Model of handball players' technique for executing a 7-meter penalty throw

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[1]Akramov Jasur Anvarovich

[1]Uzbekistan state university of physical education and sport, Chirchik, Uzbekistan

Abstract

This study presents a detailed biomechanical analysis of the technique for executing a 7-meter penalty throw in handball. 3D motion capture technology enabled in-depth examination of joint angles, maximum angular velocities, displacement of the center of gravity (COG), and spatio-temporal parameters. Results indicate that effective throw execution is based on the sequential activation of the entire kinetic chain - force generated from the legs is transmitted through the pelvis and torso to the shoulder, elbow, and wrist joints. Foot and heel movements play a crucial role in generating thrust and ensuring stability, while torso and neck rotation controls the throw direction. Shoulders and elbows achieve the highest angular velocities, imparting speed and accuracy to the ball. COG displacement ensures dynamic equilibrium and enhances movement stability. Overall, this study demonstrates that successful execution of the 7-meter throw technique depends on strength, balance, proper timing, and precise synchronization of joint movements.

Keywords: Handball, biomechanical analysis, penalty throw, kinetic chain, angular velocity, center of gravity, joint mechanics, throw accuracy, sports technique.

Introduction

Handball is a highly dynamic and physically demanding sport that requires a precise combination of strength, coordination, balance, and technical execution. One of the most crucial elements in attacking play is the 7-meter penalty throw, which is executed under standardized conditions, under high pressure, and often determines the outcome of the game. Unlike throws performed during regular play, a 7-meter throw is executed in a controlled situation. However, a high level of biomechanical efficiency, coordinated movement of body segments, and optimal timing are necessary to ensure maximum power and accuracy.

The technique of the 7-meter throw relies on the coordinated interaction of several biomechanical components - the pushing force of the lower limbs, rotation of the pelvis and torso, upper body kinematics, and precise control of the center of gravity (COG) . The throw begins with establishing a stable base and generating force through the legs and feet, then the rotational momentum of the pelvis and torso transfers energy along the kinetic chain. The shoulders, elbows, and forearms produce the final acceleration, maximizing the ball's velocity and accuracy.

Research in sports biomechanics emphasizes the importance of sequential activation of the kinetic chain in the execution of a shot (Wagner et al., 2010; Rousanoglou et al., 2008). The lower limbs generate the initial impulse and stabilize the movement, while the trunk creates the rotational momentum, and the upper limbs transmit the force to the ball. Furthermore, the shift of the center of gravity plays a crucial role in maintaining postural stability and controlling the direction of the shot (Liu et al., 2019). These findings indicate that the success of a 7-meter throw depends not only on hand strength but also on the synchronization of the entire body movement.

In this study, biomechanical parameters involved in a 7-meter penalty throw - joint kinematics, angular velocities, dynamics of the center of gravity, and spatiotemporal characteristics - are analyzed using 3D motion capture technology. A detailed analysis of these elements provides a deep understanding of how elite handball players optimize one of the most critical movements during the game.

Objective

To analyze the biomechanical properties and movement structure of the 7-meter penalty throw in handball players, focusing on the role of joint kinematics, kinetic chain activation, and the shift of the center of gravity in optimizing the effectiveness of the throw.

Tasks

To study joint angles and their changes during the phases of a penalty throw.

Analyze the contribution of pelvic, torso, and upper limb movements in generating force and accelerating the ball.

Assess the displacement of the center of gravity and its role in maintaining and controlling balance.

Table 1. Gait time parameters of handball players' 7-meter penalty throw technique model

Parameter	Value
Cadence [steps/minute]	205.71 [steps/min]
Flight time	0.09 [s]
Support time	0.36 [s]
Step length	151.16 [mm]
Right foot flight time	0.0000 [s]
Left foot flight time	0.0000 [s]
Right foot support time	5.1541 [s]
Left foot support time	3.9416 [s]

Determine the effectiveness of the kinetic chain in transferring energy from the lower limbs to the ball-throwing arm.

Develop scientifically based recommendations for improving technique, increasing efficiency, and reducing the risk of injuries.

Results and discussion

Analysis of the 7-meter penalty throw time parameters (Table 1) reveals a unique performance profile for this technique, characterized by controlled execution of movement and efficient energy transfer along the kinetic chain. The cadence of 205.71 steps/min is significantly higher than for overhead or side throws, indicating faster execution of the preparatory sequence leading to the release phase. Such a high step frequency underscores the importance of quick yet controlled lower limb movements for generating momentum before the throw and stabilizing the body.

0.09 seconds is very short, indicating that the airborne phase is practically non-existent in the impact process. This characteristic is typical of 7-meter penalty kicks, where the movement is primarily executed from a static or semi-static position, with great emphasis placed on accuracy, stability, and force transfer. 0.36 seconds of ground contact time further confirms this controlled execution - it is during this brief yet crucial contact phase that force is generated and transmitted through the lower limbs to the kinetic chain.

