ORIGINAL ARTICLE

Qualification-related differences in ankle kinematics during the right-hand uppercut in competitive boxers

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Abstract

Background and Study Aim Punching performance in boxing depends on coordinated kinetic chain interactions between the lower and upper limbs. During the execution of the uppercut, the ankle joint contributes to body stabilization and force transfer across movement phases. Although various biomechanical parameters are used to analyze punching technique, the influence of qualification level on ankle joint kinematics during the uppercut remains a subject of practical interest. This study aimed to examine how qualification level influences ankle kinematics during the right-hand uppercut in male boxers of high sport qualification.

Material and Methods A total of 36 male boxers were stratified into two qualification groups: Masters of Sport (highly qualified boxers) (n = 18) and Candidate Masters of Sport (advanced-level boxers) (n = 18). Participants performed maximal-effort right-hand uppercuts under controlled laboratory conditions. Ankle joint kinematics were assessed using three-dimensional motion analysis (3DMA). The analysis included minimum and maximum joint angles, range of motion (ROM), maximum angular velocity, toe-off angle, mid-support angle, and propulsion distance. Between-group differences were evaluated using bias-corrected Hedges' g with 95% confidence intervals (CI). Effect magnitude and η^2 were calculated to estimate the practical relevance of the results.

Results The most significant standardized difference was observed in the right ankle mid-support angle (g = 0.76, 95% CI 0.08 to 1.44; η^2 = 0.14). It was followed by the right ankle minimum angle (g = 0.72, 95% CI 0.04 to 1.40; η^2 = 0.13). Moderate effects were found in the left ankle ROM (g = 0.67, 95% CI -0.00 to 1.34; η^2 = 0.11). Moderate but statistically uncertain effects were observed in the right ankle maximum angle and toe-off angle (g = 0.55; CIs crossing zero). In contrast, maximum angular velocity and propulsion distance demonstrated small standardized differences (g = 0.30–0.40), with confidence intervals overlapping the null value.

Conclusions Qualification level is primarily associated with differences in ankle joint positioning and stabilization during transitional support phases rather than with peak angular velocity output. The findings suggest that advanced technical proficiency in boxing may be characterized by refined sagittal-plane control and phase-specific joint modulation. Further studies integrating kinetic measurements and larger sample sizes are needed to confirm these biomechanical tendencies.

Keywords: boxing biomechanics, ankle joint, uppercut, effect size analysis, sagittal-plane kinematics, combat sports.

Introduction

In boxing, effective punching actions emerge from coordinated interactions across multiple segments of the kinetic chain. The generation and transfer of force during punching movements depend on the synchronized contribution of the lower limbs, trunk, and upper extremities. Within this sequence, the ankle joint contributes to postural stabilization and mechanical support during transitional phases of movement. Variations in joint positioning and movement patterns may influence how force is transmitted through the body during the execution of specific punching techniques.

Punching performance in boxing represents a high-velocity, multi-segment motor action requiring coordinated intersegmental sequencing of the lower and upper extremities. Effective force transmission from the ground to the striking fist

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depends on precise temporal coordination, joint positioning, and segmental acceleration within the kinetic chain framework [1, 2]. Earlier biomechanical analyses of punching mechanics demonstrated that effective mass transfer and impulse generation are determinants of strike performance [1, 3].

Advances in three-dimensional motion analysis have expanded understanding of punching biomechanics over the past decade. Kinematic and kinetic investigations have demonstrated that trunk rotation, coordinated segmental motion, and temporal sequencing of body segments contribute to effective force generation during punching actions [4, 5]. Subsequent biomechanical analyses have also identified distinct movement phases and emphasized the role of intersegmental coordination in the execution of various punch types, including the cross, hook, and uppercut [2, 6]. In addition, kinematic comparisons of single and combination punches indicate that punch execution involves coordinated segmental velocity patterns across the kinetic chain [7]. Comparative investigations across competitive levels further show that elite boxers demonstrate more refined temporal coordination and proximal-to-distal sequencing patterns than junior athletes [6, 8].

