JOINT ANGULAR POSITIONS THAT INFLUENCE VOLLEYBALL ATTACK HEIGHT IN MEN'S PLAYERS

ChengTu Hsieh

California State University, Chico, USA

The aim of this study was to identify the angular position differences between high (HP) and low (LP) men's volleyball performers at the instant of take-off and ball impact. Ten skilled collegiate men's volleyball players were recruited from the university club team. All joint angular positions were obtained via 3D motion analysis. Results indicated that the HP players had greater normalized CoM ($p < 0.004$) and reach height ($p < 0.004$) at the instant of take-off and ball impact than the LP players, respectively. At the instant of take-off, HP players had a greater extension at hips, right knee, right elbow, left shoulder (flexion), and right shoulder (abduction) than LP players ($p < 0.004$). At the instant of ball impact, the HP players demonstrated greater right elbow extension, right ankle plantar flexion, right shoulder abduction, and smaller left shoulder flexion than the LP players ($p < 0.004$).

KEYWORDS: 3D motion analysis, angular kinematics, jumping technique

INTRODUCTION: In men's volleyball, the attack is an essential skill to master which can determine the outcome of a match (Rodriguez-Ruiz et al., 2011; Ziv & Lidor, 2010). Attack height can provide a wide range of attack angles which results in the higher success rate of an attack (Abendroth-Smith & Kras, 1999). Anecdotally, attack height is one of the indicators used by coaches to recruit and assess young players and their training outcomes, respectively. Attack height is also considered to be essential data and is shared on the official volleyball game website (FIVB, 2018). Due to its importance, studies have focused on the enhancement of jumping ability from many different approaches to improve attack height such as plyometric training (e.g. Newton, Kraemer, & Häkkinen, 1999). However, this vast body of biomechanical studies quantifying jump height via the center of mass (CoM), from take-off to the peak, that is merely a part of overall attack height of this complex performance. Furthermore, there are only a hand full of studies examining the components of overall attack height (Matušov, Zapletalová, Duchoslav, & Hagara, 2013; Hsieh & Lamm, 2015; Vint & Hinrichs, 2004).

When overall attack height is examined, jump height only represents the vertical displacement of CoM from the instant of take-off to the peak of projectile motion. It does not signify how high a player can reach. Based on a deterministic model, Vint and Hinrichs (2004) identified a total of four components of vertical displacement that represent overall attack height for elite women's volleyball players. Those vertical displacement components are take-off height, flight height, reach height, and loss height. Vint and Hinrichs (2004) found that reach height (r = 0.70) and loss height (r = -0.47) were significantly associated with and accounted for 39.40% and -0.61% of overall ball contact height in female volleyball players, respectively. Take-off height accounted for 47.34% of overall ball contact height but had no significant relationship with ball contact height. More interestingly, jump height was not related to overall ball contact height and only accounted 14% of overall ball contact height. Hsieh and Lamm (2015) had similar findings with male volleyball players when all the components were normalized to body height. The only two components that were significantly associated with overall ball contact height were take-off (r = 0.80) and reach heights (r = 0.78), which accounted for 49% and 37% of the overall ball contact height, respectively. The jump height had no significant association with overall attack height and no difference between HP and LP players. It accounted for 14% of the ball contact height as Vint and Hinrichs's study (2004) for female elite volleyball players. The ability of jumping has been considered as an essential element for volleyball attack performance for many studies (e.g. Abendroth-Smith & Kras, 1999). However, this is based on the assumption that body posture/segments are the same from take-off to the peak of the jump. In fact, it was found that junior female volleyball players had significantly higher variability of overall ball attack height than senior female volleyball players (Matušov et al., 2013). Although studies identified the contribution of vertical components for overall attack height and variability difference between age levels, there is limited information to further apply these findings to improve attack height for volleyball players. Therefore, the purpose of this current study was to examine angular positions of body joints that may influence CoM height for volleyball attack performance at both instants of take-off and ball contact (Figure 1). In addition, the differences of joint angular positions were compared between HP and LP at these two instants.