151.16 mm step length indicates a compact and controlled step pattern - this biomechanical adaptation improves balance and ensures optimal body alignment for force direction. The longer support phase of the right leg (5.1541 s) compared to the left (3.9416 s) suggests an asymmetrical load distribution - here, the right leg serves as the primary stabilizing and propulsive support. Such asymmetry is a biomechanical feature observed in most penalty kicks, where the dominant leg supports the kinetic chain, while the non-dominant side participates in directional control and fine-tuning the kick angle.

Generally, the characteristics of time parameters indicate that the 7-meter penalty throw is executed with quick preparatory movements, minimal airborne phase, and effective ground contact mechanics. Such a controlled time profile enhances shot stability, maximizes energy transfer efficiency, and ensures high accuracy - these are the key components necessary for scoring under pressure in competitive handball.

Analysis of the spatial parameters of the 7-meter penalty throw (Table 2) provides important information about body position, impulse control, and force transfer processes during this crucial technical movement.

The vertical oscillation of the center of gravity (32.00 mm) is relatively low, indicating a controlled and energy-efficient movement pattern. Penalty kicks are characterized by a limited vertical displacement of the center of gravity, as this reduces excessive movement, improves balance, and helps maintain stability during the acceleration and release phases. This controlled oscillation reduces the risk of movement destabilization during impact and ensures efficient transfer of kinetic energy towards the goal.

The braking and push-off data demonstrate a well-developed force management strategy. The negative braking distance on both sides (−51.83 mm on the right, −19.65 mm on the left) indicates that strong decelerating forces are being applied to control momentum before

Table 2. Spatial parameters of the 7-meter penalty throw technique model for handball players

Parameter	Value
Vertical oscillation of COG	32.00 [mm]
Braking distance of right leg	-51.83 [mm]
Braking distance of left leg	-19.65 [mm]
Push-off distance of right leg	23.03 [mm]
Push-off distance of left leg	108.72 [mm]
Support distance of right leg	668.61 [mm]
Support distance of left leg	896.13 [mm]
X-coordinate of right toe at contact	-821.69 [mm]
X-coordinate of left toe at contact	13.20 [mm]

impact. This braking action is crucial for stabilizing the base of support and preparing the kinetic chain for the subsequent acceleration phase. The push-off distances reveal an asymmetrical contribution - the forward push-off force of the left foot (108.72 mm) is significantly higher than that of the right (23.03 mm). This demonstrates the primary role of the left leg in generating forward momentum and supporting the upper body kick, while the right leg provides additional propulsion and directional control.

Support distances further emphasize this functional asymmetry. The length of the left support distance (896.13 mm) is significantly greater than the right side (668.61 mm), indicating the presence of a wider and more stable support base on the non-dominant side, which is important for maintaining balance and rotational control during impact. Such asymmetry reflects a biomechanically optimized configuration: the plant foot "anchors" the motion, while the pushing leg plays an active role in impulse transmission.

Toe coordinates provide additional information about body alignment and moment generation. The significant posterior placement of the right toe (−821.69 mm) is considerably farther back than the left (13.20 mm), which increases the lever arm for rotation and, as a result, enhances body rotation and moment generation. The forward position of the left toe indicates its active role in controlling the strike direction and stabilizing the release phase.

General analysis:

The spatial characteristics of the 7-meter penalty kick demonstrate a biomechanically efficient pattern, characterized by controlled movement of the center of gravity, asymmetry of strategic braking and pushing, a stable support base, and an optimized lower leg position. Together, these elements improve balance, maximize moment generation, and ensure precise energy transfer, resulting in a significant increase in kick accuracy and power.

The kinematic data of lower limb joints (Table 3) provides a deep insight into how handball players utilize their leg, pelvic, and ankle joints during a 7-meter penalty throw - illustrating the processes of generating power, maintaining balance, and optimizing the mechanics of the throw.

Pelvic rotation:

The pelvis exhibits relatively small rotation amplitudes (from 4.65° to −24.92°), indicating the involvement of a controlled and stable body during impact. Such limited but purposeful rotation is associated with the semi-static nature of the penalty kick - excessive pelvic movement could negatively affect balance and accuracy. The larger range of the left segment (−12.20°) indicates its active participation in generating momentum, while the significant negative rotation of the right segment (−24.92°) demonstrates its role in initiating the kinetic chain impulse.

Hip joints:

Average flexion and extension values are observed in the hips - 11.05° on the right and 7.05° on the left. These values highlight the role of the hips in controlled thrust and vertical lift. When measured relative to the vertical axis, the movement of the right hip (from 9.61° to −21.14°) demonstrates its role in stabilizing

Table 3. Brief description of the kinematics of lower limb joints in the 7-meter penalty throw technique model for handball players