Lower-extremity mechanics are recognized as important contributors to punching performance. Interactions between the hip, knee, and ankle joints influence ground reaction force development, propulsion, and stabilization during punching movements [9, 10, 11, 12]. Studies examining strength–power characteristics and force-development indices have demonstrated associations between lower-limb mechanical output and punch impact magnitude in trained boxers [9, 11, 13]. In addition, recent investigations using wearable sensors, inertial measurement units, and machine-learning-based kinematic analysis have further highlighted the contribution of coordinated lower-limb mechanics to high-velocity striking movements in combat sports [14, 15, 16].

Much of the biomechanical research on punching has examined trunk rotation, segmental coordination, and the temporal sequencing of body segments during striking actions [2, 5, 10]. The uppercut differs mechanically from linear punches because it involves greater vertical movement components and dynamic transitions between support phases during strike execution [6, 17]. These characteristics suggest that lower-limb stabilization and push-off coordination may contribute to the organization of the kinetic chain and may influence proximal segment acceleration.

The ankle joint contributes to load absorption, propulsion, and postural stabilization during dynamic movements in combat sports [18, 19]. Biomechanical investigations of striking and rotational tasks indicate that variations in distal joint positioning may influence the transmission of motion through the kinetic chain [18, 20, 21]. Electromyographic studies of punching movements demonstrate coordinated activation of lower- and upper-limb musculature during strike execution [22], supporting the concept of integrated segmental control within the kinetic chain. Previous investigations have also reported differences in punch force production and coordination between athletes of different competitive levels [6, 23]. However, the specific contribution of ankle joint angular characteristics across qualification levels remains insufficiently examined. Recent developments in instrumented striking systems and biomechanical modeling provide additional methodological possibilities for joint-level analysis of punching movements [24, 25, 26].

Analysis of research findings has shown that punching performance in boxing depends on coordinated interactions among multiple segments of the kinetic chain, including contributions from the lower extremities, trunk, and upper limbs. Researchers emphasize that temporal sequencing of segmental movements, joint positioning, and force transmission patterns influence the mechanical effectiveness of striking actions. At the same time, biomechanical characteristics of different punching techniques involve specific movement demands and support-phase transitions that affect distal joint function and stabilization strategies. These factors indicate the relevance of examining ankle joint kinematics during the execution of complex punching actions in boxing. Despite these findings, qualification-dependent variation in ankle kinematics during uppercut execution remains insufficiently examined. Analysis of whether qualification status is associated with systematic differences in ankle joint positioning and angular velocity may provide insight into phase-specific motor control strategies and technical refinement mechanisms in high-level boxing performance.

Therefore, the present exploratory pilot study aimed to examine qualification-dependent differences in sagittal-plane ankle joint kinematic parameters during execution of the right-hand uppercut in boxers of high sport qualification. In accordance with this objective, it was hypothesized that boxers of higher qualification would demonstrate differences in sagittal-plane ankle joint positioning and range-of-motion characteristics during transitional support phases of the uppercut compared with boxers of lower qualification. It was also assumed that qualification level may be associated with differences in ankle angular velocity parameters during punch execution.

Materials and Methods

Participants

A total of 36 male boxers participated in this cross-sectional laboratory study and were stratified according to sport qualification into two groups: highly qualified boxers (n = 18) and advanced-level boxers (n = 18). Participants in both groups demonstrated comparable anthropometric characteristics. The highly qualified group had a mean age of 21.0 ± 1.2 years, mean body height of 176.0 ± 3.0 cm, and mean body mass of 60.0 ± 2.1 kg, whereas the advanced-level group presented similar age and stature (21.0 ± 1.4 years, 176.0 ± 2.8 cm) with slightly higher body mass (62.5 ± 3.5 kg).

Inclusion criteria required athletes to have a minimum of five years of structured boxing training and to be actively competing at the national level at the time of testing. Exclusion criteria included any lower-extremity musculoskeletal injury or other performance-limiting condition within the six months preceding data collection.

All procedures complied with the Declaration of Helsinki and were approved by the Ethics Committee of the Uzbek State University of Physical Education and Sport (Approval No. 15/AT2.10/2025). Written informed consent was obtained from all participants prior to participation.

