EFFECT OF TAKE-OFF FEET POSITION ON VOLLEYBALL ATTACK TAKE-OFF HEIGHT

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The purpose of this study was to investigate the influence of volleyball attack take-off technique on the centre of mass (CoM) take-off height. The kinematics of lower extremities at take-off was obtained via 3D motion analysis. Results showed that the group with greater normalised attack height (HA) had greater normalised CoM take-off height ($p < 0.01$) than the group with lower normalised attack height (LA). Additionally, the HA group had a greater inter-ankle distance at take-off ($p < 0.05$) than the LA group. There was no significant difference in CoM horizontal distance between the groups. The findings of this study indicate that the normalised CoM take-off height for a volleyball attack is neither influenced by the feet position at take-off nor by the horizontal CoM distance from take-off to ball impact.

KEYWORDS: approach, centre of mass, feet position, step-close

INTRODUCTION: Hitting the ball into the opponent's side of the court powerfully is an essential skill (offensive attack) in men's volleyball that can influence the outcome of a match (e.g., Rodriguez-Ruiz et al., 2011). A study by Abendroth-Smith & Kras (1999) showed that there are many different elements and phases that go into performing this complex movement. In addition, Abendroth-Smith and Kras (1999) stated that the height of ball contact can provide different attack angles, resulting in a higher success rate of an attack. Therefore, jumping has been considered as a crucial criterion for improving volleyball attack height and ultimately, attack performance. The use of the deterministic model identified that overall volleyball attack height consists of take-off height, flight height, loss height, and reach height (Vint & Hinrich, 2004, Figure 1). A vast body of studies examined the factors related to jump height only, that is the vertical displacement of the CoM from take-off to peak (flight height) in an effort to measure attack height (e.g., Fuchs et al., 2021). However, studies showed that the flight height of the CoM only accounted for about 14% of the overall attack height (Hsieh & Lamm, 2015; Vint & Hinrich, 2004). There is very little study examining the body posture or performance technique that could influence the overall volleyball attack height (Hsieh, 2019).

A few studies have examined the components of the overall attack height and found that only the reach height and take-off height were associated with the overall attack height (Hsieh & Lamm, 2015; Vint & Hinrich, 2004; Matušov, Zapletalová, Duchoslav, & Hagara, 2013). The take-off height accounts for about 47% of the overall attack height and has the highest association ($r = 0.8$) when compared to other components of the overall attack height (Hsieh & Lamm, 2015; Hsieh, 2019; Vint & Hinrich, 2004; Matušov, et al., 2013). In addition, there was a significant difference when comparing good to poor performers on these two factors but not flight and loss heights (Hsieh & Lamm, 2015). Hsieh (2019) further identified the angular kinematics that causes the difference between high and low performers at the moment of take-off and ball contact. It was concluded that the group that had greater normalised overall attack height demonstrated better follow-through of jumping technique at take-off than the group that had lower attack height.

The group with greater attack height had a greater joint extension at hip, knee, and elbow in addition to greater shoulder flexion and abduction at take-off when compared to the group with lower attack height (Hsieh, 2019). The CoM location is simply based on the distribution of the segment weights. If the hitter takes-off farther away from the ball location, they might need to adjust their feet position to have a better take-off angle toward the ball. It was observed that some of the athletes took off with feet staggered to adjust their jump with respect to the ball

location (Hsieh, 2019). It is unclear if the feet positioning (inter-ankle distance) at take-off for front row hitting may influence the take-off height. With both feet staggered (farther apart) and take-off in an angle toward the ball may influence the CoM height at take-off. Therefore, the purposes of this study were to examine and verify 1) the group with higher normalised attacked height would have higher CoM take-off height when compare to the group with lower normalised attack height, 2) the effect of the feet position (inter-ankle distance) and 3) take-off location with respect to the ball on the take-off height for the front row hitting between high and low performers. The findings could provide further crucial kinematics variables allowing coaches and athletes to visually improve and enhance their performance**.** It was hypothesized that the players who had greater inter-ankle distance and horizontal distance between CoM take-off and ball impact locations would have lower CoM take-off height.

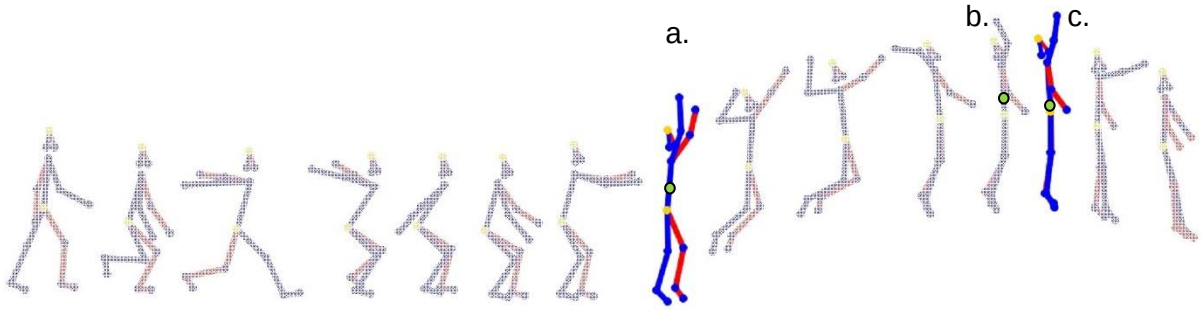

Figure 1 represents a volleyball attack jump where a. is the instant of take-off, b. is the peak of the jump, and c. is the instant of the ball impact. Overall attack height is the vertical wrist height at the instant of ball impact (c.) that consists of CoM take-off vertical height at a., CoM flight vertical height from a. to b., CoM loss height between b. and c., and wrist reach height (vertical distance from CoM to hitting wrist).

