










## Predictive power of deep squat and Abalakov jump tests in roundhouse kick performance among elite striking athletes

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### ORIGINAL PAPER

#### Abstract

This study investigated the relationship between variables of the deep squat jump (DSJ) and the Abalakov jump (ABK) and the performance of the rear leg roundhouse kick in elite combat sport athletes. Twenty-seven elite taekwondo athletes (12 females) performed three attempts of each movement: DSJ and ABK (measured with Pasco® force platforms), and the roundhouse kick (analyzed with Vicon® motion capture systems). The key findings demonstrated that specific force and power metrics from the jumps are significant predictors of kicking kinematics. For the DSJ, the rate of force development (RFD) in the first 100 ms of the concentric phase (RFDcon) was a primary predictor, independently explaining 21% of the variance in linear foot velocity ( $p=0.009$ ) and 30.3% in linear foot acceleration ( $p=0.003$ ). Furthermore, for the non-dominant (stance) limb, takeoff peak force independently predicted angular hip acceleration ( $R^2=0.144$ ,  $p=0.029$ ). For the ABK, the eccentric braking RFD at 100 ms (RFDecc) emerged as a strong predictor, accounting for 24% of the variance in angular hip acceleration ( $p=0.006$ ). In conclusion, this study validates the DSJ and ABK as practical tools for assessing qualities critical to roundhouse kick performance. Coaches should prioritize monitoring RFDcon and stance limb strength during a DSJ, as well as the RFDecc during an ABK, to evaluate and train for improved kicking power.

**Keywords:** Martial arts; combat sports; sport performance; biomechanics; kinematic analysis.

#### Poder predictivo de las pruebas de sentadilla profunda y salto Abalakov en el rendimiento de la patada circular en atletas de golpeo de élite

##### Resumen

Este estudio investigó la relación entre variables del salto en cuclillas profundo (DSJ) y del salto Abalakov (ABK) y el rendimiento de la patada circular con la pierna trasera en

#### Poder predictivo dos testes de agachamento profundo e salto Abalakov no desempenho do chute circular em atletas de striking de elite

##### Resumo

Este estudo investigou a relação entre as variáveis do salto agachado profundo (DSJ) e do salto Abalakov (ABK) e o desempenho do chute circular com a perna traseira

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atletas de deportes de combate de élite. Veintisiete atletas de élite de taekwondo (12 mujeres) realizaron tres intentos de cada movimiento: DSJ y ABK (medidos con plataformas de fuerza Pasco®), y la patada circular (analizada con sistemas de captura de movimiento Vicon®). Los hallazgos clave mostraron que las métricas específicas de fuerza y potencia de los saltos son predictores significativos de la cinemática de la patada. Para el DSJ, la tasa de desarrollo de fuerza (RFD) en los primeros 100 ms de la fase concéntrica (RFDcon) fue un predictor principal, explicando de forma independiente el 21% de la varianza en la velocidad lineal del pie ( $p=0.009$ ) y el 30.3% en la aceleración lineal del pie ( $p=0.003$ ). Además, para el miembro no dominante (de apoyo), el pico de fuerza en el despegue predijo de forma independiente la aceleración angular de la cadera ( $R^2=0.144$ ,  $p=0.029$ ). Para el ABK, la RFD de frenado excéntrico a los 100 ms (RFDec) surgió como un fuerte predictor, explicando el 24% de la varianza en la aceleración angular de la cadera ( $p=0.006$ ). En conclusión, este estudio valida el DSJ y el ABK como herramientas prácticas para evaluar cualidades críticas para el rendimiento de la patada circular. Los entrenadores deberían priorizar el monitoreo de la RFDcon y la fuerza del miembro de apoyo durante un DSJ, así como la RFDec durante un ABK, para evaluar y entrenar la mejora de la potencia de la patada.

**Palabras clave:** Artes marciales; deportes de combate; rendimiento deportivo; biomecánica; análisis cinemático.

em atletas de esportes de combate de elite. Vinte e sete atletas de elite de taekwondo (12 mulheres) realizaram três tentativas de cada movimento: DSJ e ABK (medidos com plataformas de força Pasco®), e o chute circular (analisado com sistemas de captura de movimento Vicon®). Os principais achados demonstraram que métricas específicas de força e potência dos saltos são preditores significativos da cinemática do chute. Para o DSJ, a taxa de desenvolvimento de força (RFD) nos primeiros 100 ms da fase concêntrica (RFDcon) foi um preditor primário, explicando de forma independente 21% da variância na velocidade linear do pé ( $p=0.009$ ) e 30,3% na aceleração linear do pé ( $p=0.003$ ). Além disso, para o membro não dominante (de apoio), o pico de força na decolagem previu independentemente a aceleração angular do quadril ( $R^2=0,144$ ,  $p=0,029$ ). Para o ABK, a RFD de frenagem excêntrica aos 100 ms (RFDec) emergiu como um forte preditor, respondendo por 24% da variância na aceleração angular do quadril ( $p=0,006$ ). Em conclusão, este estudo valida o DSJ e o ABK como ferramentas práticas para avaliar qualidades críticas para o desempenho do chute circular. Treinadores devem priorizar o monitoramento da RFDcon e da força do membro de apoio durante um DSJ, bem como da RFDec durante um ABK, para avaliar e treinar a melhoria da potência do chute.