Research Design

This investigation was designed as an exploratory cross-sectional pilot study aimed at identifying preliminary biomechanical tendencies in ankle joint kinematics associated with athlete qualification level. Due to the limited availability of high-level combat sport athletes and strict inclusion criteria, the study was not intended to provide causal conclusions but rather to generate hypothesis-generating insights to inform future larger-scale investigations.

Independent comparisons were performed to assess baseline anthropometric characteristics between groups. No statistically significant differences were observed ($p > 0.05$), indicating comparable baseline characteristics between the groups. A post-hoc power analysis was conducted to estimate the statistical power of the sample size. With 18 participants per group ($\alpha = 0.05$), the sample provided approximately 80% statistical power to detect large effect sizes (Hedges' $g \geq 0.90$).

Participants performed a standardized boxing-specific warm-up before testing. Each athlete executed several maximal-effort right-hand uppercuts toward a fixed target under controlled laboratory conditions. To ensure technical consistency, a certified boxing coach supervised all trials and verified correct movement execution. Given the exploratory design and the high technical consistency expected among high-level athletes, the single best technically valid trial was selected for biomechanical analysis. A trial was considered technically valid if the punch was executed with a proper uppercut trajectory and without marker occlusion. This approach was adopted to minimize variability associated with submaximal or technically inconsistent attempts. Uppercut execution was temporally divided into three biomechanical phases:

1. Preparation phase
2. Mid-support phase
3. Propulsion phase.

Phase boundaries were identified using kinematic event detection based on ankle and pelvis marker trajectories.

Instrumentation

Three-dimensional kinematic data were collected at the Sports Biomechanics Laboratory, Scientific Research Center, Uzbek State University of Physical Education and Sport, Chirchik, Uzbekistan, using the STT Systems 3D Motion Analysis platform (3DMA 2023.0, Motive software; STT Systems, San Sebastián, Spain).

The motion capture system consisted of a multi-camera infrared optoelectronic setup operating at a sampling frequency of 120 Hz, enabling full-body three-dimensional reconstruction of segmental motion during dynamic athletic movements.

Segment coordinate systems were defined according to the International Society of Biomechanics (ISB) recommendations [27, 28].

Data acquisition and processing were performed using STT Motive 3DMA software (Version 2023.0). The recording protocol followed the Full-Body 19-Point Helen Hayes biomechanical model, allowing three-dimensional reconstruction of the trunk, pelvis, neck, shoulders, elbows, hips, knees, and ankles.

Reflective markers (14 mm diameter) were placed bilaterally on standardized anatomical landmarks according to a modified Helen Hayes lower-extremity configuration, including:

- greater trochanter
- lateral femoral epicondyle
- tibial tuberosity
- medial and lateral malleoli
- calcaneus
- second metatarsal head.

The STT 3D Motion Analysis system enables computation of:

- three-dimensional joint angles (sagittal, frontal, and transverse planes)
- phase-specific angular parameters (contact, mid-support, toe-off)
- maximum angular velocity (°/s)
- spatiotemporal displacement variables (mm)
- center-of-mass oscillation
- propulsion and braking distance
- time-normalized kinematic curves.

Angular velocity was calculated as the first derivative of angular displacement with respect to time.

Although full three-dimensional kinematics were recorded, the present analysis focused on sagittal-plane ankle mechanics, reflecting the plantarflexion-dominant propulsion and predominantly vertical force-vector orientation characteristic of the uppercut technique.

The following ankle-specific variables were extracted:

- minimum dorsiflexion angle (°)
- maximum plantarflexion angle (°)
- range of motion (ROM, °)
- maximum angular velocity (°/s)
- toe-off angle (°)
- mid-support angle (°)
- propulsion displacement (mm).

Raw marker trajectories were filtered using a fourth-order zero-lag low-pass Butterworth filter with a cut-off frequency between 6 and 10 Hz, determined via residual analysis to minimize signal noise while preserving movement dynamics.

All punch cycles were time-normalized to 100% of movement duration to enable inter-individual comparison. System calibration was performed prior to each recording session to maintain reconstruction accuracy within manufacturer-recommended limits.

