ORIGINAL ARTICLE

Increasing maximum angular velocity of the jab punch in amateur boxers

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Abstract

Background and Study Aim The jab punch represents a fundamental technical element in boxing and relies on coordinated interaction of multiple body segments. Effective execution of this technique depends on the sequential involvement of the shoulder, elbow, pelvis, hip, knee, and ankle joints, which collectively contribute to punch speed and force generation. Despite the application of various training approaches aimed at improving punching performance, their relative effectiveness in modifying joint angular velocity during jab execution remains of practical interest. The aim was to quantify joint angular velocity during jab execution using 3D biomechanical analysis and to assess changes following targeted training.

Material and Methods The study was conducted using a three-dimensional motion capture system with twelve synchronized cameras. Twenty-four amateur male boxers (age 19 ± 2.1 years, height 172 ± 6.9 cm, body mass 69 ± 6.83 kg) were randomly assigned to an experimental group and a control group. To develop joint angular velocity and improve segmental coordination during jab execution, the experimental group completed a four-week targeted training program comprising ten structured exercises, while the control group followed a conventional training routine. Training load and exercise intensity were monitored using a Polar H10 heart rate sensor. Kinematic data were processed using Motive software to calculate joint angular velocity parameters.

Results The experimental group demonstrated significant increases in angular velocity at the shoulder joints, including left shoulder flexion and extension (from 512.5 ± 44.73 to 573.82 ± 68.2°/s, $p < 0.05$), as well as at the elbow joints, with left elbow angular velocity increasing from 439.4 ± 37.78 to 472.24 ± 39.11°/s ($p < 0.05$). Pelvic rotational velocity showed a pronounced increase from 153.8 ± 18.22 to 269.45 ± 33.78°/s ($p < 0.001$). Positive changes were also observed in the hip joints, particularly left hip flexion and extension (from 67.6 ± 8.62 to 89.01 ± 8.08°/s, $p < 0.001$), and in the ankle joints, with left ankle angular velocity increasing from 63.23 ± 8.32 to 68.24 ± 5.44°/s ($p < 0.001$), indicating improved kinetic chain coordination. No statistically significant changes were found in the control group.

Conclusions The specialized training program resulted in short-term improvements in jab punch mechanics. Increased angular velocity enhanced the contribution of both upper and lower body segments, leading to faster and more forceful punch execution. The findings emphasize the importance of lower-body involvement and provide practical guidance for boxing training programs.

Keywords: angular velocity, boxing, biomechanical analysis, striking technique, body alignment, technical exercises

Introduction

Punch speed and efficiency are components of boxing performance, particularly in actions used to initiate or control tactical exchanges. The jab punch involves coordinated movement of multiple body segments, in which force generation depends on the transfer of motion through the kinetic chain rather than on isolated upper-limb action. Joint angular velocity influences punch speed and mechanical execution, as it reflects the timing and sequencing of segmental movements. From this perspective, analysis of joint-specific contributions provides a basis for examining biomechanical characteristics of the jab punch and their modification through structured training interventions.

Biomechanical characteristics of punching movements in boxing have been examined with emphasis on the structural organization of straight punches and the interaction of body segments. Kinematic analyses have shown that effective punch execution involves coordinated motion of the shoulder, elbow, and wrist, rather than isolated upper-limb action [1, 2]. These studies describe punching as a structured movement

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pattern governed by joint sequencing and temporal coordination.

Subsequent investigations extended this approach to whole-body mechanics, demonstrating that lower-limb and pelvic actions contribute to force generation and transmission during straight punches [3, 4]. The involvement of the trunk and legs forms a continuous kinetic chain that supports upper-limb acceleration and punch delivery.

Variations in biomechanical parameters have been reported across different skill levels. Analyses of straight right-hand punches indicate differences in joint kinematics and execution patterns between boxers of varying qualifications, while preserving common structural features of the movement [5, 6]. These findings collectively characterize punching in boxing as a complex, multi-segmental motor action.

Segmental coordination is a defining feature of effective striking actions in combat sports. Biomechanical studies describe punching movements as sequences in which motion is transferred from proximal to distal segments, allowing mechanical energy to be accumulated and released through the kinetic chain [3, 7]. This sequencing supports the development of higher end-point velocities while maintaining movement control.

Research focusing on intermuscular and intersegmental coordination indicates that punch execution depends on precise temporal alignment of lower- and upper-body segments. Investigations of straight punches in boxing highlight the role of coordinated activation of the legs, trunk, and upper limbs in stabilizing movement patterns and regulating angular velocity across joints [2, 8, 9].

Comparative kinematic analyses of different punching strategies further demonstrate that variations in sequencing affect joint angular velocity and overall punch mechanics. Studies comparing proximal-to-distal and simultaneous movement patterns report differences in pelvic, shoulder, and elbow coordination, influencing the efficiency of force transfer during straight punches [10].

Angular velocity is a central kinematic parameter used to describe the mechanical execution of straight punches. Analyses of boxing punches have shown that joint angular velocity reflects the timing and coordination of segmental movements, particularly at the shoulder and elbow joints [1, 2]. Differences in angular velocity profiles have been reported between punch types, indicating distinct movement strategies within straight and rotational techniques.

Further studies have examined angular velocity in relation to technical variation and athlete qualification. Investigations of straight right-hand punches demonstrate that joint kinematics, including angular velocity and joint angles, vary according to execution patterns while preserving common structural features of the movement [3, 5]. These variations influence the mechanical characteristics of punch delivery.

Comparative kinematic analyses of different sequencing strategies reveal that proximal-to-distal coordination affects peak angular velocity and its distribution across joints. Distinct patterns of pelvic, shoulder, and elbow rotation have been associated with differences in punch mechanics and movement efficiency [10].

Lower-limb and pelvic mechanics play a substantial role in the execution of striking movements across combat sports. Kinematic studies indicate that effective strikes rely on coordinated actions of the pelvis, hip, knee, and ankle joints, which contribute to the generation and transfer of mechanical energy toward the striking segment [7, 9, 11]. The involvement of these segments supports the acceleration of the distal limbs during punch and kick execution.

Research on kicking techniques in taekwondo and karate provides additional insight into the influence of lower-body mechanics on striking performance. Analyses of turning, back, and roundhouse kicks show that strike velocity depends on leg positioning, joint angular velocity, and the timing of pelvic rotation [12, 13, 14]. Similar relationships have been observed in studies examining the effects of wearable resistance and joint kinematics on lower-limb strike velocity and force production [15].

