompasses vigorous muscular effort and is dependent upon the vertical velocity of the center of mass at the instant of takeoff. Vertical velocity at takeoff, in turn, is ultimately dependent upon the force production characteristics of the athlete during the jump. Research has also demonstrated clearly that the elevation of the center of mass during a vertical jumping performance (i.e., flight height) is affected greatly by the speed of the horizontal approach and by the vigor of the preparatory armswing.

**METHODS:**

**Subjects and testing arrangements:** Nine members of the 1999 USA Volleyball A2 Women's

National Team (mean age 20.1 ± 0.9 years, mean height 1.91 ± 0.07 m, mean mass 76.6 ± 6.3 kg) were filmed at the United States Olympic Training Center in Colorado Springs, Colorado. All subjects were right-handed and played as either an outside or middle attacker on their respective college teams. Data were collected during competitive drills in which outside attackers were required to hit against an imposing block.

**Filming and calibration:** Two synchronized video cameras were used to obtain video images at 60 fields·s-1. Three-dimensional calibration was performed using a modified version the multiphase interpolation technique described by Challis (1995). Fifty-five control points were used to establish the final set of DLT camera parameters. The mean resultant, re-predicted control point accuracy was 5.7 mm (0.13% maximum diagonal).

**Data reduction:** Thirty-two trials were used in the final analysis. Twenty-one anatomical landmarks were digitized to define a 14-segment model of the human. The DLT algorithm was used to reconstruct 3-D coordinates from the digitized 2-D video images. Coordinates of each digitized landmark were smoothed with a second-order, zero-lag, Butterworth digital filter using the autocorrelation-based procedure described by Challis (1999). Velocity data were computed using the smoothed coordinate data and a standard numerical differentiation equation. Segmental masses and center of mass locations were determined using data from deLeva (1996).

**Deterministic factors of ball contact height:** Takeoff, flight, reach, and loss height were calculated using the definitions described by Vint and Hinrichs (1996). Takeoff, peak CM height, and ball contact were identified to the nearest 0.1 video field and were used to extract the relevant vertical CM position data. Ball contact height was defined as the vertical position of the base of the third knuckle of the right hand at the instant of ball contact.

Approach and takeoff velocity: Horizontal approach velocity of the athlete's CM was calculated during the in-flight phase of the approach prior to the final foot plant of the attack jump. The takeoff velocity of the athlete's CM was calculated using 3D velocity components at the instant of takeoff into the attack jump.

**Statistical analyses:** Pearson's product moment correlations were used to assess the strength of relationships between selected physical characteristics of the athletes, the deterministic factors of ball contact height, and horizontal approach speed of the CM.

## RESULTS AND DISCUSSION:

**Deterministic factors of ball contact height:** Mean values for overall ball contact height, takeoff height, flight height, reach height, and loss height were consistent with those reported previously for standing jumps (Hinrichs & Vint, 1994) and jumps initiated from a running approach (Vint & Hinrichs, 1996) (Table 1).

**Table 1 Mean (±SD) deterministic factors of ball contact height (n=32). Relative values are expressed as a percent of overall ball contact height.**

| | Absolute (m) | | Relative (%) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Ball contact height | 2.70 | 0.08 | 100.00 | 0.00 |
| Takeoff height | 1.28 | 0.07 | 47.34 | 2.81 |
| Flight height | 0.38 | 0.09 | 13.86 | 3.31 |
| Reach height | 1.07 | 0.06 | 39.40 | 1.59 |
| Loss height | -0.02 | 0.02 | -0.61 | 0.60 |

Standing height and body mass were significantly correlated with takeoff height, flight height and loss height (Table 2). Standing height was also associated strongly with reach height. However, neither of these physique-related variables was significantly correlated with overall ball contact height. The only sub-heights to be significantly correlated with ball contact height were reach height ($r=0.70$, $p<0.001$) and loss height ($r=0.47$, $p<0.01$). Since loss height is a negative number, the positive correlation between loss height and contact height means that smaller loss heights (contacting the ball closer to peak CM height) were associated with higher overall ball contact heights. The relationship between reach height and ball contact height is strongly influenced by technique and points to a variable that can be used to improve performance. Takeoff height and flight height displayed correlation coefficients of 0.04 and 0.29, respectively ($p>0.1$), and therefore were not strongly associated with overall ball contact height (Table 2). These results were unexpected and were inconsistent with the standing vertical jump data presented by Vint & Hinrichs (1996, unpublished data), which had shown positive and significant correlations between standing height, takeoff height, and overall contact height. It is likely that the lack of correlation in the current data is attributable to the homogeneity of the participating athletes and the low variability of the data itself. The relationship between flight height and reach height barely failed to reach statistical significance ($p=0.06$).