Statistical Analysis

Because multiple ankle-related variables were examined, the possibility of increased Type I error associated with multiple comparisons was considered. Given the exploratory pilot design of the study and the relatively small sample size, formal multiplicity correction was not applied. Interpretation therefore emphasized standardized effect size magnitude (Hedges' g) and the precision of corresponding 95% confidence intervals.

All statistical analyses were performed using SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated as mean ± standard deviation (mean ± SD). Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test.

Between-group comparisons (highly qualified boxers vs advanced-level boxers) were conducted using independent samples t-tests. Standardized mean differences were calculated using bias-corrected Hedges' g to account for small-sample bias. Ninety-five percent confidence intervals (95% CI) were computed for all effect size estimates. Additionally, eta squared (η^2) values were derived from the t-statistic to estimate the proportion of variance explained by qualification level.

Effect size magnitude was interpreted according to the following thresholds:

- trivial (<0.20)
- small (0.20–0.49)
- moderate (0.50–0.79)
- large (⩾0.80).

Results

Between-group comparisons were conducted to examine qualification-related differences in ankle joint kinematic parameters during execution of the right-hand uppercut (Table 1).

Table 1 presents between-group comparisons

Table 1. Between-group differences in ankle kinematics during the right-hand uppercut.

№	Parameter	Limb	Highly qualified boxers (n=18) (Mean ± SD)	Advanced-level boxers (n=18) (Mean ± SD)	Δ	Hedges g	95% CI		η^2
							Lower	Upper	
1.	Minimum angle (°)	RA	10.83 ± 0.65	9.74 ± 1.98	1.09	0.72	0.04	1.40	0.13
2.	Minimum angle (°)	LA	-6.29 ± 3.37	-4.81 ± 2.94	-1.48	-0.46	-1.12	0.20	0.06
3.	Maximum angle (°)	RA	17.53 ± 1.57	16.42 ± 2.11	1.11	0.55	-0.12	1.22	0.08
4.	Maximum angle (°)	LA	1.10 ± 3.97	-0.85 ± 2.88	1.95	0.52	-0.14	1.18	0.07
5.	ROM (°)	RA	6.91 ± 1.53	6.68 ± 2.02	0.23	0.12	-0.53	0.77	0.00
6.	ROM (°)	LA	6.71 ± 4.64	3.96 ± 3.11	2.75	0.67	-0.00	1.34	0.11
7.	Maximum angular velocity (°/s)	RA	46.72 ± 12.99	41.58 ± 14.26	5.14	0.36	-0.30	1.02	0.03
8.	Maximum angular velocity (°/s)	LA	67.30 ± 48.57	54.22 ± 32.15	13.08	0.30	-0.36	0.96	0.02
9.	Toe-off angle (°)	RA	12.85 ± 2.73	10.92 ± 3.61	1.93	0.55	-0.12	1.22	0.08
10.	Toe-off angle (°)	LA	-2.64 ± 1.32	-1.83 ± 1.75	-0.81	-0.48	-1.14	0.18	0.06
11.	Mid-support angle (°)	RA	14.72 ± 3.10	12.36 ± 2.94	2.36	0.76	0.08	1.44	0.14
12.	Mid-support angle (°)	LA	-3.89 ± 4.41	-2.14 ± 3.02	-1.75	-0.45	-1.11	0.21	0.05
13.	Propulsion distance (mm)	RA	-154.6 ± 86.77	-121.42 ± 73.18	-33.18	-0.40	-1.06	0.26	0.04
14.	Propulsion distance (mm)	LA	-49.38 ± 31.09	-38.55 ± 27.74	-10.83	-0.36	-1.02	0.30	0.03

Note: Data are presented as mean ± SD. Between-group differences were quantified using bias-corrected Hedges' g ($n_1 = n_2 = 18$; df = 34), with 95% confidence intervals reported as lower and upper bounds. Effect size magnitude was interpreted as trivial (<0.20), small (0.20–0.49), moderate (0.50–0.79), and large (⩾0.80). Eta squared (η^2) was calculated as $\eta^2 = t^2 / (t^2 + df)$. RA = right ankle; LA = left ankle; ROM = range of motion.