Variations in attack angle and movement amplitude have also been shown to affect lower-limb kinematics. Changes in pelvic rotation, knee flexion, and limb trajectory influence both strike velocity and execution time, highlighting the need for coordinated lower-body control during striking actions [16].

Temporal characteristics are an integral component of punching performance in boxing. Analyses of punch execution have shown that parameters such as movement duration, active phase time, and return time to the initial position influence the overall structure and effectiveness of striking actions [6, 17]. These temporal features reflect the coordination between preparatory and execution phases of the punch.

Reaction time has been examined in relation to different punch types and skill levels. Comparative assessments indicate that faster reaction responses are associated with more efficient execution of offensive and defensive punching actions, including rapid transitions between attack and counterattack [18]. Together, these findings underline the role of temporal regulation in the organization of boxing punches.

Methodological approaches to teaching punching techniques are commonly based on biomechanical models of movement execution. Studies focusing on the instruction of basic punches describe the use of structured motor models that emphasize sequential learning and controlled progression of technical elements [19]. Such approaches aim to standardize movement patterns and support the development of stable punching techniques.

Pedagogical analyses also highlight the role of coordination training in technical instruction. Research on intermuscular coordination during straight punches indicates that targeted exercises and regulated external loads influence movement stability and the timing of muscle activation, which is relevant for technical refinement in boxing training [8]. Biomechanical comparisons of different punch execution strategies further contribute to instructional design by identifying movement characteristics associated with coordinated joint action and sequential movement organization [10]. In addition, analyses of biomechanical and physical factors related to performance in amateur boxing emphasize the contribution of coordinated interaction between the lower limbs, shoulder girdle, and arm muscles to punch effectiveness [20].

Analysis of research findings has shown that punching techniques in boxing are based on coordinated interaction of multiple body segments, with angular velocity and temporal sequencing influencing strike execution. Researchers emphasize that effective punch performance depends on the integration of upper- and lower-body mechanics and on the regulation of joint-specific kinematic parameters under dynamic conditions. At the same time, the complexity of these interactions and their modification through structured training interventions continue to present methodological challenges in applied biomechanics. In this context, the aim was to measure angular velocity during jab execution using three-dimensional biomechanical analysis and to evaluate improvements after targeted training.

Materials and Methods

Participants

Twenty-four healthy athletes without musculoskeletal injuries participated in the study. All participants were students of the Uzbek State University of Physical Education and Sports. They were randomly assigned to an experimental group (EG) and a control group (CG). Participation was voluntary, and all athletes provided informed consent prior to data collection. The study protocol was approved by the Ethics Committee of the Uzbek State University of Physical Education and Sports, and all procedures were conducted in accordance with institutional ethical standards.

Study Design

Punching movements were recorded using the STT Full Body Analysis system, which enables synchronized three-dimensional tracking of whole-body motion. The motion-capture setup consisted of Q13 fixed optoelectronic cameras mounted on wall or ceiling fixtures and FFY cameras installed on tripods around the capture area to ensure adequate coverage of dynamic body segments. Q13 cameras were connected to the network via Ethernet, while FFY cameras were linked to the workstation using USB 3.1 interfaces. All devices were operated through 3DMA Full Body software, which controlled system calibration, data acquisition, and three-dimensional reconstruction of joint kinematics.

Before testing, a standard calibration procedure was performed to ensure spatial accuracy and synchronization across all cameras. Kinematic data included three-dimensional positions and joint angles of the shoulder, elbow, pelvis, hip, knee, ankle, and foot in the sagittal, coronal, and transverse planes. Motion analysis focused on punching actions, allowing assessment of joint coordination and movement efficiency during jab execution. Angular velocity and acceleration parameters were calculated to characterize punch mechanics and segmental interaction.

As part of the training intervention, a structured set of physical exercises was included to regulate training load and to support the development of general and boxing-specific physical qualities. Exercise intensity was monitored using heart rate responses and basic workload parameters. The intervention comprised ten exercises targeting strength, coordination, endurance, and segmental interaction relevant to jab execution, with detailed load characteristics summarized in Table 1:

1. *Jumping rope* was used as a general conditioning exercise aimed at developing endurance, balance, and foot speed. Heart rate increased from 111 bpm at rest to 158–180 bpm during exercise and decreased to 110–120 bpm during recovery. The exercise duration was 12–14 min, repeated 3–4 times, with an estimated energy expenditure of approximately 150 kcal and a total distance of about 610 m. The exercise was performed in an upright posture with continuous rope rotation, slight knee flexion, and minimal ground contact during landing.
2. *Pull-ups on a horizontal bar* were performed to develop upper-body strength and static–dynamic endurance. Heart rate increased from 115 bpm before exercise to 162–175 bpm during execution and decreased to 120–130 bpm during recovery. The protocol consisted of 2–4 sets with a total duration of 15–20 min and an estimated energy expenditure of approximately 150 kcal. The exercise was executed using a wide or shoulder-width grip, with controlled vertical movement and maintenance of a straight body alignment throughout the action.
3. *Medicine ball slams* were included to develop explosive strength and coordination. Heart rate

increased from 129 bpm at rest to 169–176 bpm during exercise and decreased to 110–120 bpm during recovery. The exercise was performed in 2–4 sets with a total duration of 12–14 min and an estimated energy expenditure of approximately 170 kcal. The movement involved coordinated throwing and rotational actions, requiring synchronized activation of the upper limbs and trunk to support whole-body coordination relevant to punching mechanics.

