BIOMECHANICAL STUDY OF MID-FLIGHT BODY SEGMENT ACTION AND ITS EFFECT ON HANG-TIME FOR VOLLEYBALL SPIKE JUMPS

Dhruv Gupta, Jody Jensen and Lawrence Abraham

Department of Kinesiology and Health Education, The University of Texas at Austin, Austin, Texas, United States of America

This study examined pilot data exploring approaches to testing whether the existing explanation about the biomechanics of hang-time in a basketball jump shot proposed by Bishop and Hay (1979) is applicable for spike jumps in volleyball and to identifying possible additional factors that could have an influence on hang-time in volleyball. Kinematics of spike jumps of volleyball players (n=3) using a technique that would theoretically increase hang-time were compared to jumps using a technique that would theoretically decrease it. The results suggested that the mechanisms creating hang-time in volleyball spike jumps are not the same as those in a basketball jump shot. These results suggested that the leg contributions are different and that the motion of the trunk also contributes to hang-time.

KEY WORDS: “hang”, hang-time, center of mass, knee flexion, volleyball

INTRODUCTION: In volleyball, hitting spikes is the primary way of scoring points and winning. Great extensor physical strength is required to jump high enough to clear the block and to hit the ball hard enough to avoid defensive players. But extensor physical strength is only important when the athlete is on the ground and pushes against it in order to jump high. Once the athlete is in the air, movement of the athlete’s body segments is what determines the success of the performance. The only major force on the body while the athlete is in flight is gravity. This means that the center of mass of the athlete follows a parabolic trajectory governed by Newton’s laws and so motion of the segments of the body interact with each other. By voluntarily controlling the motion of certain segments, the athlete also affects the motion of other segments, which can potentially enhance performance.

This paper examines the concept commonly known as hang-time, which is a short period of time at the top of a jump when an athlete appears to neither rise nor fall. Bishop and Hay (1979) explained this concept for a basketball jump shot. Essentially, the athlete flexes and then extends his/her knees mid-flight, which causes the center of mass (COM) to rise and then drop within the athlete’s trunk. This results in reduced vertical motion of the athlete’s head and trunk, although the center of mass continues to follow the same parabolic trajectory. The flattened path of the head and trunk is perceived as “hang”. Ideally, there is knee flexion before the peak of the whole body COM and knee extension after the peak of whole body COM; both of which are important for “hang“ because the knee flexion before the peak raises the lower leg segments, which reduces the upward motion of the head, while the knee extension after the peak lowers the lower leg segments, ensuring that the head rises relative to the center of mass and so does not follow its downward trajectory. Hence, for a longer hang-time, one would raise the lower leg segments more before the peak of whole body COM and lower them again after the peak of the whole body COM trajectory. In volleyball, if this technique enables an athlete’s head to remain at a constant height for an extended period of time, the benefits may include more time to adjust to the set and also a better view of the opponents to assist in deciding how and where to hit. This aspect of a spike jump has not been studied previously and could potentially affect performance greatly.

This report describes a pilot study to test the applicability of the theory just mentioned to volleyball and to determine other factors that could be important in understanding “hang“ in volleyball. Future work will focus on methods by which volleyball athletes can control their “hang“ optimally in order to enhance their performance.

METHODS: Three players from a university men’s volleyball team participated in the study. With shoes, their heights were 1.890m, 1.886m and 1.797m and masses were 65kg, 83kg and 67kg, respectively. Each player was asked to perform 5 trials of each of three different jumping styles for hitting. First was their natural jumping style; in the second style, they were asked to flex their knees as much as possible during flight; and in the third style they were asked not to flex their knees at all during flight. Based on the theory described above, we hypothesized that the time of “hang“ or the hang-time would be the highest for the knee flexion condition and lowest for the no knee flexion condition. Data analysis focused primarily on those two jump styles. In all the jumps, the instruction was to “Jump as high as possible and swing high and fast just as you would do in a game”, though no ball was actually being hit. To simulate a game environment, athletes were asked to warm up before data collection and a wire at the standard volleyball net height (243 cm) was also tied across the motion capture laboratory. A Vicon motion capture system was used for data collection. The software Vicon Nexus 1.6.1 with an inbuilt template for motion capture was used. 39 passive markers were placed at different anatomical locations on the body. The motion capture system captured the 3D position of each marker at a sampling rate of 120 Hz and the template generated a human body model using the marker data and some anatomical data of the participant. Outputs included the 3D position data of all markers, 3D position of joint centers (the model calculated the location of joint centers and fit bones into the body model) and the 3D angles between all adjacent bones.