of ankle joint kinematic parameters during execution of the right-hand uppercut. The analyzed variables included minimum and maximum ankle angles, range of motion (ROM), maximum angular velocity, toe-off angle, mid-support angle, and propulsion distance for both the right and left ankles. Standardized mean differences ranged from trivial to moderate magnitude across the analyzed parameters. The largest effects were observed for the right ankle mid-support angle and the right ankle minimum angle, whereas several additional parameters demonstrated moderate effect sizes with confidence intervals overlapping the null boundary. For most remaining variables, effect sizes were small or accompanied by wide confidence intervals. Several left ankle parameters showed negative effect sizes, indicating slightly greater values in advanced-level boxers. Overall, the pattern of results indicates that qualification-related differences were more apparent in sagittal-plane ankle positioning variables during transitional phases of support, whereas angular velocity and propulsion-related variables showed smaller and less consistent differences.

The integrated effect-size analysis presented in Figures 1–4 summarizes between-group differences in ankle joint kinematic parameters during execution of the right-hand uppercut. Overall, the observed pattern indicates that qualification-related differences are primarily associated with sagittal-plane ankle joint positioning during transitional support phases, whereas variables related to peak

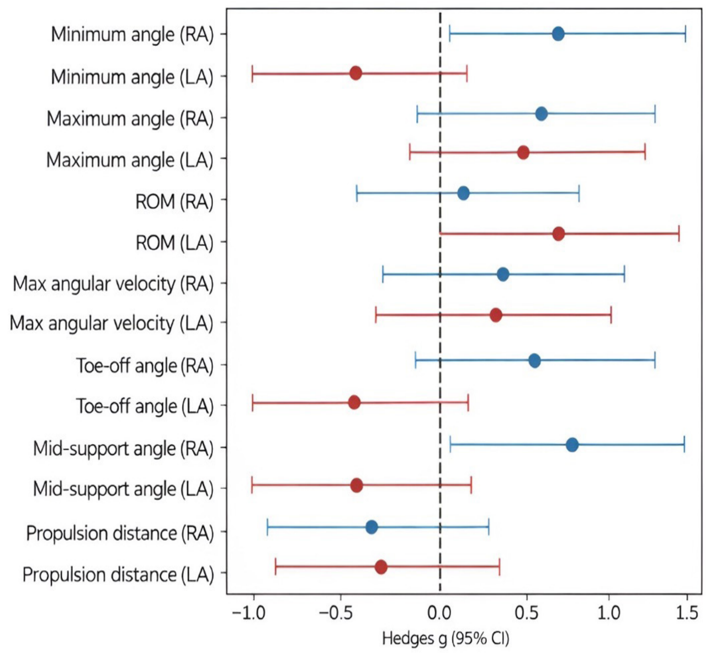

Figure 1. Effect size analysis of ankle joint angles (pre-jump and support phases)

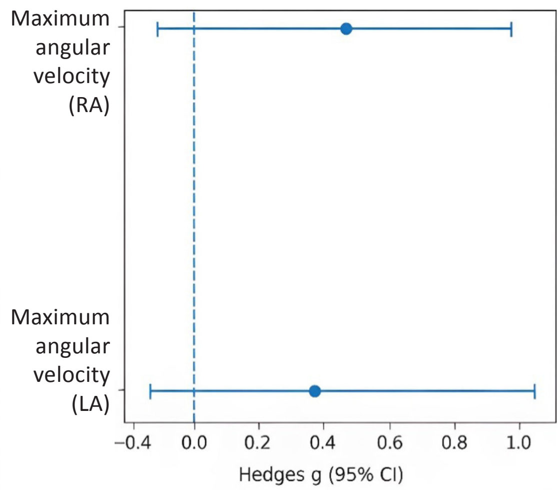

Figure 3. Between-group standardized differences in maximum ankle angular velocity during the right uppercut

