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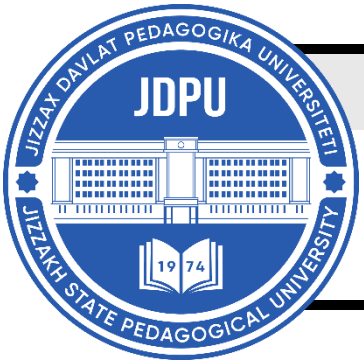

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3D KINEMATIC PROFILE OF LOWER AND UPPER BODY SEGMENTS AND THEIR INTERSEGMENTAL COORDINATION IN THE LEFT-SIDE BENDING THROW TECHNIQUE OF WRESTLERS

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ABOUT ARTICLE

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Abstract: This study aimed to determine the 3D kinematic profile of the lower and upper body segments during the execution of the left-side bending throw technique by wrestlers and to evaluate their intersegmental coordination. Maximum and minimum angular changes of the primary joints involved in the movement—pelvis, hip, knee, ankle, as well as the shoulder and elbow joints—were recorded using a digital motion-capture system. The amplitudes of pelvic rotation, hip flexion and abduction, knee extension, ankle flexion, and shoulder and elbow movements were examined as key criteria for assessing the spatiotemporal structure of the technique. The results demonstrated that during the execution of the left-side bending throw, the lower body segments play a leading role in ensuring stability and impulse transmission, while the upper body joints are crucial for forming the final force impulse. The findings of this study may be applied to optimize technical training, improve coordination structures, and develop scientifically grounded training recommendations for coaches.

Introduction. The current stage of development of modern wrestling requires high-precision execution of technical movements, coordinated interaction of body segments, and scientifically grounded control of force–impulse exchange processes [1]. In particular, the left-sided variant of the bending throw is distinguished by its complex spatial structure, asymmetric locomotion, and the requirement for synchronous movement throughout the entire joint chain [2]. The effectiveness of this technique is directly dependent on angular changes occurring in the lower and upper body segments, maximum and minimum kinematic indicators, the sequence of impulse transmission, and the trajectory of the body's center of mass [3].

In recent years, the introduction of digital biomechanics—especially 3D motion-capture technologies—into sports analysis has enabled highly accurate investigation of complex technical movements [4]. However, the coordinative interaction of the pelvis, hip, knee, ankle, shoulder, and elbow joints during the execution of the left-sided bending throw in wrestlers has not yet been sufficiently substantiated by scientific research [5]. The sharp changes in body rotation mechanics, stability phases, and the direction of applied force vectors during left-side bending further increase the relevance of this topic [6].

In practical training, technical evaluation often relies on the coach's visual observation, which may prevent a full understanding of the true kinematic structure of the movement [7]. Determining the kinematic profile makes it possible to establish precise criteria for identifying inter-joint delays, excessive angular deviations, losses in impulse transmission, and the spatial organization of movement phases [8]. This process contributes to the individualization of technical training, early detection of errors, and improvement of the quality of technical re-learning [9].

Therefore, this study is highly relevant, as it aims to improve the scientifically grounded analysis of wrestling techniques by developing a 3D kinematic model of the lower and upper body segments involved in the left-sided bending throw, evaluating their intersegmental coordination, and identifying the key biomechanical factors influencing technical effectiveness [10].

Methodology. The purpose of this study was to determine the 3D kinematic profile of the lower and upper body segments during the execution of the left-sided bending throw technique by wrestlers.

Objectives of the Study

- To identify the 3D kinematic parameters of the lower and upper body segments (hip, knee, ankle, shoulder, and elbow) during the execution of the left-sided bending throw and record their primary angular changes.

- To evaluate the intersegmental coordination of the lower and upper body segments based on the spatiotemporal structure of the movement and analyze segmental harmony and impulse transmission mechanisms.
- To assess the biomechanical efficiency of the left-sided bending throw technique and determine the main factors influencing technical execution based on the obtained kinematic indicators.

Results and Discussion. According to the study results, pronounced and technique-specific kinematic changes were observed in both the lower and upper body segments during the execution of the left-sided bending throw by wrestlers. In the pelvic segment, maximum rotation reached 35.1°, while the minimum value was −12.4°, indicating that active pelvic rotation during left-side bending generates the initial impulse of the technical action.

In the hip joint, a maximum flexion value of 66.7° and a minimum value of −38.8° reflected the athlete's effective organization of support through the left leg. A knee flexion angle of 93.1° observed during the deepest phases of bending played a crucial role in maintaining stability.

The ankle joint demonstrated a maximum dorsiflexion of 32.0° and a minimum value of −17.7°, confirming that the foot–ankle segment plays a key role in maintaining stability during the phase of lowering the body's center of mass. In the upper body segments, maximum shoulder flexion reached 142.8°, and elbow extension reached −12.0°, indicating that arm movements serve as the primary mechanism for generating the final force–impulse during the left-side bending phase.

Overall, the obtained kinematic profiles confirmed that the lower body segments (pelvis–hip–knee–ankle) are coordinately involved in initiating and stabilizing the movement, while the upper body segments (shoulder–elbow) contribute primarily to generating the final throwing impulse. It was found that this intersegmental coordination directly determines the quality of technical execution, whereas excessive angular deviations during movement phases negatively affect performance efficiency. The results of the study have practical significance for coaches in correcting technical preparation, improving coordinative harmony, and eliminating individual biomechanical errors.