**Palavras-chave:** Artes marciais; desportos de combate; desempenho esportivo; biomecânica; análise cinemática.

## 1. Introduction

Among the techniques common to striking combat sports, the roundhouse kick stands out as one of the most efficient and frequently employed attacks (Diniz et al., 2021; Estevan et al., 2014; Gavagan & Sayers, 2017; Moenig, 2012; Vagner et al., 2023). Its effective execution requires high levels of agility, muscular power, flexibility, and motor precision (Diniz et al., 2021). Athletes' preference for using this kick is related to its execution speed (Antonietto et al., 2024; Corcoran et al., 2024). In a review on the force and speed of kicks used by striking athletes, Corcoran et al. (2024) observed that the roundhouse kick produces the highest linear velocity at the foot (18.3 m/s). From a biomechanical perspective, effective performance of this kick is characterized by a dynamic sequence that includes: (1) rapid pelvic axial rotation, (2) hip abduction and flexion, (3) explosive knee extension, and (4) accelerated displacement of the center of mass towards the target (Estevan et al., 2014; Gavagan & Sayers, 2017). Although universal, specific terminological variations exist according to the striking discipline: *Bandal Chagi* in taekwondo (Estevan et al., 2014), *Mawashi-Geri* in karate, *Tei Chiyang* in muay Thai, and *Roundhouse Kick* in kickboxing and Mixed Martial Arts, each adapted to the specific rules and objectives of their respective competitions (Diniz et al., 2021).

Due to its technical and tactical relevance, the roundhouse kick has been the subject of biomechanical studies seeking to identify the kinematic determinants associated with its performance (Diniz et al., 2021; Estevan et al., 2014; Gavagan & Sayers, 2017; T. Y. Huang et al., 2025; Miziara et al., 2019). Diniz et al. (2021) observed similarities (linear acceleration and knee velocity) and disparities (distance to the target and hip velocity) when comparing taekwondo, karate, and muay Thai athletes. In a similar comparison, Gavagan and Sayers (2017) noted that muay Thai athletes exhibit greater center of mass movement when performing the roundhouse kick compared to karate and taekwondo athletes. Meanwhile, Miziara et al. (2019) analyzed the relationship between pelvic angular velocity and impact force, demonstrating that elite athletes achieve pelvic rotation peaks 23% higher than novices. T. Y. Huang et al. (2025) investigated the kinematic and kinetic demands of high-performance kicks, identifying that the synchronization between hip flexion and knee extension explains 72% of the variance in kick power.

Like the aforementioned studies, the review by Corcoran et al. (2024) emphasized the importance of kinematic analysis for the performance of striking combat athletes. Indeed, kinematic



analyses are widely recognized as essential tools for optimizing sports movements in high performance (Ahmadi et al., 2009; Li et al., 2025). However, three-dimensional motion capture videophotogrammetric systems, such as Vicon®, involve high costs and are difficult to use outside laboratory environments (Fiorentino et al., 2013; Torvinen et al., 2024). Furthermore, these systems require substantial time for analysis and a high level of evaluator expertise (Torvinen et al., 2024). Given this context, it is desirable to have more accessible methods to evaluate large numbers of athletes. Recently, Antonietto et al. (2024) showed that CMJ stiffness and the rate of force development in the squat jump (SJ) are the primary variables associated with roundhouse kick performance in international-level taekwondo athletes.

Similarly, other previous studies have used the CMJ to predict the performance of striking athletes (Albuquerque et al., 2021; Chaabène et al., 2012; Chiang et al., 2025). Chiang et al. (2025) observed that taekwondo medalists exhibit better CMJ performance. Albuquerque et al. (2021) showed that CMJ correlates ( $r=0.44$ ) with performance on the Frequency Kick Speed Test. Despite the widespread use of jump tests in combat sports, the vast majority of studies focus on the CMJ and SJ (Tabben et al., 2014). Few studies have used the Abalakov Jump (ABK) and the Deep Squat Jump (DSJ).

The novelty of employing DSJ and ABK lies in the fact that these jumps may provide complementary information to CMJ and SJ, as they emphasize distinct biomechanical demands. DSJ and ABK were specifically chosen for this study because they assess key biomechanical qualities, such as explosive lower limb power, rapid force production, and neuromuscular coordination, which are fundamental to the execution of the roundhouse kick (Jia, Liu, et al., 2024; Jia, Yong, et al., 2024). Furthermore, the knee flexion achieved in these jump tests is more similar to the range of motion required during this kick (Liu et al., 2023; Rafael et al., 2008). Both the DSJ and ABK emphasize powerful hip and knee extension, high angular velocities, and efficient transfer of force from the lower limbs, which are biomechanical characteristics shown to be critical for effective roundhouse kicking and high scoring in combat sports (Jia, Liu, et al., 2024; Jia, Yong, et al., 2024; Vagner et al., 2023). While the DSJ isolates concentric muscle action from a deep knee angle, the ABK integrates trunk and upper limb coordination into explosive lower-limb actions. Therefore, testing these jumps in combat athletes could reveal performance predictors not captured by traditional CMJ and SJ assessments.

