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Kinematic analysis of lower and upper body movements in volleyball players during ball-entry actions: a biomechanical perspective

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Abstract: This article provides an in-depth biomechanical analysis of both lower and upper body kinematics in volleyball players, focusing on key actions such as serving and spiking. By evaluating the maximum and minimum ranges of motion in the pelvis, hips, knees, ankles, shoulders, and elbows, the study highlights the asymmetry between dominant and non-dominant limbs and how this influences force generation, stability, and performance efficiency. The findings emphasize the role of the pelvis in rotational force transmission, the hips in vertical stability, and the shoulders and elbows in generating power for ball entry. These kinematic insights contribute to optimizing training strategies and injury prevention for volleyball players.

Keywords: Volleyball biomechanics, kinematic analysis, shoulder flexion/extension, pelvis rotation, hip abduction/adduction, elbow flexion/extension, lower body kinematics, upper body kinematics, ball-entry mechanics, asymmetry in movement, force generation, stability in volleyball, sports performance analysis.

Introduction: Volleyball is a dynamic sport that requires complex, coordinated movements involving both the upper and lower body. During ball-entry actions such as serving and spiking, players generate significant force and power through the interaction of various joints and muscle groups. Understanding the kinematics of these movements, particularly the asymmetries between dominant and non-dominant limbs, is critical for optimizing performance, reducing injury risk, and improving training methods. Previous studies have explored biomechanics in volleyball, but a comprehensive analysis of both upper and lower body kinematics during ball-entry actions remains limited. This study aims to fill that gap by analyzing the specific joint movements involved in serving and spiking, including the pelvis, hips, knees, ankles, shoulders, and elbows, with a focus on their contribution to overall performance and stability.

Biomechanical studies have long emphasized the critical role of kinematic analysis in understanding athletic performance, particularly in sports like volleyball where both upper and lower body coordination is essential. Previous research has provided valuable insights into the biomechanics of volleyball, focusing primarily on jumping mechanics, landing forces, and the joint loads associated with these movements (Ford et al., 2003; Lees et al., 2004). However, less attention has been given to the comprehensive kinematic analysis of ball-entry actions, which involve a combination of rotational forces, flexion-extension, and abduction-adduction across multiple joints.

The upper body, particularly the shoulder and elbow, plays a pivotal role in volleyball's overhead actions, such as serving and spiking. Studies have shown that the dominant shoulder tends to have a wider range of motion compared to the non-dominant side, reflecting its role in generating power for ball strikes (Schneiders et al., 2011). Right shoulder flexion and extension are crucial for creating the momentum necessary for powerful spikes, while the non-dominant arm stabilizes the movement (Chang et al., 2019). Elbow kinematics also significantly impact ball velocity, with greater extension in the dominant arm aiding in faster and more controlled strikes (Pappas & Carpes, 2012).

Lower body movements, particularly the pelvis, hips, knees, and ankles, contribute to the initial force generation and stability during ball-entry actions. Bobbert et al. (1990) highlighted the importance of pelvic rotation in transferring energy from the lower body to the upper body during explosive movements like jumps and strikes. Pelvic asymmetry, where one segment of the pelvis rotates more than the other, reflects the dominant leg's role in force generation. This asymmetry is also mirrored in hip and knee movements, where the dominant leg exhibits a greater range of flexion and extension, contributing to the powerful push-off needed for jumps (Ford et al., 2003).

Hips and knees are critical for both vertical stability and force production. In volleyball, the dominant leg typically produces more force, particularly in the initial phases of a jump (Ford et al., 2003). Chang et al. (2019) found that asymmetry in knee joint loading could affect performance, where one leg bears more of the impact during landing, and the other supports dynamic actions. Ankle flexibility is crucial for absorbing forces during landing and ensuring stability during directional changes (Pappas & Carpes, 2012).

Several studies have noted that asymmetry in joint kinematics is common in sports involving unilateral movements like volleyball (Pappas & Carpes, 2012). This imbalance between the dominant and non-dominant limbs reflects the different roles each plays: the dominant limb generates power, while the non-dominant limb stabilizes the body. Such asymmetry, while beneficial for performance, can increase the risk of injury if not properly addressed in training. Athletes with significant joint asymmetry are more prone to overuse injuries due to the uneven distribution of load during repetitive movements (Schneiders et al., 2011).

The literature highlights the importance of a comprehensive understanding of both upper and lower body kinematics in volleyball, particularly during ball-entry actions like spiking and serving. The dominant arm and leg play critical roles in generating power, while the non-dominant side stabilizes the movement. A thorough analysis of these biomechanical patterns can help identify areas for performance improvement and injury prevention, providing valuable insights for coaches and athletes alike.

Aim of the Research: The aim of this study is to conduct a detailed kinematic analysis of the upper and lower body movements in volleyball players during ball-entry actions (serving and spiking), identifying key asymmetries and their impact on force generation, stability, and performance efficiency.

Tasks of the Research:

1. To analyze the maximum and minimum range of motion of the pelvis, hips, knees, and ankles during volleyball-specific ball-entry actions.