4. *Kettlebell swings* were used to develop explosive strength and general physical endurance. Heart rate increased from 129 bpm before exercise to 170–176 bpm during execution and decreased to 110–120 bpm during recovery. The protocol consisted of 2–4 sets with a total duration of 15–20 min and an estimated energy expenditure of approximately 150 kcal. The exercise was performed with controlled sagittal-plane movement and trunk rotation while maintaining an upright posture, engaging the lower limbs, trunk, and shoulder girdle to support balance and coordinated force production during punching actions.
5. *Squat exercises* were used to develop lower-limb strength, explosive power, and balance. Heart rate increased from 117 bpm before exercise to 160–173 bpm during execution and decreased to 110–120 bpm during recovery. The exercise was performed in 2–4 sets with a total duration of 10–12 min and an estimated energy expenditure of approximately 90 kcal. Squats were executed with knee flexion to approximately 90° and controlled trunk positioning, engaging the lower limbs and core to support movement stability and force production relevant to boxing actions.
6. *Barbell rotational strikes* were used to develop rotational strength and coordinated striking actions. Heart rate increased from 121 bpm before exercise to 168–172 bpm during execution and decreased to 110–120 bpm during recovery. The protocol consisted of 2–4 sets with a total duration of 15–20 min and an estimated energy expenditure of approximately 195 kcal. The exercise involved trunk rotation with unilateral external resistance, engaging the abdominal and back musculature to support force generation and coordination during punching movements.
7. *Sledgehammer tire slams* were applied to develop upper-body strength and explosive movement patterns. Heart rate increased from 117 bpm before exercise to 171–180 bpm during execution and decreased to 110–120 bpm during recovery. The exercise was performed in 2–4 sets with a total duration of 15–20 min and an estimated energy expenditure of approximately 245 kcal. The movement involved repeated overhead striking actions with external resistance, requiring coordinated activation of the upper limbs and trunk to support force transmission during punching movements.
8. *Agility ladder drills* were used to develop foot speed, balance, and coordination. Heart rate increased from 119 bpm before exercise to 161–169 bpm during execution and decreased to 110–120 bpm during recovery. The exercise was performed in 2–3 sets with a total duration of 12–14 min and an estimated energy expenditure of approximately 105 kcal. The drills involved rapid multidirectional foot movements along predefined patterns, requiring precise lower-limb coordination to support movement control during boxing actions.
9. *Push-up exercises* were included to develop upper-body strength and muscular endurance. The exercise engaged the chest, shoulder, arm, and trunk muscles and was performed with controlled movement while maintaining a straight body alignment to support upper-body stabilization relevant to punching actions.
10. *Floor-based speed bag punching* was applied to develop upper-body muscular endurance and coordination. Heart rate increased from 119 bpm before exercise to 149–152 bpm during execution and decreased to 110–120 bpm during recovery. The protocol consisted of 2–4 sets with a total duration of 15–20 min and an estimated energy expenditure of approximately 120 kcal. The exercise involved rhythmic, high-frequency punching movements performed with controlled upper-limb coordination to support muscular endurance during punching actions.

To summarize the structure, intensity, and physiological characteristics of the training intervention, the parameters of the complex exercise set used to increase joint angular velocity during jab execution are presented in Table 1.

To classify training load intensity based on heart rate responses recorded during the exercises, heart rate zones used for workout intensity differentiation are presented in Table 2.

Statistical Analysis

Three-dimensional kinematic variables were obtained using Motive software and processed for statistical evaluation. Data are presented as mean values with standard deviations. Comparative analysis was performed to assess differences between the experimental and control groups, as well as changes in joint angular velocity before and after the training intervention. Statistical significance of differences was determined using parametric comparison procedures, with p-values reported for each analyzed variable. Coefficients of variation were calculated to evaluate the consistency of movement execution. Statistical analysis was applied to identify changes in joint angular velocity

Table 1. Complex exercise set used to increase joint angular velocity during jab execution in boxers

No.	Exercise	Heart rate before workout (bpm)	Heart rate during workout (bpm)	Heart rate after workout (bpm)	Rest time between sets (s)	Repetitions per set	Exercise duration per set (min)	Estimated energy expenditure (kcal)	Estimated distance (m)
1	Jump rope	89 ± 9.3	158 ± 14.7	110–120	110–120	3–4	12–14	150 ± 10	–
2	Pull-ups	85 ± 8.1	153 ± 12.5	110–120	110–120	2–4	15–20	150 ± 11	–
3	Medicine ball slams	91 ± 9.5	169 ± 15.2	110–120	110–120	2–4	12–14	170 ± 12	145 ± 14
4	Kettlebell swings	93 ± 8.8	170 ± 16.0	110–120	110–120	2–4	15–20	150 ± 13	60 ± 8
5	Squats	87 ± 7.9	159 ± 13.8	110–120	110–120	2–4	10–12	90 ± 9	20 ± 5
6	Barbell rotational strikes	92 ± 9.0	168 ± 15.1	110–120	110–120	2–4	15–20	195 ± 14	70 ± 9
7	Sledgehammer tire slams	96 ± 8.7	171 ± 17.3	110–120	110–120	2–4	15–20	245 ± 18	55 ± 7
8	Agility ladder drills	88 ± 8.5	156 ± 12.4	110–120	110–120	2–3	12–14	105 ± 9	250 ± 20
9	Push-ups	91 ± 8.3	149 ± 11.9	110–120	110–120	2–4	15–20	120 ± 8	–
10	Speed bag punches	79 ± 8.9	157 ± 13.4	110–120	110–120	2–3	12–14	105 ± 10	225 ± 18

Table 2. Heart rate intensity zones used to categorize training load during workouts

No.	Intensity zone	Heart rate range (bpm)
1	Very low intensity	89–119
2	Low intensity	120–139
3	Moderate intensity	140–159
4	High intensity	160–179
5	Very high intensity	180–200

and intersegmental coordination associated with the training program.

Results

Specialized training led to an increase in the angular velocity of the jab punch at several joints, including the shoulder, pelvis, hip, and elbow, in the experimental group. Changes in angular velocity were associated with modifications in movement coordination and segmental interaction within the kinetic chain. In contrast, the control group demonstrated only minor changes in these parameters, indicating limited adaptation under standard training conditions.

Baseline kinematic characteristics of maximum joint angular velocity during jab execution in the control group before the experiment are presented in Figure 1. The data illustrate the distribution of angular velocity across upper- and lower-body joints during punch execution.

Kinematic assessment of the control group's jab technique before the intervention, as shown in Figure 1, demonstrated that maximum angular velocities were observed at the left shoulder (522.6°/s), left elbow (441.4°/s), and left ankle (61.17°/s). These values indicate that the jab was executed with the left arm, with the shoulder and elbow joints contributing primarily to punch speed generation. Low coefficients of variation (V% < 12%) across most joints suggest a relatively consistent technical execution among participants. Lower-extremity joints, including the hip, knee, and ankle, also contributed to jab execution but showed slightly greater variability (V% = 11–13%), indicating less stable coordination in these segments. Overall, jab execution followed a sequential pattern involving the left shoulder, elbow, and pelvic rotation, supporting momentum transfer along the kinetic chain.

Kinematic indicators of maximum joint angular velocity during jab execution in the experimental group before the intervention are presented in Figure 2.