Although rarely used, the DSJ appears to be an interesting alternative for athlete testing. Two previous studies indicated this jump is a valuable tool for assessing Olympic weightlifting athletes (Soriano et al., 2024; Vizcaya et al., 2009). In basketball players, Bazanov et al. (2019) suggested that the DSJ not only assesses vertical jump capacity but also differentiates athletic performance levels, as athletes with better performance in this jump exhibited greater lower limb power. The ABK has been proposed as a comprehensive jump for assessing sports performance, as it not only measures the explosive force of the lower limbs through the countermovement but also incorporates a coordinated movement of the trunk and upper limbs (Ruiz et al., 2006). Previous studies have shown that ABK can be an assessment tool for soccer and basketball players (Sáez de Villarreal et al., 2015; Santos & Janeira, 2008; Vargas-Molina et al., 2022). In this regard, Vargas-Molina et al. (2022) observed significant improvements after a 10-week strength program in young basketball players, while Sáez de Villarreal et al. (2015) reported similar gains after plyometric and speed training in adolescent soccer players.

Regarding the use of these jumps in combat sports athletes, to the best of our knowledge, only the study by Cárdenas et al. (2019) applied the ABK test to wrestlers, where results indicated that Greco-Roman style athletes performed better than freestyle wrestlers. However, this study used a smartphone application (MyJump®), which limits measurement accuracy due to its indirect nature. Indeed, studies recommend using force platforms over contact mats, which are only valid for measuring jump height and flight time (Pojskić et al., 2022). Force platforms, in contrast, can measure ground reaction force (Chavda et al., 2025), peak force, and rate of force development (Joffe et al., 2023; Pojskić et al., 2022), which are important performance measures. Given this context, the present study aimed to verify whether variables measured in the DSJ and ABK are associated with rear roundhouse kick performance in elite fighters. We hypothesized that both jumps would contain variables predictive of roundhouse kick performance.

## 2. Materials and methods

### 2.1. Experimental approach

This cross-sectional study analyzed elite taekwondo athletes in a biomechanics laboratory setting. Following approval from the institutional ethics committee of the State University of Minas Gerais (CAAE: 82274124.6.0000.5112; protocol: 7.108.464), we obtained permission from the National Taekwondo Federation and main coaches. All assessments were completed during a single laboratory visit. The standardized testing protocol proceeded in the following sequence: (a) Anthropometry; (b) Standardized Warm-up; (c) ABK; (d) DSJ and (e) rear roundhouse kick.

### 2.2. Participants

This cross-sectional study included elite male and female taekwondo athletes. Inclusion criteria were: (1) age  $\geq 18$  years, (2)  $\geq 5$  years of uninterrupted competitive training, (3) black belt certification, and (4) attainment of  $\geq$  national champion status. Exclusion criteria comprised: (1) acute or chronic injuries impairing test performance, (2) technical errors during kinematic signal acquisition, or (3) voluntary withdrawal from the study. From an initial pool of 120 athletes screened, 56 met the inclusion criteria. Of these, 28 (16 male, 12 female) consented to participate. One male athlete was excluded due to errors in kinematic signal capture, resulting in a final cohort of 27 athletes (15 male, 12 female). The sample included 11 national champions, 8 South American medalists, and 8 Pan-American medalists (2022 competition cycle).

### 2.3. Anthropometric measures

Height and body mass were measured using a calibrated wall-mounted stadiometer (Detecto® Model 339, USA; precision  $\pm 0.1$  cm) and a digital floor scale (Detecto® Model 339, USA; precision  $\pm 0.1$  kg), respectively. Participants were assessed barefoot in lightweight clothing following standardized protocols (Norton, 2018). Body fat percentage was estimated via the Jackson-Pollock 7-site skinfold method, with gender-specific equations applied: (a) male: Chest, mid-axillary, triceps, subscapular, abdomen, suprailiac, and thigh sites (Jackson & Pollock, 1978) and (b) female: Triceps, suprailiac, thigh, abdominal, subscapular, chest, and mid-axillary sites (Jackson et al., 1980). All skinfold measurements were taken in triplicate using a Harpenden caliper (Baty International, UK; precision  $\pm 1$  mm).