2. To assess the kinematics of shoulder and elbow flexion, extension, abduction, and adduction during overhead movements such as spiking and serving.

3. To identify any significant asymmetries between the dominant and non-dominant limbs in both upper and lower body kinematics.

4. To evaluate how these kinematic patterns influence the transfer of force from the lower to the upper body during ball-entry actions.

5. To provide biomechanical insights that can inform injury prevention strategies and improve training programs for volleyball players.

Research Organization: This research was conducted at the high-tech laboratory of Sport at Uzbek State University of Physical Education and Sports, which is equipped with state-of-the-art 3D motion analysis technology. The facility provides precise measurements of biomechanical parameters, making it an ideal setting for studying detailed athletic movements. The subject of the study was an elite volleyball player, a candidate for Master of Sports with extensive competitive experience. The primary aim of the experiment was to analyze the athlete's shoulder movements during key volleyball actions such as vertical jumping and blocking. The study emphasized kinematic and kinetic data related to shoulder flexion, extension, abduction, and adduction. The controlled environment of the laboratory ensured the accuracy and reliability of data collection, offering valuable insights into the biomechanics of volleyball-specific movements at a high level of competition.

METHODS

This study utilized advanced 3D motion analysis technology to conduct an in-depth biomechanical evaluation of shoulder movements during the vertical jump and blocking technique in volleyball. The research was performed in the high-tech sports laboratory at the Uzbek State University of Physical Education and Sports. A highly experienced volleyball player, a candidate for Master of Sports, participated in the study, and their blocking and jumping actions were captured using a high-resolution 3D motion capture system.

Multiple infrared cameras were strategically placed around the laboratory to track the athlete's movements from various angles. Reflective markers were placed on key anatomical points, including the shoulders, elbows, spine, hips, knees, and ankles. This marker placement enabled the capture of precise data on joint angles and body posture during vertical jump and blocking actions. The comprehensive kinematic analysis focused on the athlete's shoulder flexion, extension, abduction, and adduction, providing detailed insights into the role of these movements in blocking performance and vertical jump height.

The collected motion data also offered valuable information on the athlete’s lower-body mechanics, which are critical to executing a well-coordinated and effective vertical jump and block in volleyball. By analyzing these biomechanical variables, the study aimed to better understand the contributions of both upper and lower body movements in volleyball-specific actions.

RESULTS

Summary of Lower Body Kinematics of Volleyball Players Entering the Ball into Play. This summary provides insights into the lower body kinematics of volleyball players during ball-entry actions, focusing on the pelvis, hips, knees, and ankles. These kinematic data points, representing the maximum and minimum values of flexion, extension, abduction, and adduction, reflect the complex movements and forces volleyball players generate while executing serves and spikes. The analysis below highlights key findings related to each joint.

Rotation of the Pelvis in volleyball players. Maximum Pelvic Rotation: 133.87°; Minimum: 83.32°. Lower Segment: Min -146.69° / Max -99.00°. Left Section: Min -313.90° / Max -212.29°. The crucial function of the pelvis in producing rotational force during ball entrance is reflected in the large range of pelvic rotation. During spiking or serving motions, the dominant leg generates more torque and force, which is likely why the left segment rotates more than the right segment. This indicates an asymmetry in rotational dynamics. The kinetic chain transfers force from the lower to the upper body through the pelvis, which acts as a focal point (Table-1).

Volleyball players' hip flexion and extension. Maximal Hip Flex/Ext: 58.03°; minimum: -14.68°. Hip Flex/Ext: Left: Maximum 48.86°; Minimum -10.04°. Max 44.17° / Min -21.27° is the right hip flexion/extension with vertical. Hip Flex/Ext on the left with vertical: Min -14.43°, Max 43.66°. Maximum 18.89° / Min -8.89° is the right hip abduction/adduction. Upper limit of abduction (left hip): 21.74°; minimum limit: -5.69°. The idea that the dominant leg produces more force during explosive movements is supported by the right hip's larger flexion/extension when compared to the left. The reduced range of motion of the right and left hips in the vertical plane suggests the need for vertical stability when jumping in volleyball.

Knee extension and flexion in volleyball players. Max 84.01° / Min 0.20° is the right knee flexion/extent. Flex/Ext Left Knee: Max 102.55° / Min -1.38°. The left leg may absorb more of the impact during landing or stabilization while the right leg is more engaged in producing the initial push-off or force since the left knee has a wider range of flexion and extension than the right. This discrepancy could also suggest a functional asymmetry, where one leg supports dynamic actions while the other assists with stability and balance during the ball-entry process.