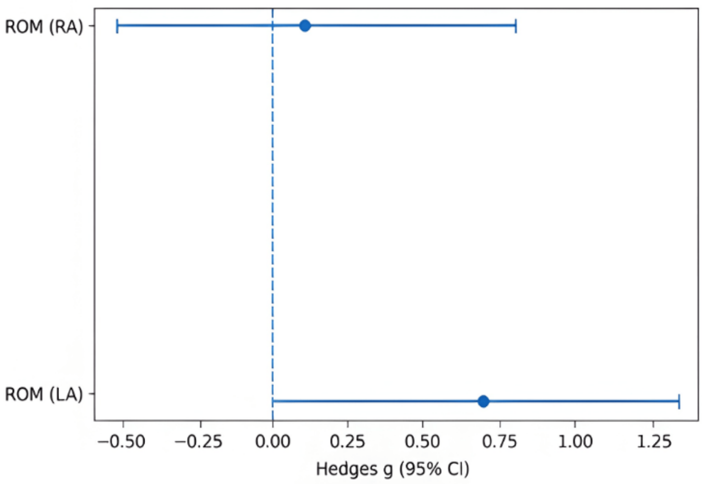

Figure 2. Between-group standardized differences in ankle range of motion (ROM) during the right uppercut

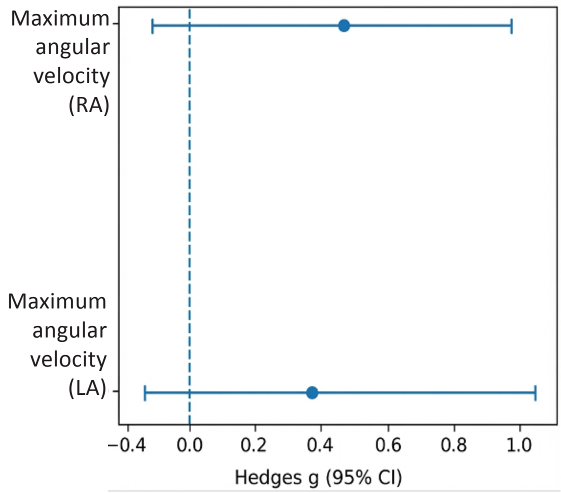

Figure 4. Between-group standardized differences in ankle propulsion distance during the right uppercut

angular velocity and propulsion displacement demonstrate smaller and less consistent effects.

The most consistent between-group difference was observed in the right ankle mid-support angle (Figure 1), where the effect size indicated a moderate directional difference between the examined qualification groups. The confidence interval for this parameter remained above the null boundary. This variable reflects ankle joint positioning during the mid-support phase of the movement, which represents a transitional stage of weight transfer within the lower-limb support sequence during the uppercut. A comparable effect magnitude was observed for the right ankle minimum angle (Figure 1). This parameter describes ankle joint positioning during the preparatory stage of the movement preceding propulsion. Moderate effect sizes were also observed for left ankle range of motion (Figure 2) and for the right ankle maximum and toe-off angles (Figure 1). However, the corresponding confidence intervals overlapped the null boundary, indicating limited precision of these estimates. In contrast, maximum angular velocity parameters (Figure 3) demonstrated small standardized differences between groups, with confidence intervals crossing the null boundary. Similarly, propulsion distance variables (Figure 4) showed small negative effects with confidence intervals overlapping the null boundary. Overall, the figures indicate that between-group differences were more apparent in sagittal-plane ankle positioning variables during transitional phases of the movement, whereas variables describing peak angular velocity and propulsion displacement showed smaller and less consistent differences.

Discussion

This exploratory pilot study examined qualification-related variations in sagittal-plane ankle kinematics during execution of the right-hand uppercut in boxers of high sport qualification. Because of the cross-sectional design and moderate statistical precision, the findings should be interpreted as descriptive patterns rather than causal mechanisms. The results showed that the most apparent differences between groups were observed in ankle joint positioning during transitional support phases of the movement, particularly during mid-support and the preparatory stage preceding propulsion. Greater sagittal-plane ankle positioning was observed in highly qualified boxers during these phases. Moderate effects were also identified for the right ankle maximum and toe-off angles; however, their confidence intervals overlapped zero, indicating limited statistical precision. In contrast, maximum ankle angular velocity and propulsion distance demonstrated small and less consistent differences between groups. These results indicate that qualification-related distinctions may be reflected primarily in ankle joint positioning and phase-specific joint configuration rather than in peak angular velocity or propulsion displacement during the uppercut movement.