### 2.4. Kinematic of roundhouse kick

Kinematic measurements were conducted using a 3D motion capture system, Vicon® Vantage V5 (Vicon® Motion Systems Ltd., Oxford, UK). The setup consisted of ten synchronized optoelectronic cameras, model Vicon® V5 (maximum FPS 420; resolution 2432H x 2048V; ratio 1:1; lens 12,5mm) operating at a sampling frequency of 200 Hz. Prior to data collection, the system was calibrated in accordance with manufacturer specifications, achieving sub-2 mm residual error (Merriault et al., 2017). Reflective spherical markers (14 mm diameter, deformable) were affixed bilaterally to anatomical landmarks based on the Lower Limbs Plug-in Gait biomechanical model Marker placements (VICON, 2023) included: (a) anterior and posterior superior iliac spines; (b) upper and lower thirds of the lateral thigh; (c) upper and lower thirds of the lateral shank; (d) lateral femoral epicondyle; (e) transmalleolar axis spanning the medial and lateral malleoli; (f) second metatarsal head; and (g) calcaneus.

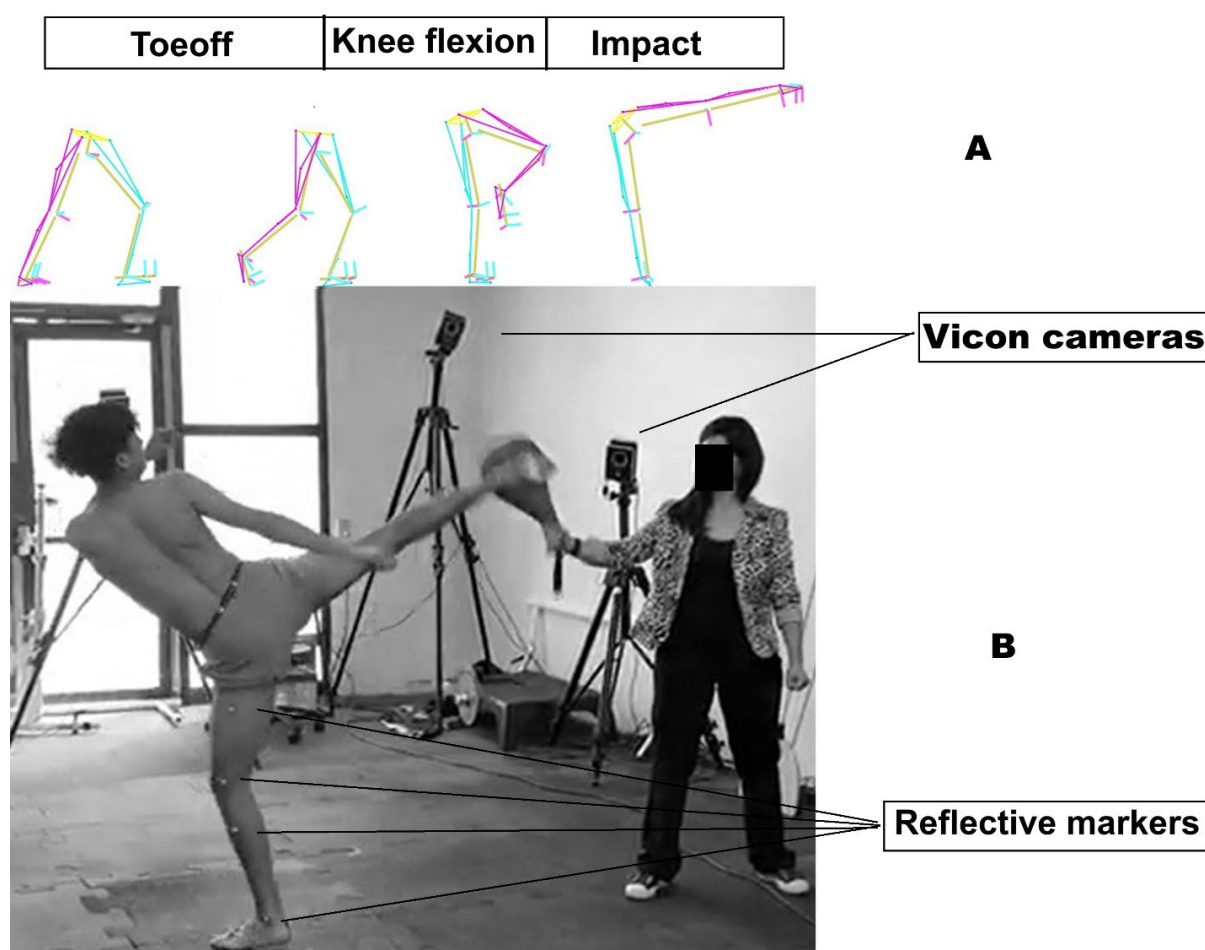
To capture and calculate kinematic variables, software VICON Nexus® 2.8 was used. This was calculated with the Direct Linear Transformation approach to three-dimensional reconstructions undertaken from images (Wood & Marshall, 1986). The coordinate data from these 16 points were smoothed using a low-pass second-order Butterworth digital filter with a 12 Hz cut-off frequency and used to define nine segments: left thigh, left shank, left foot, left toe, right thigh, right shank, right foot, right foot, right toe, and pelvis (VICON, 2023). To ensure measurement consistency, all kicks were directed toward a standardized taekwondo kick mitt held by the same trained evaluator, who maintained a fixed position and arm extension. The target height and distance were individually adjusted during familiarization and then kept constant across all recorded trials, with the mitt's position verified relative to the laboratory's global coordinate system.