To calculate the hang-time, the vertical velocity of the mean trajectory of the head markers was determined and normalized to the height of the athlete. The hang-time was defined as the time for which the absolute value of this vertical velocity was less than 0.005m/s. This value was chosen because it yielded the greatest difference in hang-time between the knees flexed and the no knee flexion conditions. The trajectories of the whole body COM and of the COM of the legs were also calculated using the segmental method based on Zatsiorsky’s model adjusted by de Leva (1996).

RESULTS: All data were normalized to allow comparisons between participants. Unless otherwise mentioned, position data were normalized to the height of the participant and time data were normalized to the flight time, such that when the participant left the ground, the time was 0% and when he touched the ground again, the time was 100%. In order to test our hypothesis, the mean hang-time for each of the jump styles for each participant was calculated and the values compared. Table 1 displays these values. Table 1 also displays the mean difference in the maximum knee flexion angle between these two styles.

Table 1
Mean hang-time and mean normalized hang-time (averaged across all trials in the condition)

	Hang-time(sec) (normalized hang time (% flight-time))		
Participant	knees flexed	no knee flexion	Difference in max knee flexion
1	0.27 (40.69)	0.17 (25.02)	121.11
2	0.30 (41.88)	0.30 (41.63)	121.95
3	0.28 (37.77)	0.20 (27.22)	125.70

There was a large mean difference in the maximum knee flexion angle between the 2 styles for all three participants, however, a difference in hang-time between the two conditions was observed only in participants 1 and 3. One possible factor could be that participant 2 did not time the knee flexion correctly, that is, to begin before the peak of whole body COM. The motion sequences also revealed that participant 2, in all hitting styles, flexed at his hips as he swung his arm. This helped him generate higher angular momentum in the arm, based on the conservation of angular momentum and the absence of external torque. This hip flexion caused a rotation of the legs at the hips, which involves much more mass than the lower leg. For this reason, in volleyball, it becomes important to study the trajectory of the COM of the legs instead of just studying the knee flexion angle. Table 2 displays the normalized peak elevation of the legs COM, the normalized time at which this peak occurred, and the ratio of the peak of legs COM to the whole body COM height at that time. This ratio eliminates actual jump height (and time) as factors.

Table 2
Legs COM compared to whole body COM when legs COM reaches peak (averaged across all trials in the condition)

Participant	Normalized legs COM max (%body height)		Normalized time of legs COM reaching max (% flight-time)		Ratio of legs COM to whole body COM at max legs COM	
	knees flexed	no knee flexion	knees flexed	no knee flexion	knees flexed	no knee flexion
1	0.28	0.27	50.61	49.68	0.31	0.29
2	0.33	0.32	49.99	53.02	0.33	0.33
3	0.33	0.31	45.91	56.53	0.32	0.31

DISCUSSION: Table 2 shows that across the two styles, participant 2 had the same ratio of maximum rise in Legs COM to the whole body COM (0.33 and 0.33) and at approximately same normalized times (49.99 and 53.02). Note that in Table 1 participant 2 did not show a larger hang-time for the knee flexion condition compared to the no knee flexion condition. This can be attributed to the great amount of hip flexion he had for both styles; essentially making the movement of the legs at the hips, which are heavy, very similar for both styles, even though the movement of lower legs, which are much lighter, was very different. For the same reason, results in Table 2 fail to explain why we observed greater hang-time in the knee flexion condition compared to the no knee flexion condition for participant 1. Across the two styles, he also had approximately the same ratio of maximum rise in legs COM to whole body COM (0.31 and 0.29) and at approximately the same times (50.61 and 49.68). This could be because participant 1 had a very lean body structure with BMI of only 18.2; and so the standard tables used for calculation of COM using the segmental method might not be valid and the results obtained might not be a correct representation of the motion. For participant 3, although the ratio of the maximum of legs COM to the whole body COM in the two styles was again approximately the same (0.32 and 0.31), the time of peak of legs COM differed greatly between the two styles (45.91 for the knee flexion style and 56.53 for the no knee flexion style). Clearly, in the knee flexion condition, the legs COM attained its maximum before the whole body COM reached its peak, which would increase hang-time. Also, in the no knee flexion condition, the legs COM attained its maximum after the whole body COM reached its peak, which would reduce hang-time. Hence Table 2 does explain why participant 3 had higher hang-time in the knee flexion style compared to the no knee flexion style.