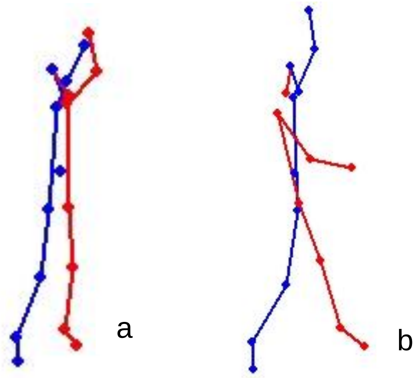

Figure 1: (a) represents the instant of take-off; (b) represents the instant of ball impact (blue is the right side of the body)

METHODS: Ten male university volleyball club team players were recruited (BH: 1.82 ± 0.09m; BM: 80.13 ± 13.22kg). All subjects had experience of playing volleyball competitively for an average of seven years. The positions of these players on the team were either outside or middle attackers. All subjects were right-handed and took-off with both feet staggered (left side in the front). No physical injury was reported during the past six months or during the data collection. All policies and procedures were followed and approved by the university's Institutional Review Board.

The data were collected in a regular hitting drill during the practice of which an experienced coach tossed the ball to the hitting zone for each hitter. Three-dimensional coordinate data were obtained with three digital video cameras (60Hz) in conjunction with a motion analysis system (Vicon Motus: 10.0) and synchronized by using the Remote Audio Synchronization Unit. Three digital cameras were set up 120 degrees from each other focusing on the volume analysed. A model using 19 points composed of 14 segments was used. Anthropometric parameters from deLeva (1996) were adapted for CoM calculation.

Each subject started with the regular team warmup routine, which included jogging and dynamic stretching for 5 to 10 minutes. After warmup, all subjects practiced hitting balls that were tossed by the coach in front of the camera until they were comfortable for data collection. A good trial consisted of a good toss in the volume analyzed one meter away from the net as well as the subject hitting the ball within the boundary toward the requested area. All participants were requested to hit the ball directly toward where they were facing when they took off (i.e., no cutting or changing the direction of the hit). The coach also provided feedback to determine a good or bad hit. A total of ten maximal effort good hit were collected and three good trials from each subject were selected for further analysis by the coach.

In order to obtain angular kinematics from both sides of the body, all the 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 local coordinate system was used at each joint to determine the flexion/extension and ab/adduction of the joint. All joint and segment angles were reported at both instants of take-off and ball contact. To compare HP and LP volleyball players, all ten subjects were separated into two groups based on their normalized overall attack height. Top five were identified as HP group and the rest were LP group. Take-off height was defined as the vertical height of CoM at the instant of take-off. Reach height was the vertical distance between locations of CoM and hitting wrist at the instance of ball contact. All distances were normalized to the subject's body height for comparison. Independent t-tests were applied to examine the difference of all angular components between Hp and LP players. To control Type I error, the Holm's correction was performed to calculate new statistical significance level. The effect size was also calculated due to a small number of subjects (Cohen, 1988).

RESULTS: At the instant of take-off, the HP group had significantly greater normalized CoM height than the LP group ($p < 0.004$) with an effect size of 0.97. At this instant, seven out of the twelve angular positions displayed a significant difference. Those were right hip, right knee, right ankle, right elbow, right shoulder, left hip, and left shoulder ($p < 0.004$, Table 1).
At the instant of ball impact, the HP group had significantly greater normalized reach height than the LP group ($p < 0.004$) with an effect size of 0.78. At this instant, four out of the twelve angular positions had a significant difference. Those were the right ankle, right elbow, right shoulder, and left shoulder ($p < 0.004$, Table 2).

Table 1: Angular positions at take-off (L & R represents left and right, respectively)

	R Ankle	R Knee	R Hip	R Elbow	R Shoulder (Ab/Ad)	L Hip	L Shoulder (Flex/Ext)
HP	127.25±24.87	162.4±7.79	167.82±6.85	119.84±30.3	130.16±23.5	171.94±3.84	148.84±15.75
LP	146.46±17.45	152.52±12.69	163.05±5.43	82.2±28.82	111.22±24.34	165.40±10.12	129.46±22.17
ES	-0.91	0.96	0.78	1.27	0.79	0.94	1.02