In line with Windolf et al. (2008), the following parameters were analyzed across three rear kick phases (1st, 2nd, 3rd) and their cumulative totals: (a) Phase duration and total execution time; (b) Foot linear velocity and acceleration; (c) Hip and knee angular velocities; (d) Hip and knee angular accelerations. Total values were derived from the summation of individual phase measurements. Kick kinematics were assessed using the three-phase model by Kim et al. (2010): (a) Toe-off: Initial ground separation of the kicking foot; (b) Maximum Knee Flexion: Peak knee flexion of the kicking leg and; (c) Impact: Foot-target contact instant. The start and end points of each phase were determined by visual inspection of the displacement–time curves synchronized with video recordings.

Before the measurement, all participants completed 10-warm-up kicks, including  $\geq 2$  maximal-intensity trials, prior to data collection. Athletes self-selected target distances for strikes against a standardized kick mitt. Three recorded attempts were performed with 14 s inter-trial intervals, consistent with elite competition cadence (Santos et al., 2014). Representative kinematic data from a male athlete’s rear roundhouse kick are illustrated in Figure 1.

**Figure 1.** A. Roundhouse kick model constructed by Vicon® software divided into Toe-off, Maximum Knee Flexion and Contact. B. Example of a male kick, indicating the cameras position, sensors and mitt



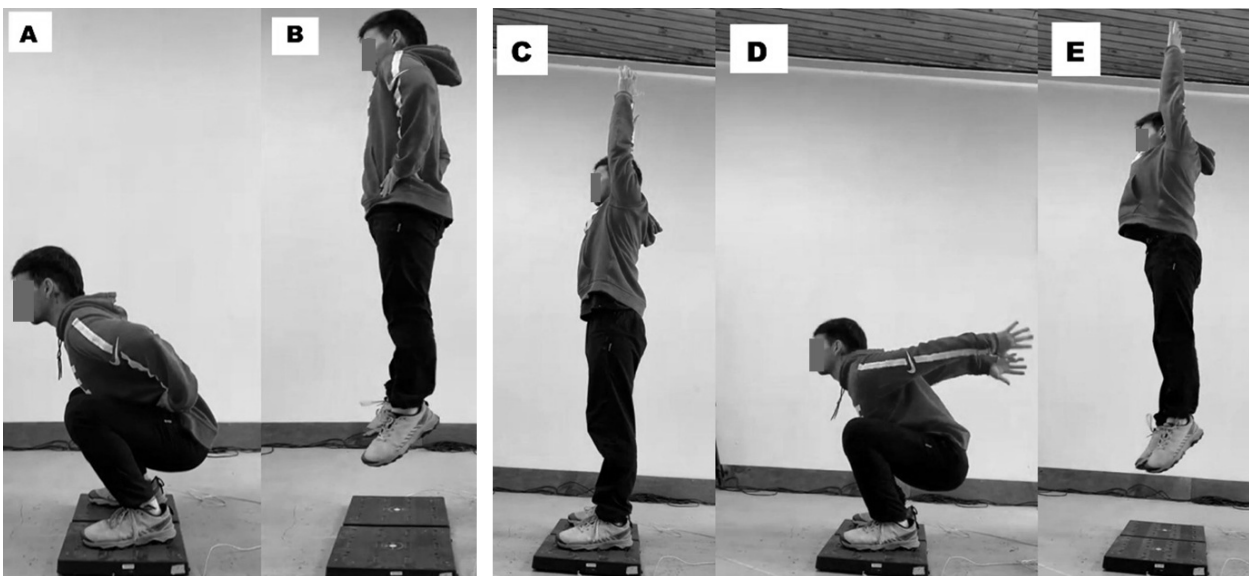
### 2.5. Jump tests

All participants performed the DSJ and ABK. Following the procedures described by Vizcaya et al. (2009), for the DSJ the athletes assumed a standardized starting position on two force platforms (Pasco® CI-6461, Pasco Scientific, USA), maintaining a deep squat position with trunk held upright, hands fixed on the hips and knees flexed to approximately 120°. This starting angle was verified using a plastic goniometer during the initial warm-up trial, and participants were subsequently instructed to replicate this specific position during all official trials. However, it should be noted that the knee angle was not objectively monitored or systematically controlled via goniometry or kinematic analysis during each individual official attempt. Feet were positioned shoulder-width apart (measured via anthropometric markers) with toes aligned forward or slightly abducted ( $\leq 15^\circ$ ).