Kinematic assessment of the experimental group's jab technique before the intervention, as shown in Figure 2, demonstrated peak angular

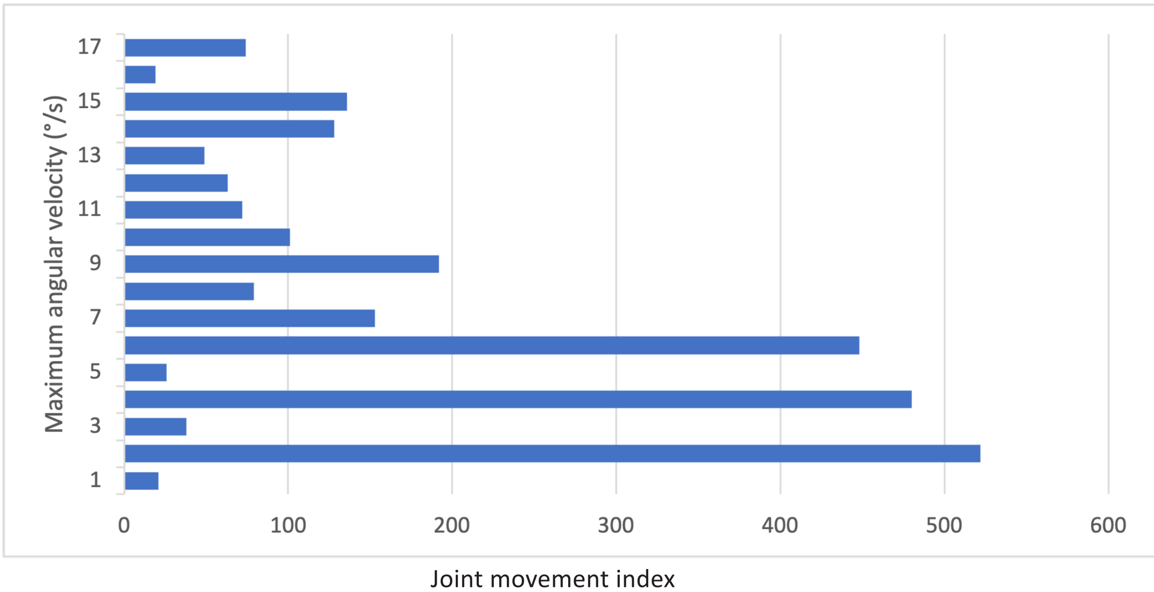

Figure 1. Kinematic indicators of the maximum angular velocity of body joints during jab technique execution in control group boxers before the experiment (n = 12). Note: 1 – right shoulder flexion/extension; 2 – left shoulder flexion/extension; 3 – right shoulder flexion/extension (vertical movement); 4 – left shoulder flexion/extension (vertical movement); 5 – right elbow flexion/extension; 6 – left elbow flexion/extension; 7 – pelvis rotation; 8 – pelvis rotation (right segment); 9 – pelvis rotation (left segment); 10 – right hip flexion/extension; 11 – left hip flexion/extension; 12 – right hip abduction/adduction; 13 – left hip abduction/adduction; 14 – right knee flexion/extension; 15 – left knee flexion/extension; 16 – right ankle flexion/extension; 17 – left ankle flexion/extension.

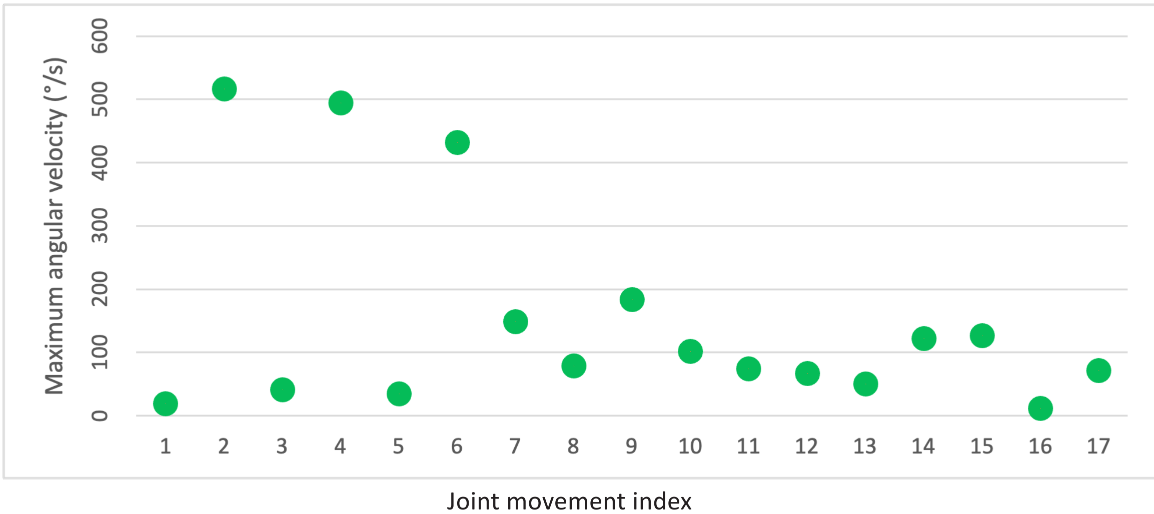

Figure 2. Kinematic indicators of the maximum angular velocity of body joints during jab technique execution in experimental group boxers before the experiment (n = 12). Note: 1 – right shoulder flexion/extension; 2 – left shoulder flexion/extension; 3 – right shoulder flexion/extension (vertical movement); 4 – left shoulder flexion/extension (vertical movement); 5 – right elbow flexion/extension; 6 – left elbow flexion/extension; 7 – pelvis rotation; 8 – pelvis rotation (right segment); 9 – pelvis rotation (left segment); 10 – right hip flexion/extension; 11 – left hip flexion/extension; 12 – right hip abduction/adduction; 13 – left hip abduction/adduction; 14 – right knee flexion/extension; 15 – left knee flexion/extension; 16 – right ankle flexion/extension; 17 – left ankle flexion/extension.

velocities at the left shoulder (512.5°/s), left elbow (439.4°/s), and left ankle (63.23°/s). These values indicate left-arm execution of the jab, with the shoulder and elbow joints contributing substantially to punch velocity. Low coefficients of variation in these joints (V% ≈ 8–9%) suggest relatively consistent movement patterns across participants. Lower-extremity joints, including the hip, knee, and ankle, exhibited higher variability (V% = 11–15%), indicating less stable coordination in these segments. Overall, jab execution was characterized by a biomechanical sequence involving the left shoulder, elbow, and hip, reflecting integrated participation of upper and lower body segments.

Comparative kinematic indicators of maximum joint angular velocity for the experimental and control groups are summarized in Table 3.