Pelvis	*Maximum*	*Minimum*
Pelvic rotation	4.65°	0.00°
Pelvic rotation (right segment)	0.00°	-24.92°
Pelvic rotation (left segment)	-12.20°	0.00°
Thighs	Maximum	Minimum
Right thigh flexion/extension	11.05°	-3.80°
Left thigh flexion/extension	7.05°	1.40°
Right thigh flexion/extension (relative to vertical)	9.61°	-21.14°
Left thigh flexion/extension (relative to vertical)	12.19°	-7.09°
Right thigh abduction/adduction	20.49°	-6.92°
Left thigh abduction/adduction	34.58°	0.68°
Knees	Maximum	Minimum
Right knee flexion/extension	35.67°	1.60°
Left knee flexion/extension	36.24°	-26.30°
Ankle joints	Maximum	Minimum
Right ankle flexion/extension	9.47°	-13.72°
Left ankle flexion/extension	14.26°	-12.04°

support and directing force upwards, while the movement of the left hip (from 12.19° to −7.09°) contributes to forward motion. High abduction/adduction values - especially on the left side (34.58°) - indicate strong lateral stability, which is crucial for balance and directional control during impact.

Knee joints:

A significant dynamic of knee flexion is observed - the right knee bends up to 35.67°, and the left up to 36.24°. These values indicate their crucial role in absorbing ground reaction forces and providing upward propulsion. The extended range of the left knee (up to -26.30°) signifies its role in maintaining dynamic stability and supporting body rotation.

Ankle movement is moderate, ranging from 9.47° to -13.72° on the right side and from 14.26° to -12.04° on the left side. These values demonstrate the efficiency of the propulsion mechanics and fine-tuning of balance. Controlled plantar and dorsal flexion allow the athlete to manage power transfer and adjust the final body position before releasing the ball.

General interpretation:

The kinematics of the lower limb joints exhibit a coordinated, asymmetrical movement pattern: the right foot provides the main push-off and balance, while the left foot significantly contributes to controlling torque and direction. The pelvis and thighs act as a "bridge" between lower and upper body movements, ensuring smooth energy transfer along the kinetic chain. The knees and ankles support this process by managing ground reaction forces and stabilizing the body. This synergy is crucial for creating a stable base, generating momentum, and enhancing shot effectiveness during a 7-meter penalty throw.

Conclusion

The biomechanical analysis of the 7-meter penalty throw demonstrates that this action is a highly coordinated, multi-segmented process requiring precision, stability, and sequential energy transfer along the kinetic chain. Research findings confirm that successful execution depends on the interrelation of lower body strength, pelvic and torso rotation, and upper limb acceleration. The lower legs form the foundation of the movement, providing sta-

Table 4. Summary of lower limb kinematics of shooting the ball at the goal from above while leaning

Pelvis	*Maximum*	*Minimum*
Pelvis rotation	0.18 o	0.00 o
Pelvis rotation (right segment)	0.00 o	-12.25 o
Pelvis rotation (left segment)	-11.09 o	0.00 o
Thighs	Maximum	Minimum
Right thigh flexion/extension	7.86 o	-15.04 o
Left thigh flexion/extension	30.85 o	11.28 o
Right thigh flexion/extension (relative to vertical)	8.89 o	-16.36 o
Left thigh flexion/extension (relative to vertical)	27.40 o	13.24 o
Abduction/adduction of right hip	21.66°	0.31°
Abduction/adduction of left hip	28.02°	-0.21°
Knees	Maximum	Minimum
Flexion/extension of right knee	29.25°	22.43°
Flexion/extension of left knee	53.67°	24.46°
Ankle joints	Maximum	Minimum
Flexion/extension of right ankle	10.33°	-6.94°
Flexion/extension of left ankle	9.13°	-6.30°

bility and generating force through the motion of the thighs, knees, and ankles. The pelvis and torso play a crucial role in creating momentum and transmitting rotational impulse. Notably, the shoulder and elbow on the dominant side achieve the highest angular velocity, highlighting their significance in accelerating and releasing the ball.

Furthermore, the controlled shift of the center of gravity ensures dynamic balance and

Table 5. Summary of upper limb kinematics of shooting the ball at the goal from above while leaning

Shoulders	*Maximum*	*Minimum*
Right shoulder flexion/extension	5.19 o	-39.12 o
Left shoulder flexion/extension	5.01 o	-52.82 o
Right shoulder flexion/extension (relative to vertical)	-4.45 o	-46.04 o
Left shoulder flexion/extension (relative to vertical)	-5.33 o	-55.31 o
Right shoulder abduction/adduction	0.00 o	9.81 o
Left shoulder abduction/adduction	67.67 o	50.76 o
Elbows	Maximum	Minimum
Right elbow flexion/extension	104.46 o	76.44 o
Left elbow flexion/extension	104.47 o	39.69 o

postural control, facilitating efficient energy transfer without compromising accuracy. Overall, the 7-meter penalty throw depends not only on arm strength but also on the coordinated activity of the entire body system, with each segment creating a continuous flow of energy transfer from the ground to the ball. Understanding these biomechanical principles helps coaches and athletes improve throwing technique, optimize training programs, enhance performance under pressure, and reduce the risk of injuries.

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AUTHOR BIOGRAPHY:



Jasur Anvarovich AKRAMOV

Employment
Professor at Uzbekistan state university of physical education and sports

Degree
PhD

Research interests
Handball, physical education and sport, Theory of physical education.