Participants held this position motionless for 3 s, verified via force plate data, to eliminate countermovement and pre-activation of muscles. Upon an auditory cue from synchronized data acquisition software Forcedecks Valperformance® (Force Decks 2.0.9.2.1.0, NMP Technologies, London, UK), participants executed a vertical jump explosively without any preparatory movement or downward displacement. Force plate signals were monitored in real time to confirm the absence of countermovement (i.e., the force trace remained stable within  $\pm 2\%$  body weight during the static phase). Participants performed three maximal trials, with 2 min rests between attempts to mitigate fatigue. Any trial with detectable countermovement (via force-time curve analysis) was discarded and repeated.

ABK were performed with the same force platform and software acquisition, according to the methods followed by Arede et al. (2019). For this, all athletes began in a standing position with an upright posture (neutral spinal alignment), their feet shoulder-width apart, and arms extended along the body. The countermovement phase involved self-selected knee and hip flexion (with unrestricted angles) to generate reactive force, followed by a synchronized backward arm swing and an explosive forward-and-upward arm motion during extension. During propulsion, full extension of the ankles, knees, and hips was achieved at takeoff, accompanied by maximal arm acceleration overhead to enhance vertical momentum. In the aerial phase, the legs remained fully extended after takeoff to minimize aerodynamic resistance, while the torso stabilized in a neutral position to avoid detrimental rotations. Three trials were performed, with 2 min rests between attempts, jumps lacking arm-leg synchronization, incomplete joint extension, or imbalance during landing were discarded. Figure 2 illustrates the ABK and DSJ phases.

**Figure 2.** Deep squat jump start (A) and final position (B). Abalakov start (C), countermovement (D) and final position (E)



## 2.6. Statistical analysis

The Shapiro-Wilk test was employed to assess data normality. One-way ANOVA was used to compare differences in anthropometric measures (Table 1), DSJ, ABK, and kinematic measures. Assumptions of homogeneity of variance (Levene's test) and normality were verified. Where variances were unequal, Welch's ANOVA was applied. Post hoc comparisons used Tukey's HSD (equal variances) or Games-Howell tests (unequal variances). Effect sizes and 95% confidence intervals were reported. A hierarchical linear regression (stepwise method) evaluated the predictive power of jumps for kinematic outcomes. Multicollinearity among predictors was assessed using Variance Inflation Factor (VIF) and tolerance values, with  $VIF < 10$  and tolerance  $> 0.1$  considered acceptable. Adjusted  $R^2$  values and Akaike Information Criterion were reported to balance model fit and parsimony. To mitigate overfitting from stepwise selection, results were cross-validated using a 70:30 training-test split or k-fold cross-validation ( $k = 5$ ). All analyses were performed using IBM SPSS Statistics (version 25.0), with  $p \leq 0.05$ . Descriptive data for anthropometric, jump, and

kinematic variables are presented for the total sample and also stratified by sex to provide a comprehensive characterization of the cohort. However, due to the exploratory nature of the study and the specific sample size of elite athletes, all regression analyses were conducted using the total sample to maintain adequate statistical power and focus on the primary objective of identifying general performance associations.

### 3. Results

The participants' demographic and anthropometric characteristics are detailed in Table 1.

**Table 1.** Participants' demographic and anthropometric characteristics

Measure	Male	Female	Total
Age (years)	20.8 ± 3.0	22.6 ± 3.8	21.6 ± 3.4
Experience (years)	11.4 ± 3.1	12.1 ± 2.3	11.7 ± 2.8
Body mass (kg)	68.6 ± 8.5 <sup>a</sup>	55.2 ± 4.4	62.9 ± 9.7
Body fat (%)	4.7 ± 1.9 <sup>a</sup>	14.9 ± 3.0	9.1 ± 5.6
Height (m)	1.8 ± 0.1 <sup>a</sup>	1.6 ± 0.1	1.7 ± 0.1
Side domain	12 R and 4 L	11 R and 1 L	23 R and 5 L
Length of the lower right limb (cm)	100.8 ± 5.0 <sup>a</sup>	93.6 ± 4.2	97.9 ± 5.9
Length of lower left limb (cm)	100.5 ± 4.9 <sup>a</sup>	93.5 ± 3.6	97.5 ± 5.6
Right knee bone diameter (cm)	9.9 ± 0.3 <sup>a</sup>	9.2 ± 0.4	9.6 ± 0.5
Left knee bone diameter (cm)	10. ± 0.3 <sup>a</sup>	9.1 ± 0.4	9.6 ± 0.6
Right ankle bone diameter (cm)	7.3 ± 0.6 <sup>a</sup>	6.7 ± 0.4	7.0 ± 0.6
Left ankle bone diameter (cm)	7.4 ± 0.4 <sup>a</sup>	6.5 ± 0.4	7.0 ± 0.6

Note: Data are present as mean ± standard deviation. R – right lower limb domain. L – left lower limb domain. <sup>a</sup> p≤0.004 vs. female.