As shown in Table 3, the analysis of maximum shoulder angular velocity during jab execution demonstrated statistically significant improvements in the experimental group compared with the control group. Significant increases were observed in both

Table 3. Kinematic indicators of the maximum angular velocity of body joints during jab execution in experimental and control groups (n = 24)

Parameters	Stage	CG (mean ± SD)	V%	EG (mean ± SD)	V%	t	P
Shoulders							
Right shoulder flexion/extension	BE	23.63 ± 2.40	10.16	24.68 ± 3.21	13.01	1.74	>0.05
	AE	31.14 ± 3.51	11.27	38.67 ± 3.10	8.02	3.14	<0.001
Left shoulder flexion/extension	BE	522.6 ± 44.73	8.56	512.5 ± 44.73	8.73	10.21	>0.05
	AE	534.6 ± 52.41	9.80	573.82 ± 68.20	11.89	2.25	<0.05
Right shoulder flexion/extension (vertical)	BE	34.8 ± 4.05	11.64	34.3 ± 5.11	14.90	0.77	>0.05
	AE	42.4 ± 5.12	12.08	48.21 ± 3.49	7.24	3.16	<0.001
Left shoulder flexion/extension (vertical)	BE	490.9 ± 42.51	8.66	495.9 ± 42.51	8.91	0.15	>0.05
	AE	540.4 ± 54.24	10.04	614.17 ± 64.14	10.44	2.37	<0.05
Elbows							
Right elbow flexion/extension	BE	25.3 ± 2.14	8.46	26.4 ± 2.97	11.25	1.14	>0.05
	AE	31.3 ± 2.14	6.84	35.26 ± 3.68	10.44	2.23	<0.05
Left elbow flexion/extension	BE	441.4 ± 54.14	7.73	439.4 ± 37.78	8.60	0.87	>0.05
	AE	452.3 ± 52.24	11.54	472.24 ± 39.11	8.28	2.34	<0.05
Pelvis							
Pelvis rotation	BE	156.8 ± 16.22	10.34	153.8 ± 18.22	11.85	0.81	>0.05
	AE	208.4 ± 25.97	12.46	269.45 ± 33.78	12.54	5.63	<0.001
Pelvis rotation (right)	BE	71.25 ± 8.20	11.51	74.77 ± 9.21	12.31	1.41	>0.05
	AE	81.3 ± 9.97	12.26	87.88 ± 8.93	10.16	2.25	<0.05
Pelvis rotation (left)	BE	182.4 ± 20.60	11.29	176.3 ± 17.65	10.01	1.24	>0.05
	AE	225.3 ± 32.97	14.63	299.07 ± 33.34	11.15	6.68	<0.001
Hips							
Right hip flexion/extension	BE	102.2 ± 10.52	10.29	104.2 ± 12.20	11.71	0.92	>0.05
	AE	108.3 ± 12.97	2.74	112.47 ± 11.32	10.06	2.25	<0.05
Left hip flexion/extension	BE	65.6 ± 5.77	8.80	67.6 ± 8.62	8.31	0.74	>0.05
	AE	74.3 ± 9.97	13.41	89.01 ± 8.08	9.08	4.23	<0.001
Right hip abduction/adduction	BE	46.2 ± 5.89	12.75	48.45 ± 7.65	15.79	1.23	>0.05
	AE	47.2 ± 5.97	12.64	53.66 ± 6.43	11.98	2.25	<0.05
Left hip abduction/adduction	BE	35.06 ± 3.90	11.12	37.0 ± 4.25	11.48	1.04	>0.05
	AE	41.4 ± 5.97	14.42	47.75 ± 5.54	11.60	4.37	<0.001
Knees							
Right knee flexion/extension	BE	127.75 ± 13.80	10.80	128.14 ± 14.21	11.09	0.37	>0.05
	AE	121.3 ± 17.97	14.81	116.31 ± 11.43	9.83	2.63	<0.05
Left knee flexion/extension	BE	135.8 ± 15.80	11.63	132.12 ± 14.21	10.76	0.74	>0.05
	AE	138.3 ± 17.97	12.95	142.72 ± 11.74	8.23	2.58	<0.005
Ankles							
Right ankle flexion/extension	BE	12.70 ± 1.65	12.99	13.41 ± 1.84	13.72	0.87	>0.05
	AE	14.4 ± 1.85	12.85	15.20 ± 1.88	12.37	2.31	<0.05
Left ankle flexion/extension	BE	61.17 ± 7.21	11.79	63.23 ± 8.32	13.16	0.74	>0.05
	AE	54.4 ± 8.97	16.49	68.24 ± 5.44	7.79	3.23	<0.001

Note: BE – before experiment; AE – after experiment; CG – control group; EG – experimental group.

right and left shoulder flexion/extension movements, including vertical components ($p < 0.05$ to $p < 0.001$). In contrast, the control group exhibited minimal or non-significant changes. A similar pattern was observed for elbow joint kinematics. The experimental group demonstrated significant increases in maximum angular velocity in both right and left elbow flexion/extension after the intervention ($p < 0.05$), whereas no statistically significant changes were detected in the control group.

Kinematic indicators of maximum joint angular velocity during jab execution in the control group after the experiment are presented in Figure 3. Figure 3 provides a visual representation of post-intervention joint angular velocity patterns in the control group.

As shown in Table 3, the experimental group demonstrated a substantial improvement in pelvic rotation during jab execution, particularly in total and left segment rotation. Specifically, total pelvic rotation increased from 153.8 to 269.45 ($p < 0.001$), while left segment rotation increased from 176.3 to 299.07 ($p < 0.001$). The right segment rotation also exhibited a statistically significant increase ($p < 0.05$). In contrast, the control group showed only modest and statistically non-significant changes. Significant improvements were also observed in hip joint angular velocity in the experimental group. Increases were most pronounced in left hip flexion/extension (from 67.6 to 89.01, $p < 0.001$) and left hip abduction/adduction (from 37 to 47.75, $p < 0.001$). Additional statistically significant changes were found in right hip flexion and right hip abduction (both $p < 0.05$). No statistically significant changes were observed in the control group.

As illustrated in Figure 4, the experimental group demonstrated statistically significant changes in knee joint angular velocity during jab execution for both lower limbs. The right knee showed a decrease in angular velocity from 128.14 to 116.31 ($p < 0.05$), indicating altered movement control during punch delivery. In contrast, the left knee exhibited an increase from 132.12 to 142.72 ($p < 0.005$), reflecting changes in movement contribution of the supporting leg. No statistically significant changes were observed in the control group. Significant changes were also observed in ankle joint angular velocity in the experimental group, as shown in Figure 4. The right ankle demonstrated an increase from 13.41 to 15.20 ($p < 0.05$), while the left ankle showed a more pronounced increase from 63.23 to 68.24 ($p < 0.001$). The control group did not exhibit statistically significant changes in ankle joint angular velocity. These results indicate modifications in lower-limb kinematic behavior associated with the training intervention.