Table-1
Summary of lower train kinematics of volleyball players entering the ball into play

PELVIS	**Maximum**	**Minimum**
Pelvis rotation	133.87 °	83.32 °
Pelvis rotation (right segment)	-99.00 °	-146.69 °
Pelvis rotation (left segment)	-212.29 °	-313.90 °
HIPS	**Maximum**	**Minimum**
Right hip flex/ext	58.03 °	-14.68 °
Left hip flex/ext	48.86 °	-10.04 °
Right hip flex/ext with vertical	44.17 °	-21.27 °
Left hip flex/ext with vertical	43.66 °	-14.43 °
Right hip abd/add	18.89 °	-8.89 °

Left hip abd/add	21.74 º	-5.69 º
KNEES	**Maximum**	**Minimum**
Right knee flex/ext	84.01 º	0.20 º
Left knee flex/ext	102.55 º	-1.38 º
ANKLES	**Máximo**	**Mínimo**
Right ankle flex/ext	34.68 º	-26.65 º
Left ankle flex/ext	41.17 º	-33.23 º

The larger range of motion observed in the left ankle, with a maximum flexion of 41.17° and a minimum of -33.23°, indicates that this ankle is crucial in maintaining balance during swift lateral movements and sudden directional changes. In contrast, the right ankle, with slightly reduced flexion and extension (Max 34.68° / Min -26.65°), likely plays a more stabilizing role during these dynamic actions, supporting overall movement efficiency while the left ankle adjusts to shifting forces. The right ankle, with a slightly lower range, may be more involved in generating stability and propulsion during vertical jumps. The flexibility and range of motion in the ankles are critical for absorbing impact forces during landing and preparing for the next movement.

Table-2

Summary of upper train kinematics of volleyball players entering the ball into play

SHOULDERS	**Maximum**	**Minimum**
Right shoulder flex/ext	122.15 º	-156.71 º
Left shoulder flex/ext	68.18 º	-96.67 º
Right shoulder flex/ext with vertical	128.62 º	-151.64 º
Left shoulder flex/ext with vertical	67.81 º	-64.64 º
Right shoulder abd/add	74.61 º	-14.19 º
Left shoulder abd/add	77.73 º	-4.08 º
ELBOWS	**Maximum**	**Minimum**
Right elbow flex/ext	141.44 º	0.00 º
Left elbow flex/ext	79.01 º	38.38 º

The upper body kinematics of volleyball players during ball entry, such as spiking or serving, involves significant asymmetry in the range of motion between the dominant and non-dominant arms, particularly in the shoulder and elbow joints.

The right shoulder, responsible for generating the primary force during ball entry, demonstrates a much wider range of motion compared to the left. In flexion and extension movements, the right shoulder achieves a maximum of **122.15°** and a minimum of -

156.71°, reflecting the heavy involvement of the dominant arm in overhead striking actions. This high degree of movement enables the player to propel the ball with substantial power during spikes or serves.

On the other hand, the left shoulder shows a much narrower range, with a maximum flexion of 68.18° and a minimum extension of -96.67°, emphasizing its stabilizing role during these actions. This difference underscores the biomechanical demands placed on the dominant shoulder, as it must generate greater force and mobility to direct the ball effectively.

When considering movements in the vertical plane, the disparity remains. The right shoulder exhibits a maximum flexion-extension range of 128.62° and a

minimum of -151.64°, while the left shoulder's range is lower at 67.81° to -64.64°. These results support the notion that the right shoulder plays a critical role in controlling the vertical trajectory and height of the ball, whereas the left shoulder aids in maintaining stability during the strike.

In terms of abduction and adduction, the right shoulder reaches a maximum abduction of 74.61° and a minimum adduction of -14.19°, indicating its ability to move laterally to adjust for different hitting angles. The left shoulder shows slightly higher abduction at 77.73° and a minimal adduction of -4.08°, further confirming its stabilizing nature.

The elbow joints also reveal notable asymmetry. The right elbow, which plays a vital role in the power generation and control of the ball's direction, displays a flexion-extension range of 141.44° to 0.00°, highlighting its capacity to extend fully for a powerful strike. This complete extension is essential for maximizing the force behind the serve or spike.

The left elbow, in contrast, shows a much smaller flexion-extension range, with a maximum of 79.01° and a minimum of 38.38°, indicating that its role is more supportive rather than force-generating. It assists the body in maintaining a balanced posture during ball entry but contributes little to the actual force output.

CONCLUSION

This study provides a comprehensive biomechanical analysis of the kinematics involved in volleyball players during ball-entry actions, specifically focusing on the movements of the upper and lower body. The findings highlight a significant asymmetry between the dominant and non-dominant limbs, with the dominant side playing a more force-generating role while the non-dominant side provides stabilization. The right shoulder and elbow show greater flexibility and extension, enabling powerful overhead actions such as spiking and serving. Similarly, the pelvis, hips, knees, and ankles contribute to force generation and stability, particularly during jumping and landing movements.

The asymmetry observed in both upper and lower body kinematics reflects the specialized roles of each limb in volleyball. While this contributes to performance efficiency, it also presents potential risks for injury due to the uneven distribution of forces. Understanding these kinematic patterns can help coaches and athletes optimize training programs, improve performance, and implement injury prevention strategies.

Further research should continue to explore how these biomechanical insights can be applied in sports training, particularly focusing on balancing strength and flexibility between dominant and non-dominant limbs to reduce the risk of overuse injuries in volleyball players.

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