No significant differences were observed in age ( $F = 0.931$ ,  $p = 0.401$ ) or experience ( $F = 0.186$ ,  $p = 0.831$ ) across groups. However, significant differences were observed between male and female in all other measures. Despite these differences, men's means aligned with the total sample averages for lower limb length (right:  $F = 6.186$ ,  $p = 0.004$ ; left:  $F = 6.675$ ,  $p = 0.003$ ), knee diameter (left:  $F = 12.479$ ; right:  $F = 9.996$ ,  $p \leq 0.001$  for both comparison), ankle diameter (left:  $F = 4.177$ ,  $p = 0.021$ ; right:  $F = 8.844$ ,  $p \leq 0.001$ ), body mass ( $F = 8.529$ ,  $p = 0.001$ ), height ( $F = 10.104$ ,  $p \leq 0.001$ ), and fat percentage ( $F = 18.448$ ,  $p \leq 0.001$ ). To provide a clearer summary of the main findings, Table 2 present only the key jump variables that were identified as significant predictors of roundhouse kick performance in the subsequent regression analysis, rather than the complete set of measured variables.

**Table 2.** Results of deep squat jump test variables

Measure	Male	Female	Total
Concentric Mean Power / BM [W.kg <sup>-1</sup> ]	15.8 ± 2.5	16.5 ± 3.1	16.1 ± 2.7
RFDcon / BM [N·s <sup>-1</sup> ·kg <sup>-1</sup> ]	51.7 ± 6.2 <sup>a</sup>	62.9 ± 5.0	56.5 ± 8.0
Force at Peak Power (ND) [N]	603.7 ± 127.7 <sup>a</sup>	630.5 ± 107.6	615.2 ± 118.1
Takeoff Peak Force (D) [N]	589.4 ± 117.2 <sup>a</sup>	625.1 ± 104.5	634.1 ± 122.9

Note: Data are presented as mean ± standard deviation. RFDcon – concentric rate of force development. BM – body mass. D – dominant lower limb. ND – non-dominant lower limb. <sup>a</sup> p≤0.027 vs. female.

According to Table 2, significant differences were observed between groups for RFDcon/BM ( $F = 8.905$ ;  $p \leq 0.001$ ; post hoc:  $p \leq 0.001$  male vs. female,  $p = 0.027$  total vs. female), force at peak power ( $F = 4.012$ ;  $p = 0.024$ ; post hoc:  $p = 0.018$  male vs. female), and takeoff peak force/BM ( $F = 4.054$ ;  $p = 0.023$ ; post hoc:  $p = 0.017$  male vs. female). Table 3 presents the key predictive results for ABK.

**Table 3.** Results of Abalakov jump test variables

Measure	Male	Female	Total
Concentric Peak Force / BM [N.kg <sup>-1</sup> ]	23.1 ± 1.3	23.1 ± 1.4	23.1 ± 1.3
Eccentric Peak Force / BM [N.kg <sup>-1</sup> ]	21.1 ± 2.6	21.6 ± 2.5	21.3 ± 2.5
RFDecc (D) [N·s <sup>-1</sup> ]	1495 ± 588.2	1415 ± 822.1	1461 ± 685.0

Data are present as mean ± standard deviation. RFDcon – concentric rate of force development. BM – body mass. D – dominant lower limb. <sup>a</sup> p≤0.044 vs. female.

Regarding the means observed in Table 3, there were no significant differences when comparing men, women and the total sample (p>0.05). Table 4 shows the results of the kinematic analysis of rear roundhouse kick performed by the athletes.