Relationships between joint angular velocity parameters in the experimental group after the intervention are summarized in Table 4.

As shown in Table 4, strong inter-joint correlations ($r \geq 0.7$) were identified when the maximum angular velocity of body joints during jab execution was analyzed in the experimental group after the experiment. Specifically, right pelvis rotation correlated with right shoulder flexion/extension ($r = 0.8$), left ankle flexion/extension correlated with right shoulder flexion/extension ($r = 0.7$), left hip flexion/extension correlated with both

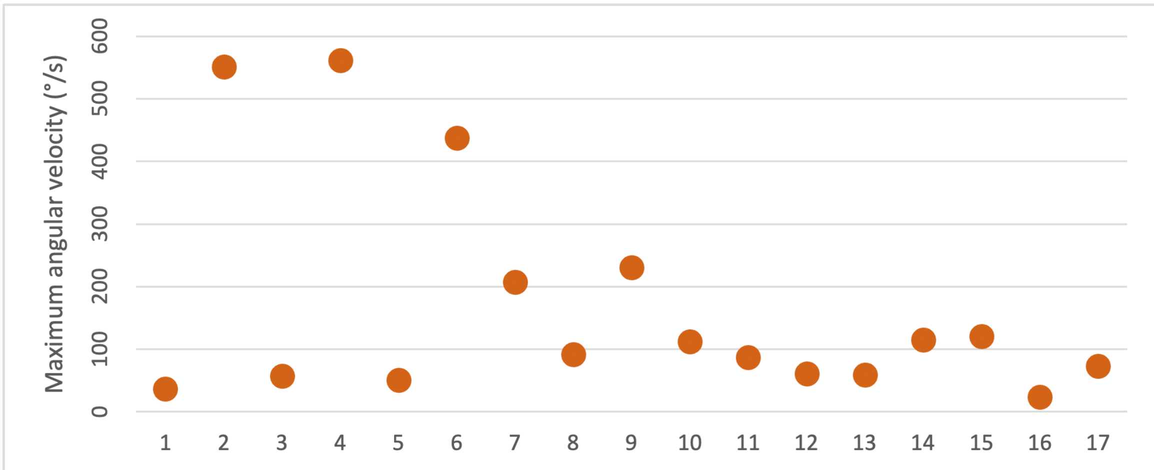

Figure 3. Kinematic indicators of the maximum angular velocity of body joints during jab technique execution in control group boxers after the experiment (n = 12). Note: 1 – right shoulder flexion/extension; 2 – left shoulder flexion/extension; 3 – right shoulder flexion/extension (vertical movement); 4 – left shoulder flexion/extension (vertical movement); 5 – right elbow flexion/extension; 6 – left elbow flexion/extension; 7 – pelvis rotation; 8 – pelvis rotation (right segment); 9 – pelvis rotation (left segment); 10 – right hip flexion/extension; 11 – left hip flexion/extension; 12 – right hip abduction/adduction; 13 – left hip abduction/adduction; 14 – right knee flexion/extension; 15 – left knee flexion/extension; 16 – right ankle flexion/extension; 17 – left ankle flexion/extension.

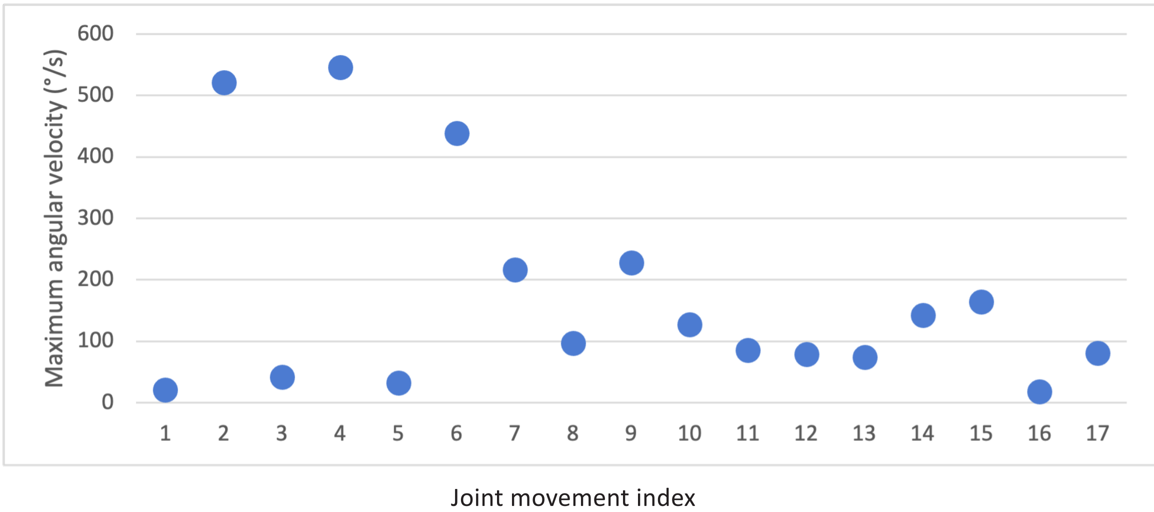

Figure 4. Kinematic indicators of the maximum angular velocity of body joints during jab technique execution in experimental group boxers after the experiment (n = 12). Note: 1 – right shoulder flexion/extension; 2 – left shoulder flexion/extension; 3 – right shoulder flexion/extension (vertical movement); 4 – left shoulder flexion/extension (vertical movement); 5 – right elbow flexion/extension; 6 – left elbow flexion/extension; 7 – pelvis rotation; 8 – pelvis rotation (right segment); 9 – pelvis rotation (left segment); 10 – right hip flexion/extension; 11 – left hip flexion/extension; 12 – right hip abduction/adduction; 13 – left hip abduction/adduction; 14 – right knee flexion/extension; 15 – left knee flexion/extension; 16 – right ankle flexion/extension; 17 – left ankle flexion/extension.