Phase-Specific Ankle Stabilization

The right ankle mid-support angle demonstrated the largest standardized difference between groups ($g = 0.76$; $\eta^2 = 0.14$), indicating a moderate effect magnitude. The mid-support phase represents a transitional stage of weight transfer within the lower-limb support sequence. The greater sagittal-plane ankle positioning observed in highly qualified boxers may reflect differences in phase-specific joint alignment during this stage of the uppercut movement.

Although these positional differences may be related to variations in movement control during support and weight transfer, the absence of direct kinetic or neuromuscular measurements means that such interpretations should be considered cautiously and viewed as hypothesis-generating rather than definitive biomechanical explanations.

These observations are broadly consistent with previous biomechanical investigations highlighting the role of intersegmental coordination during punching actions. For example, the results of the study [1] indicated that lower-limb mechanics contribute to the sequencing of movement during punching tasks. However, because the present study focused specifically on ankle joint kinematics, the current findings should be interpreted as reflecting differences in joint positioning strategies rather than direct evidence of force transmission or energy transfer mechanisms.

Joint Excursion and Pre-Propulsive Modulation

Moderate standardized differences were observed in the right ankle minimum angle ($g = 0.72$) and left ankle range of motion (ROM) ($g = 0.67$). These findings indicate that highly qualified boxers demonstrated slightly greater dorsiflexion positioning during the preparatory stage preceding propulsion. Such differences may reflect variation in ankle joint configuration during the loading phase of the movement. However, because the present study did not include kinetic measurements, these observations should be interpreted cautiously and regarded as descriptive rather than mechanistic.

Previous biomechanical investigations have emphasized the importance of lower-limb coordination and joint positioning during the preparatory phases of punching movements [2, 5, 6]. Three-dimensional analyses of punching mechanics have shown that body-segment positioning and temporal coordination influence the mechanical conditions under which propulsion is initiated [2, 5]. In this context, the present findings suggest that ankle joint excursion may contribute to phase-specific movement organization during the execution of the uppercut.

The trivial effect observed in right ankle ROM indicates that not all displacement-related variables vary consistently with qualification level. This pattern suggests that phase-specific joint positioning may be more informative than global displacement measures alone. A similar perspective has been noted in previous biomechanical analyses of punching movements, where overall range of motion was not considered the primary determinant of punching performance in highly trained athletes [7].

Angular Velocity Considerations

Maximum ankle angular velocity demonstrated small standardized differences (g = 0.36 for the right ankle; g = 0.30 for the left ankle), indicating limited differentiation between qualification groups in peak ankle angular velocity during the uppercut movement.

Previous biomechanical studies have suggested that trunk and upper-limb rotational velocities contribute substantially to punching speed and impact performance [10, 16]. Investigations of neuromuscular performance and punch-force production further indicate that explosive activation and coordination of upper- and lower-limb musculature influence strike velocity and force generation in amateur boxers [29]. In addition, recent machine-learning and kinematic classification studies demonstrate that punch recognition and performance analysis rely strongly on coordinated upper-limb velocity patterns and movement sequencing [15]. In this context, the present results may indicate that the ankle joint contributes primarily to movement support and phase-specific positioning rather than serving as the principal source of angular acceleration during the strike.

Similar interpretations have been proposed in earlier biomechanical analyses. For example, the results of the study [10] indicated that lower-limb positioning and coordination during punching movements may contribute to maintaining stability during the support phase. However, because the present study focused solely on kinematic measurements, these interpretations should be considered tentative and hypothesis-generating rather than definitive biomechanical conclusions.

Propulsion-Phase Orientation

Moderate directional differences were observed in the right ankle toe-off angle (g = 0.52; η^2 = 0.12), indicating variation in ankle joint orientation during the propulsion phase. The toe-off event represents the final stage of ground contact preceding the upward acceleration of body segments involved in the punching action. In this context, sagittal-plane ankle orientation at toe-off may reflect differences in movement organization during the transition from support to propulsion.