METHODS: Due to the pandemic, any contact with human subjects for research purposes was prohibited by the IRB board on campus. Therefore, the data was obtained via a retrospective review of the sixteen male club volleyball players' attack performance, which was approved by the campus IRB board. Ten outside attackers between the ages of 18-23 (Body Height: 1.83 ± 0.07m; Body Mass: 79.13 ± 12.22kg) were selected for analysis. These subjects had an average of seven years of experience (± 2.88 yrs.) in practicing and competing in volleyball. No previous or current injuries were reported at the time of data collection.

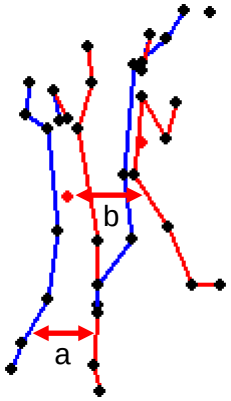

Figure 2 represents the instant of take-off and ball impact; a and b represent the inter-ankle distance and the horizontal distance between take-off and the ball impact, respectively (blue is the right side of the body).

The data was collected during the team attack practice drill in which the ball was tossed by an experienced coach for the front row outside attack. Three digital cameras (Cannon Zr950, 60Hz) were synchronized by the Remote Audio Synchronization Unit in conjunction with a motion analysis system (Motus: 10.0) to obtain 3D coordinates. A model using 19 points

composed of 14 segments was used (Churchill, Salo, & Trewartha, 2015; Colyer, Evans, Cosker, & Salo, 2018). Anthropometric parameters from deLeva (1996) were adapted for CoM calculation. To obtain linear kinematics from both sides of the body, all trials were cropped from the 10th frame before take-off to the 10th frame after initial ball contact. All landmarks were manually digitized. The coordinate data were filtered using quantic spline processing (Winter, 1990; Woltring, 1986). The resultant inter-ankle distance at take-off (distance a in Figure 2) and the horizontal distance between CoM location from the instant of take-off to the ball contact were calculated (distance b in Figure 2).

Based on the normalised attack height, all ten outside hitters were further categorized into groups with higher (HA, n = 5) and lower (LA, n = 5) attack height for comparison. All lengths were normalised to the subject's body height (BH) for comparison except the CoM horizontal distance to the ball location. A total of 30 trials were analysed. To compare the difference between high attack (HA) and low attack (LA), the independent t-test was performed. The statistical assumptions were checked for normality and equal variance. Holm's correction was used to control Type I error and the effect size was calculated due to the small sample size.

RESULTS: The results showed that the HA group had a significantly higher take-off CoM height than the LA group ($p < 0.01$) with an effect size of 1.24. The only significant difference was the inter-ankle distance ($p < 0.05$) with an effect size of 0.74. There was no significant difference in the CoM horizontal distance from take-off to the ball impact ($p = 0.12$). Table 1 shows the means and standard deviations of the comparison between HA and LA groups.

Table 1: Normalised distances (% of BH) between HA and LA groups

	Take-off Ht%	Inter-Ankle Dist%	CoM Horizontal Dist (m)
HA	0.80 ± 0.04	0.26 ± 0.08	0.65 ± 0.21
LA	0.65 ± 0.20	0.19 ± 0.12	0.57 ± 0.09
ES	1.24*	0.74*	0.51

Note: ** represents $p < 0.01$; * represents $p < 0.05$

DISCUSSION: After separating the outside hitters into top (HA) and bottom (LA) half of groups based on their normalised overall attack height, the current study verifies that HA group had significantly higher normalised take-off height by about 15% of body height than LA group. The HA group demonstrated significantly higher inter-ankle distance at take-off indicating that these players had their feet farther apart at take-off. This implies that the position of the lower extremities for the staggered feet did not influence the distribution of the segment weights to lower the CoM height at take-off. Although the inter-ankle distance did not influence the CoM height at take-off, it is an important factor related to volleyball attack jump performance. Studies have found a positive association between approach velocity and jump (flight) height (i.e., Wagner, Tilp, von Duvillard, & Mueller, 2009). Due to a greater horizontal approach velocity, the players were required to take a bigger last step to slow down horizontally and change the direction of motion to jump upward (Fuchs et al., 2019). This last step at take-off facilitates the transition of the horizontal approach to vertical jump performance which contributes to the flight height components. It also explains the importance of this staggered feet position for the front row attack so that the hitter would not jump forward too much in the front row. Cheng and Huang (2008) compared front to back row volleyball attacks and found that back row attack had greater flight height and CoM horizontal distance after take-off when compared to the front row attack. The HA group had about 14% more CoM horizontal distance after take-off in this study, which may be one factor explaining why the HA group had greater overall attack height. In summary, the inter-ankle distance and the CoM horizontal distance to the ball impact did not have a negative effect on the CoM height at take-off. To enhance jump height, it is suggested that the players take an approach further behind the ball impact location with greater approach velocity and inter-ankle distance to efficiently conserve part of the horizontal momentum and

convert it to the vertical direction of the jump performance. Studies have shown this process would benefit the flight height (Fuchs et al., 2019 & 2021). Although the inter-ankle distance at take-off and the CoM horizontal distance did not lower the CoM take-off height, it remains unclear regarding the technique to enhance the biggest contributor of the overall attack height, take-off height. The limitations of the current study are but not limited to 1) retrospective review of the available data from the previous studies, 2) small sample size may have influence the statistical analysis, 3) the data were collected during the practice drills, not during a real game, and 4) the ball tossed by the coach may have different influence on attack height.

CONCLUSION: The current study found that the HA group had greater inter-ankle distance at take-off than the LA group, and there was no significant difference in the CoM horizontal distance to the ball impact location between the two groups. The CoM height at take-off was not influenced by these two factors.

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