Table 2: Angular positions at the instant of ball impact

	R Ankle	R Elbow	R Shoulder (Ab/Ad)	L Shoulder (Flex/Ext)
HP	146.71±7.5	142.29±20.2	152.7±9.04	6.69±20.5
LP	130.81±14.33	116.42±15.26	124.11±33.81	22.53±23.72
ES	1.46	1.46	1.33	-0.72

DISCUSSION: Hsieh and Lamm (2015) previously identified two deterministic factors, take-off and reach heights, that were positively associated with overall ball attack height for men's volleyball players. The current study found that the HP players had significantly greater normalized CoM and reach heights than the LP players ($p < 0.004$) at the instant of take-off and the ball contact, respectively. To follow up, HP and LP men's volleyball players had significant differences in seven and four angular positions at the instant of take-off and ball contact, respectively. At the instant of take-off, all players took-off with both feet staggered and left side in the front. Among these seven angular positions at the instant of take-off, five of them are on the right side of the body. For lower extremities, the HP players were able to extend both of their hips farther than the LP players in addition to the right knee (Table 1) which resulted in greater CoM height at take-off for HP players. However, the LP group had greater ankle plantar flexion than the HP group at this instant. The difference of angular positions at the lower extremities between these two groups of players may be attributed to the distance between feet at the instant of take-off (how close the feet were staggered). It was possible that the HP group had both of their feet staggered closer to each other where the LP group had their feet apart farther. This might have helped the HP group to extend both sides of their joints at the lower extremities during the propulsive phase of the jump. In order to jump toward the ball in the air, the staggered feet could provide better control of the jumping direction with respect to the location of the ball in the air. This also may explain why the LP players might not be able to determine the proper location to take-off because these players seem to need a wider stance to control the direction of the jump based on the trajectory of the ball tossed by the coach. Of course, this warrants further study to examine the effect of stance width on jumping performance of a volleyball attack. Additionally, the angular position at upper extremities also explains why the HP group had greater normalized take-off height at CoM than the LP group. The HP players had greater the left shoulder flexion and abduction than LP players at the instant of take-off. This represents that the HP players were able to raise their left arm higher than the LP players. One interesting finding was that the LP players had greater right elbow flexion than the HP players. Combined with the right shoulder difference, this represents that the LP players started their bow and arrow position earlier than the HP players, which may lower the CoM height at the instant of take-off.

Reach height was determined as the vertical distance from the location of CoM to the right wrist at the instant of the ball contact (Vint & Hinrichs, 2004). To achieve greater reach height, a player needed to have higher ball contact height meanwhile have lower CoM at this instant. The current study found that the HP players demonstrated greater shoulder abduction and elbow extension for the right arm (Table 2). This represented that the HP players were able to reach higher than the LP players with their attacking arm. Meanwhile, the HP players were able to have smaller shoulder flexion angle than the LP players for the non-attacking arm which may help to lower the CoM location more than LP players did. These differences might be attributed to the timing of the overall performance. That said, at the moment of the ball contact, the LP players had to hit the ball at a lower position of the ball trajectory when tossed by the coach. This suggested that the LP players may need to start their approach earlier to catch the ball at a higher position of the trajectory. However, the timing of the performance can be complicated since it depends on multiple factors such as the height of ball toss, player's approach distance, and velocity of the approach.

The limitations of the present study are 1) small sample size, 2) hitting direction is not controlled, and 3) even though the coach is experienced, the ball tossed height can vary from trial to trial. Suggestions for the future study are to examine the coordination between the ball height and overall performance timing including the width of staggered feet.

CONCLUSION: The current study identified several different angular postures between HP and LP men's volleyball that contributed to the overall attack height at two different instants of the performance, take-off and ball impact. At the instant of take-off, the HP players were able to raise all the body segment higher than LP players. In contrast, the LP players seemed to start the bow and arrow position earlier than HP players. This, together, may result in greater CoM height at take-off for HP players. At the instant of ball impact, the HP players demonstrated the ability to hit the ball higher with hitting arm more abducted at the shoulder and extended at the elbow in addition to the less shoulder flexion of the non-hitting arm which may result in greater reach height at the instant of ball impact.

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