Table 4. Correlation of maximum angular velocity kinematics of body joints during jab execution in experimental group boxers after the experiment (n = 12)

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.3																
2	0.6																
3	0.4	0.3															
4	0.3	0	0.3														
5	0.5	0.3	0.1	0.7													
6	0.3	0.2	0.4	0.4	0.3												
7	0.6	0.5	0.8	0.3	0.1	0.6											
8	0.8	0.7	0.3	0.3	0.6	0.2	0.4										
9	0.6	0.2	0.5	0.2	0.3	0.5	0.6	0.4									
10	0.4	0.2	0.2	0.4	0.3	0.2	0.2	0.1	0.7								
11	0.6	0.1	0.2	0.5	0.5	0.2	0.3	0.4	0.7	0.7							
12	0.6	0.2	0.6	0	0.2	0.5	0.7	0.4	0.8	0.6	0.6						
13	0.2	0.2	0	0.3	0.1	0.3	0.1	0	0.6	0.7	0.7	0.5					
14	0.5	0.5	0.5	0.2	0.6	0.1	0.4	0.5	0.2	0	0.2	0.3	0.2				
15	0.6	0.5	0.6	0.2	0.6	0	0.5	0.6	0.4	0.2	0.3	0.4	0.1	0.8			
16	0.5	0.1	0.1	0.7	0.6	0	0.1	0.4	0.5	0.6	0.7	0.4	0.6	0.1	0.2		
17	0.7	0.4	0.7	0.7	0.3	0.4	0.8	0.5	0.7	0.4	0.5	0.7	0.2	0.6	0.6	0.3	0.5

Note: 1 – right shoulder flexion/extension; 2 – left shoulder flexion/extension; 3 – right shoulder flexion/extension (vertical movement); 4 – left shoulder flexion/extension (vertical movement); 5 – right elbow flexion/extension; 6 – left elbow flexion/extension; 7 – pelvis rotation; 8 – pelvis rotation (right segment); 9 – pelvis rotation (left segment); 10 – right hip flexion/extension; 11 – left hip flexion/extension; 12 – right hip abduction/adduction; 13 – left hip abduction/adduction; 14 – right knee flexion/extension; 15 – left knee flexion/extension; 16 – right ankle flexion/extension; 17 – left ankle flexion/extension. Correlation coefficients are presented as Pearson's r.

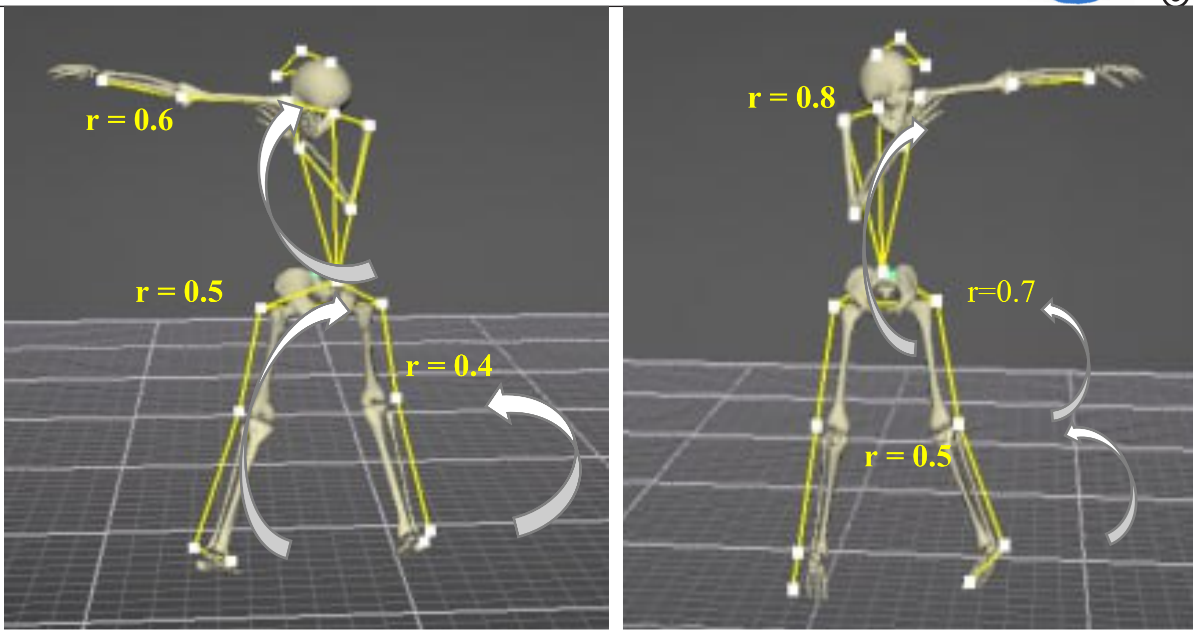

Figure 5. Correlation of body joint movements during the execution of a jab by boxers. Note: Correlation coefficients represent Pearson's r calculated between the maximum angular velocity values of body joints during jab execution in the experimental group after the experiment (n = 12).

right hip flexion/extension and pelvis rotation ($r = 0.7$), and right hip abduction/adduction correlated with left pelvis rotation ($r = 0.8$). These relationships indicate coordinated interaction between the upper and lower limbs and the pelvis during jab execution. Weak or negligible correlations ($r < 0.4$) were also observed for several joint movements in the experimental group. In particular, left shoulder flexion/extension in the vertical plane and left elbow flexion/extension demonstrated low correlation coefficients, suggesting a more supportive role of these joints during punch execution.

A graphical representation of the correlation structure between body joint movements during jab execution is presented in Figure 5.

As illustrated in Figure 5, post-experiment kinematic analysis of jab execution in the experimental group revealed interdependence among joint movements across multiple body segments. The strongest relationships were observed between the pelvis, hip joints, shoulder girdle, and ankle joints, indicating coordinated involvement of these segments during jab execution. The observed pattern reflects sequential interaction along the kinetic chain, with motion transferred from the lower extremities toward the upper body. Moderate correlations were also identified among several joint movements, suggesting partial coordination between these segments during the punch. In particular, joints on the non-dominant side demonstrated lower correlation values, indicating a more limited contribution to the overall movement pattern. These findings highlight variability in segmental involvement during jab execution and illustrate differences between primary and supportive joint actions.

Discussion

The aim was to quantify joint angular velocity during jab execution using 3D biomechanical analysis and to assess changes following targeted training. The results showed that the applied training intervention was associated with increased angular velocity in several upper- and lower-body joints, including the shoulder, elbow, pelvis, hip, and ankle, in the experimental group, while no comparable changes were observed in the control group. These findings indicate that modifications in segmental motion characteristics occurred alongside the training program, providing a basis for further interpretation of joint coordination and kinetic chain involvement during jab execution.

The observed increase in ankle joint angular velocity during jab execution in the experimental group can be discussed in the context of both earlier and recent biomechanical research. Previous studies have reported that modifications in lower-limb kinematics, including ankle joint motion, are associated with changes in movement coordination and force transmission during punching actions [2, 6, 7, 10]. These findings support the interpretation that alterations at the ankle level reflect adjustments in lower-limb involvement within the kinetic chain during jab execution.