**Table 2 Pearson's product correlation coefficients between selected physique and subheight variables (n=32). Single and double asterisks represent significance at p< 0.05 and p< 0.01, respectively.**

| | Mass (kg) | Standing Height (m) | Takeoff Height (m) | Flight Height (m) | Reach Height (m) | Loss Height (m) | Contact Height (m) |
|---|---|---|---|---|---|---|---|
| Mass (kg) | 1.00 | | | | | | |
| Standing Height(m) | 0.68** | 1.00 | | | | | |
| Takeoff height (m) | 0.82** | 0.92** | 1.00 | | | | |
| Flight height (m) | –0.88** | –0.83** | –0.87** | 1.00 | | | |
| Reach height (m) | 0.27 | 0.35* | 0.41* | –0.34 | 1.00 | | |
| Loss height (m) | –0.50** | –0.59** | –0.51* | 0.59** | 0.01 | 1.00 | |
| Contact height (m) | –0.23 | –0.04 | 0.04 | 0.29 | 0.70** | 0.47** | 1.00 |

**Approach and takeoff velocity:** Resultant horizontal approach speed ranged from 2.9 to 4.1 m·s-1 while resultant takeoff speed ranged from 2.8 to 3.8 m·s-1. Elevation angle of the CM at takeoff ranged from 42.4 to 68.7 degrees with an average value of 58.6±6.4 degrees. Strong negative associations were found between physique-related variables and approach and flight characteristics. Specifically, body mass and standing height were significantly and negatively correlated with resultant approach speed, vertical takeoff speed, elevation takeoff angle, flight height, and time of flight. This means that the shorter and lighter attackers tended to approach the net faster and propel their bodies higher into the air than taller and heavier athletes. As expected, strong positive relationships were observed between approach speed, vertical takeoff speed, and flight height.

**DISCUSSION AND IMPLICATIONS FOR PERFORMANCE:** The relative contributions of takeoff height, flight height, reach height, and loss height were similar to those observed in one- and two-legged vertical jumps using four-step, self-paced approaches (Vint & Hinrichs, 1996). In the present study, takeoff and reach heights accounted for 84-86% of overall contact height. Flight height, the factor most directly related to the vigorous muscular effort involved in jumping, accounted for only about 14% of overall contact height. Loss height, the loss in overall height due to contacting the ball on the way down from the peak of the jump was less than 1%. These results have clear implications for volleyball coaches, recruiters, trainers, and players: physique and technique, not the ability to propel the body into the air, account for the overwhelming percentage of ball contact height.

In this study, reach height was the only relevant sub-height to be significantly correlated with overall ball contact height. Since reach height is described by the distance between the hand and the center of mass of the whole body at the instant of ball contact, it is clear that the physique of the athlete and the position of the athlete at the instant of ball contact are the ultimate deterministic factors of reach height. For a given body position at the instant of ball contact, athletes with longer arms and/or lower centers of mass will tend to have greater reach heights than athletes with shorter arms and/or higher centers of mass. However, since these physique-related variables did not appear to drive the relationship between takeoff height and overall contact height, it seems likely that the technique used by the athletes at the instant of contact is the more important parameter among such a homogeneous group of athletes. That is, among athletes of similar ability and stature, it may be that the position of the body is an important variable in discriminating between "good" and "poor" technique at the instant of ball contact. For many attackers, it was clear that reach height could have been significantly improved since the hips and knees were typically flexed at the instant of ball contact (Figure 1).


Figure 1: Outside attacker at the instant of ball contact. Here, the hips and knees are flexed and the left arm is elevated which raises the height of the CM within the body and decreases reach height. Extending the hips and knees and lowering the left arm could easily improve reach height and therefore the overall ball contact height for this athlete.

Increased horizontal approach speed was strongly associated with increased flight height. In this study, the mean resultant approach speed was only 3.4 m·s-1. Research related to high jumping performance and some limited research related to volleyball and basketball jumping performance has demonstrated that an optimum approach speed exists and that this optimum is likely to be different for each athlete. At an average of 3.4 m·s-1, it is likely that the athletes in this study used approach speeds that were considerably slower than their theoretical optimum approach speeds and should therefore be encouraged to approach the net faster.

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