Since the data in Table 2 only partially explained the phenomenon of “hang”, the theory explored was found incomplete and other factors that might influence “hang” were considered. These efforts revealed that the periods for which athlete 3 exhibited “hang” were instructive. Within athlete 3’s four analyzable trials in the knee flexion style, there were some differences that suggested additional factors affecting hang-time generation. Table 3 shows some results for participant 3.

Table 3
Knee flexion style jump data for participant 3

Trial	Normalized hang-time	Start of "Hang"	End on "Hang"	Ratio of legs COM to whole body COM at max legs COM	Normalized time of legs COM reaching max
1	32.22	30.00	62.22	0.32	44.44
2	29.41	31.82	60.23	0.32	46.59
3	47.13	27.59	74.71	0.32	44.83
4	43.33	31.11	74.44	0.32	47.78

The results in Table 3 show that for participant 3's knee flexion hitting style, the hang-time was less for the first 2 trials and higher for the last 2 trials, even though the ratio of maximum of legs COM relative to whole body COM and also the time at which legs COM reached maximum were very similar across all 4 trials. This result shakes the very foundation of the original theoretical analysis and revealed the incomplete nature of this theory. The data in Table 3 suggest that something was happening in the 60 to 70% flight-time range that extended the hang-time for trials 3 and 4. Figure 1 displays these results for trials 2 and 3. One explanation consistent with these results is that the trunk flexed more in the first two trials compared to the last two during this 60 to 70% flight-time range. Since the trunk includes a large mass relative to the whole body, its motion affects the motion of other body parts and hence it seems that it could be an important factor that deserves additional study.

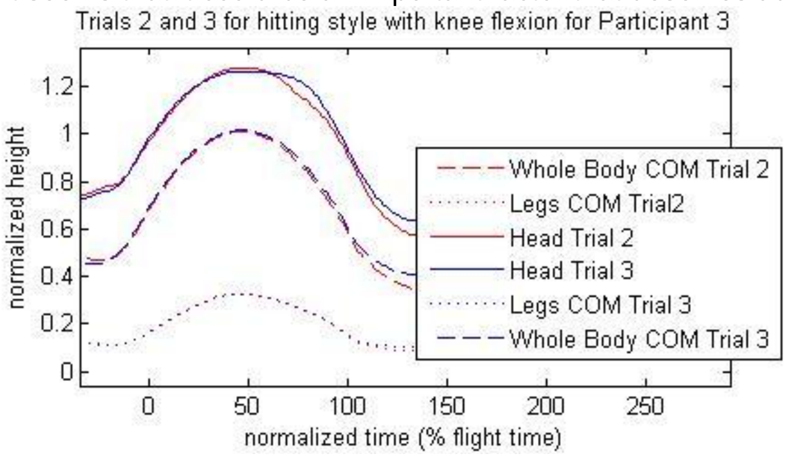

Figure 1: Important trajectories for participant 3 in knee flexion style

CONCLUSION: This study tested theory proposed by Bishop and Hay (1979) for basketball to explain the phenomenon of "hang" in volleyball. That theory did not fully explain the data collected in volleyball. Motion of the lower limbs during volleyball spiking did not completely explain "hang". It appeared that the motion of the trunk might also be an important factor that affects hang-time. The reason the previous theory by Bishop and Hay (1979) failed in volleyball is probably that a volleyball spike is a much more dynamic movement compared to a basketball jump shot, particularly considering the amount of upper body motion and arm swing. Further investigation is needed in order to completely understand "hang" in volleyball and how athletes can control it and use it to their advantage. An IRB approved full study is currently underway at The University of Texas at Austin to investigate this question.

REFERENCES:

Bishop, R. D., & Hay, J. G. (1979). Basketball: the mechanics of hanging in the air. *Medicine and science in sports, 11*(3), 274-277

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230. doi: http://dx.doi.org/10.1016/0021-9290(95)00178-6