Recent biomechanical investigations further reinforce this perspective. Studies employing synchronized three-dimensional motion capture and force platform analysis have demonstrated that lower-extremity force development and foot–ground interaction variables are related to straight-punch kinematics and punching speed, highlighting the contribution of distal lower-limb segments to effective punch execution [21]. In addition, contemporary research has shown that lower-limb kinetic variables remain relevant across different punch types, including the jab, and may be influenced by fatigue, indicating that changes in ankle joint behavior can affect overall biomechanical efficiency during striking movements [22]. Phase-based analyses based on ground reaction force timing also indicate that lower-body involvement precedes and supports upper-limb motion, which is consistent with the view that ankle joint kinematics contribute to segmental coordination during jab execution [23].

The observed changes support the concept that punching movements are executed through a kinetic chain involving force transmission from proximal to distal segments [10]. This interpretation is consistent with recent research showing that lower-limb kinetic variables (including ground reaction force and rate of force development) contribute to punch output across common punch types, including the jab, indicating that lower-body mechanics form part of the force–velocity pathway during striking actions [23]. Evidence from studies examining boxing-specific fatigue further indicates that perturbations to lower-body and trunk function can modify punching performance, supporting the view that whole-body sequencing is relevant to punch execution mechanics [24]. In addition, recent work examining jab and cross performance through whole-body mechanical models (e.g., effective mass and force-transfer characteristics) reinforces that punch effectiveness depends on coordinated segmental contribution rather than isolated upper-limb action [25]. Within this framework, ankle joint motion plays a role in initiating and supporting the mechanical sequence of jab execution, providing a distal component for force transmission through the kinetic chain [1, 8].

The importance of lower-extremity stability and coordinated joint action in punching performance is supported by both earlier and recent biomechanical research. Stanley and colleagues reported that coordinated movements of the lower limbs contribute to changes in punch force generation [6, 20]. The absence of comparable changes in the control group in the present study suggests that the observed kinematic modifications are associated with the applied targeted training approach rather than general training effects [9].

Contemporary evidence further highlights relationships between lower-limb stability, muscle strength, and dynamic control with striking performance. A recent investigation assessing hip strength, foot posture, and dynamic stability in boxers found significant correlations between hip strength and lower-limb dynamic stability, suggesting that stronger lower-limb musculature and improved balance contribute to more stable and effective movement patterns relevant to upper-body actions [26]. Another study reported that dynamic balance measures were significant predictors of punching performance, with better balance associated with faster and more powerful strikes, indicating that stability of the lower limbs is linked to global striking mechanics [27]. Additionally, research using force plates and biomechanical analysis demonstrated that lower-limb force generation and rate of force development contribute to punch effectiveness and fatigue resilience, underscoring the role of lower-limb kinetics in coordinated whole-body performance [23].

Earlier investigations indicated that non-specific physical training may not lead to measurable changes in joint kinematics during punching movements [2]. The current findings are consistent with these observations and support the use of targeted exercises aimed at modifying specific joint motion characteristics in order to achieve detectable biomechanical changes. Recent studies comparing variable resistance training and constant resistance training within complex training programs in elite boxers reported different adaptation patterns, with training modalities that were closely aligned with boxing movements producing greater improvements in strength and punch-related performance measures than general conditioning approaches [28]. A four-week contrast training intervention in amateur boxers also demonstrated that structured strength and power oriented programs resulted in more pronounced enhancements in punch force and physical performance compared with traditional conditioning, suggesting that training specificity influences neuromuscular adaptations relevant to striking actions [29]. In addition, investigations of boxing specific conditioning tasks such as punch related dumbbell exercises reported acute improvements in punch performance when compared with less specific preparatory activities, indicating that conditioning methods closely matched to the movement task can induce measurable performance effects [30].

The present findings are consistent with biomechanical models that emphasize coordinated integration of upper- and lower-body segments during jab execution. Earlier work demonstrated that lower-limb stability and initial force generation contribute to effective upper-limb motion during punching actions, supporting the concept of whole-body involvement in strike production [1]. Similarly, the intersegmental kinetic transfer model proposes that power and velocity generated by the lower-limb segments influence upper-body movement characteristics during striking tasks [7].

Recent investigations further support this framework. A biomechanical analysis of lead straight punches in boxers of different performance levels demonstrated that coordination between lower-limb force production and upper-limb kinematics is associated with higher punching velocity and mechanical efficiency, highlighting the role of segmental integration across the body [21]. In addition, whole-body modeling of jab and cross punches showed that effective mass and force transmission depend on synchronized contributions of the lower extremities, trunk, and upper limbs rather than isolated arm action [25]. Contemporary studies examining lower-limb kinetics and ground reaction force timing also reported that force generation in the lower body precedes and supports upper-limb acceleration during punching movements, reinforcing the relevance of integrated segmental coordination [23]. Within this context, observed changes in ankle joint motion may reflect adjustments in the lower-body contribution to the overall kinetic sequence of jab execution.

Limitations and Future Research

Several limitations of the present study should be acknowledged. First, the sample size was relatively small and consisted of amateur boxers of a similar age and training background, which may limit the generalizability of the findings to athletes of different competitive levels, age groups, or training histories. Second, the duration of the intervention was limited to a short training period, which does not allow conclusions to be drawn regarding long-term adaptations or retention of the observed kinematic changes. Third, the analysis focused primarily on kinematic parameters derived from three-dimensional motion capture, while kinetic variables such as ground reaction forces and muscle activation patterns were not directly assessed. As a result, interpretations regarding force generation and neuromuscular mechanisms remain indirect.

Future research should consider larger and more diverse samples, including boxers of different skill levels and competitive experience, to further examine the generalizability of the findings. Longitudinal study designs would allow investigation of long-term adaptations to targeted training interventions and their influence on punching mechanics over time. In addition, the integration of kinetic measurements, electromyography, and fatigue-related protocols may provide a more comprehensive understanding of the mechanisms underlying changes in joint angular velocity and segmental coordination during jab execution. Further studies may also explore the transfer of biomechanical changes to competitive performance indicators and injury risk in boxing.

Conclusions

This study addresses biomechanical aspects of jab execution in amateur boxing with an emphasis on joint angular velocity and segmental coordination. The findings highlight the relevance of movement organization based on proximal-to-distal sequencing and coordinated involvement of lower- and upper-body segments in boxing technique. From an applied perspective, the study supports the integration of kinematically oriented lower-body exercises into boxing training programs as a means of refining technical execution and movement efficiency. The conclusions may be useful for coaches, sports scientists, and rehabilitation specialists when designing training and corrective interventions aimed at improving movement quality and technical consistency in boxing.

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Conflict of Interest

The authors declare no conflicts of interest related to the research, authorship, and publication of this article.

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