However, because the present study did not include ground reaction force or impulse measurements, the mechanical implications of these angular tendencies remain uncertain. Consequently, the observed differences should be interpreted as potential variations in joint positioning strategies rather than determinants of force production. Similar observations have been noted in previous biomechanical and analytical investigations of striking techniques. Previous studies have suggested that lower-limb alignment and segmental coordination may influence the mechanical conditions under which force is transmitted through the body segments involved in striking actions [8, 30]. In addition, analytical reviews of combat-sport biomechanics indicate that lower-limb mechanics and kinetic-chain coordination represent important components of striking performance and remain active areas of scientific investigation [31].

Integrative Interpretation

The effect-size distribution suggests that qualification-related differences may be more apparent in sagittal-plane ankle joint positioning during transitional support phases than in peak angular velocity or propulsion displacement variables. This pattern may indicate that variations between qualification groups are more closely associated with phase-specific joint positioning characteristics rather than differences in distal segment velocity.

Importantly, η^2 values ranging from 0.12 to 0.17 indicate that qualification level explained a modest proportion of variance in several ankle kinematic parameters. However, the relatively wide confidence intervals observed across many variables reflect moderate statistical uncertainty. These findings should therefore be interpreted cautiously and considered hypothesis-generating rather than conclusive, particularly given the cross-sectional design and sample size of the present study.

Limitations of the Study and Future Directions

Several limitations should be considered when interpreting the present findings:

1. Although the sample consisted of boxers of high sport qualification (n = 36; 18 per group), the statistical precision of several estimates remained moderate, as reflected in the relatively wide confidence intervals. Consequently, the reported effect sizes should be interpreted as indicative of directional tendencies rather than population-level differences. The cross-sectional design and sample size also limit statistical power.
2. Despite the use of three-dimensional motion capture, the analysis focused primarily on sagittal-plane ankle mechanics. Because the uppercut movement involves multiplanar joint interactions, the exclusion of frontal

and transverse plane contributions restricts the comprehensiveness of the biomechanical interpretation.

3. The study did not include synchronized kinetic measurements such as ground reaction forces or impulse variables. As a result, the relationship between the observed kinematic differences and mechanical output during punching cannot be directly established.
4. Biomechanical analysis was based on a single technically valid maximal trial per participant. While this approach minimized execution variability, it did not allow assessment of intra-individual reliability or movement consistency across repeated attempts.
5. The analysis included multiple kinematic variables within a moderately sized cohort, which may increase statistical uncertainty in effect size estimation. Additionally, although the participants were nationally competing boxers, the findings may not necessarily generalize to athletes of different competitive levels, age groups, or training backgrounds. Potential confounding factors such as training volume, stance dominance, and competitive experience were not controlled in the present analysis.

Future research should extend the present exploratory findings through more comprehensive biomechanical analyses. In particular, integrating synchronized kinetic–kinematic modeling would allow simultaneous examination of joint motion and force-related variables influencing punching performance. Multiplanar joint analysis may provide a more complete description of how qualification-related differences manifest across sagittal, frontal, and transverse planes of motion. Further investigation may also incorporate electromyographic (EMG) assessment of lower-limb muscle activation to examine neuromuscular control strategies involved in ankle stabilization during punching actions. Studies involving larger multicenter samples may improve statistical power and allow validation of the tendencies observed in the present pilot investigation.

Conclusions

From a practical standpoint, the present findings suggest that training strategies aimed at improving uppercut performance may benefit from emphasizing phase-specific ankle stabilization and controlled dorsiflexion–plantarflexion modulation, rather than focusing exclusively on increasing distal joint angular velocity. Such an approach may contribute to more consistent joint positioning during transitional support phases of the striking movement.

The present exploratory pilot study indicates that qualification-related differences in uppercut execution may be associated with ankle joint positioning during transitional support phases of the movement. These observations highlight the potential role of phase-specific joint control in the organization of punching mechanics. However, given the cross-sectional design, moderate statistical precision, and absence of synchronized kinetic measurements, the findings should be interpreted cautiously and regarded as preliminary evidence requiring further confirmation in larger biomechanical investigations.

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The authors used AI-assisted language editing tools to improve the clarity and grammar of the manuscript. All scientific content, analysis, and interpretations remain the sole responsibility of the authors.

Conflict of Interest

The authors declare that they have no conflict of interest.

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