In this study, the 3D kinematic profile of the lower and upper body segments during the execution of the left-sided bending throw by wrestlers was analyzed in depth. The results demonstrated that, within the spatiotemporal structure of the technical movement, the coordinated interaction of the pelvis, hips, knees, ankles, as well as the shoulders and elbows, represents one of the key factors determining the effectiveness of the technique.

During pelvic motion, maximum rotation was 35.1°, while the minimum value was −12.4°, indicating that active pelvic rotation during the initial phase of the bending throw facilitates direction change and impulse accumulation. These indicators confirm the role of the pelvic segment as a primary "generator" initiating movement.

In the hip joint, maximum flexion of 66.7° and abduction of 41.8° demonstrated the decisive importance of the left leg in providing support, lowering the body's center of mass, and generating the vertical impulse required for throwing.

The knee joint exhibited a maximum flexion of 93.1° and a minimum value of −4.9°, highlighting its shock-absorbing and stabilizing function during the force accumulation phase. The ankle joint showed a maximum dorsiflexion of 32.0° and a minimum plantar flexion of −17.7°, emphasizing the critical role of the ankle segment in controlling the base of support and maintaining lateral stability (Table 1).

Table 1. Lower-Body Kinematic Indicators During the Left-Side Bending Throw Technique in Wrestlers (n = 14)

Segment / Indicator	Maximum (°)	SD	CV (%)	Minimum (°)	SD	CV (%)
Pelvic rotation	92.21°	9.3	10.09	75.65°	7.6	10.05
Pelvic rotation (right segment)	−48.93°	-5	10.22	−110.24°	-10.9	9.89
Pelvic rotation (left segment)	110.94°	10.9	9.83	41.78°	4.2	10.05
Right hip flexion/extension	17.16°	1.8	10.49	−11.00°	1.2	10.91
Left hip flexion/extension	50.34°	4.9	9.73	−11.01°	1.9	17.26
Right hip flexion/extension relative to vertical	12.37°	1.3	10.51	1.20°	0.11	9.17
Left hip flexion/extension relative to vertical	40.56°	3.9	9.62	16.87°	1.7	10.08
Right hip abduction/adduction	13.32°	1.2	9.01	−10.89°	-1.1	10.10
Left hip abduction/adduction	57.79°	5.3	9.17	9.52°	0.9	9.45

Right knee flexion/extension	69.92°	6.5	9.30	27.08°	2.8	10.34
Left knee flexion/extension	109.49°	10.8	9.86	9.86°	0.9	9.12
Right ankle flexion/extension	30.61°	2.8	9.15	2.19°	0.2	9.13
Left ankle flexion/extension	25.64°	2.5	9.75	−9.85°	-0.9	9.14

In the upper body segments, the maximum shoulder flexion reaching 142.8° and elbow extension reaching −12.0° confirmed that arm movements act as the primary mechanism for generating the external impulse during the final phase of the throw. These indicators demonstrate that the arm segments effectively transmit the impulse generated by the lower body and play a decisive role in forming the final force vector that completes the movement.

Table 2. Upper-Body Kinematic Indicators During the Execution of the Left-Side Bending Throw

№	Segment / Indicator	Maximum (°)	SD	CV (%)	Minimum (°)	SD	CV (%)
1.	Right shoulder flexion/extension	104.06°	10.5	10.09	39.84°	4.1	10.29
2.	Left shoulder flexion/extension	84.23°	8.5	10.09	52.32°	5.3	10.13
3.	Right shoulder flexion/extension (relative to vertical)	125.57°	12.6	10.03	45.89°	4.6	10.02
4.	Left shoulder flexion/extension (relative to vertical)	112.26°	12	10.69	57.45°	5.9	10.27
5.	Right shoulder abduction/adduction	58.98°	5.9	10.0	−35.14°	-2.9	8.25
6.	Left shoulder abduction/adduction	91.48°	9.2	10.06	−63.34°	-6.4	10.10
7.	Right elbow flexion/extension	129.96°	13.1	10.08	0.00°	0	-
8.	Left elbow flexion/extension	59.75°	6.1	10.21	43.23°	4.5	10.41

The generalized results indicate that during the left-sided execution of the bending throw, the lower body segments (pelvis–hip–knee–ankle) play a primary role in initiating the movement, changing direction, and ensuring stability, while the upper body segments shape the final vector of throwing force and determine the effectiveness of the technical action. It was found that disruptions in this intersegmental coordination may lead to excessive angular deviations, loss of impulse, and technical errors.

Thus, the findings of the study have significant scientific and practical importance for individualizing technical training, identifying kinematic errors, and optimizing the bending throw technique.

Conclusion. The study demonstrated that complex biomechanical coordination between the lower and upper body segments is the main factor determining technical effectiveness during the execution of the left-side bending throw by wrestlers. Pelvic rotation, hip flexion and abduction, knee flexion, and ankle dorsiflexion play leading roles in generating the initial movement impulse, controlling the body's center of mass, and forming the stabilization necessary for throwing.

The results showed that maximum pelvic rotation reaching 92.21° and left hip flexion of 50.34° during the left-side bending phase are key biomechanical factors enhancing throwing efficiency.

In the upper body segments, shoulder flexion up to 104.06° and elbow extension up to 129.96° indicated that arm movements play a decisive role in the final phase of external impulse formation, ensuring optimal transmission of the impulse generated by the lower body. Disruptions in intersegmental coordination or excessive angular deviations may lead to impulse loss, technical errors, and reduced throwing effectiveness.

Overall, the left-side bending throw represents a complex biomechanical system whose optimal execution requires precise spatiotemporal coordination of the lower and upper body joints. The obtained results have practical significance for individualizing technical training, improving coordination structures, and enhancing movement quality.

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