**Table 4.** Roundhouse kick kinematic analysis, categorised by sex and phase

Measure	Male	Female	Total
Time 1 <sup>st</sup> phase (s)	0.12 ± 0.04	0.14 ± 0.03	0.13 ± 0.04
Time 2 <sup>nd</sup> phase (s)	0.13 ± 0.02	0.13 ± 0.01	0.13 ± 0.02
Time 3 <sup>rd</sup> phase (s)	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01
Total time (s)	0.34 ± 0.04	0.37 ± 0.05	0.36 ± 0.05
Foot linear speed 1 <sup>st</sup> phase (m/s)	2.2 ± 0.7	2.0 ± 0.4	2.1 ± 0.6
Foot linear speed 2 <sup>nd</sup> phase (m/s)	9.8 ± 1.2	9.4 ± 1.3	9.6 ± 1.3
Foot linear speed 3 <sup>rd</sup> phase (m/s)	13.3 ± 1.4	12.2 ± 1.8	12.8 ± 1.7
Total Foot linear speed (m/s)	25.4 ± 2.5	23.5 ± 2.8	24.6 ± 2.7
Knee angular speed 1 <sup>st</sup> phase (°/s)	654.3 ± 141.3	676.7 ± 123.9	663.9 ± 131.0
Knee angular speed 2 <sup>nd</sup> phase (°/s)	970.3 ± 300.0	861.3 ± 169.4	923.6 ± 254.4
Knee angular speed 3 <sup>rd</sup> phase (°/s)	1764 ± 352.6	1687 ± 230.3	1730 ± 303.6
Total Knee angular speed (°/s)	3389 ± 657.8	3225 ± 338.5	3318 ± 542.1
Hip angular speed 1 <sup>st</sup> phase (°/s)	258.1 ± 60.7	271.8 ± 112.2	263.9 ± 85.0
Hip angular speed 2 <sup>nd</sup> phase (°/s)	481.6 ± 95.6	440.6 ± 89.7	464.1 ± 93.7
Hip angular speed 3 <sup>rd</sup> phase (°/s)	626.0 ± 170.6	603.1 ± 223.8	616.2 ± 191.6
Total Hip angular speed (°/s)	1366 ± 187.0	1316 ± 344.3	1334 ± 261.5
Foot acceleration 1 <sup>st</sup> phase (m/s <sup>2</sup> )	71.7 ± 24.2	59.4 ± 11.6	66.6 ± 20.4
Foot acceleration 2 <sup>nd</sup> phase (m/s <sup>2</sup> )	132.7 ± 34.3	120.5 ± 37.0	127.5 ± 35.4
Foot acceleration 3 <sup>rd</sup> phase (m/s <sup>2</sup> )	366.2 ± 82.0	308.0 ± 67.8	341.3 ± 80.4
Total Foot acceleration (m/s <sup>2</sup> )	570.7 ± 114.5	488.0 ± 87.0	535.2 ± 110.0
Knee acceleration 1 <sup>st</sup> phase (°/s <sup>2</sup> )	12011 ± 2127	12649 ± 3233	12284 ± 2622
Knee acceleration 2 <sup>nd</sup> phase (°/s <sup>2</sup> )	23028 ± 11000	17846 ± 5098	20031 ± 8391
Knee acceleration 3 <sup>rd</sup> phase (°/s <sup>2</sup> )	41394 ± 19577	41160 ± 12291	41629 ± 16230
Total Knee acceleration (°/s <sup>2</sup> )	77021 ± 29576	71654 ± 16167	74721 ± 24490
Hip acceleration 1 <sup>st</sup> phase (°/s <sup>2</sup> )	7128 ± 1528	8463 ± 3498.4	7700 ± 2610
Hip acceleration 2 <sup>nd</sup> phase (°/s <sup>2</sup> )	6623 ± 1793	6144 ± 1490.4	6417.4 ± 1658
Hip acceleration 3 <sup>rd</sup> phase (°/s <sup>2</sup> )	25286 ± 15870	25930 ± 10478	25562 ± 13586
Total Hip acceleration (°/s <sup>2</sup> )	39037 ± 17111	40057 ± 13184	39680 ± 15159

Note: Data are present as mean ± standard deviation.

There were no significant differences (p>0.05) between the kinematic variables between male, female all participants. The results for linear regression analyses between the variables of DSJ and ABK and the roundhouse kick performance are presented in Table 5. For DSJ, RFDcon independently predicted linear foot velocity ( $R^2 = 0.21$ ,  $p = 0.009$ ), linear foot acceleration ( $R^2 =$



0.303,  $p = 0.003$ ), and angular knee acceleration ( $R^2 = 0.194$ ,  $p = 0.021$ ). RFDcon combined with concentric mean power/BM also predicted angular knee acceleration ( $R^2 = 0.27$ ,  $p = 0.04$ ). For the ND lower limb, takeoff peak force independently predicted angular hip acceleration ( $R^2 = 0.144$ ,  $p = 0.029$ ), while combined with force at peak force ( $R^2 = 0.315$ ,  $p = 0.013$ ). Already for ABK, eccentric peak force/BM predicted total time ( $R^2 = 0.123$ ,  $p = 0.039$ ). Concentric peak force/BM predicted angular knee velocity ( $R^2 = 0.173$ ,  $p = 0.018$ ). RFDecc (D) predicted both angular hip velocity ( $R^2 = 0.135$ ,  $p = 0.034$ ) and angular hip acceleration ( $R^2 = 0.24$ ,  $p = 0.006$ ).

**Table 5.** Summary of significant stepwise linear regression models for jump variables predicting roundhouse kick performance

Dependent Variable	Predictor(s)	B	SE	$\beta$	t	p	Adjusted R <sup>2</sup>
<b>Deep Squat Jump</b>							
Linear foot velocity	RFDcon	0.003	0.001	0.49	2.8	0.009	0.245
Linear foot acceleration	RFDcon	0.1	0.03	0.6	3.3	0.003	0.327
Angular knee acceleration	RFDcon	34.0	10.0	0.70	3.4	0.02	0.216
	Concentric Mean Power/BM	-4045	1866	-0.5	-2.2	0.04	0.34
Total foot linear acceleration	Takeoff Peak Force (ND)	782.6	272.3	6.3	2.9	0.008	0.168
	Force at Peak Force (ND)	-765.5	284.5	-5.9	-2.7	0.013	0.268
<b>Abalakov Jump</b>							
Total time	Eccentric Peak Force/BM	0.007	0.003	0.4	2.2	0.04	0.12
Angular knee velocity	Concentric Peak Force/BM	-177.9	70.0	-0.5	-2.5	0.018	0.118
Angular hip velocity	RFDecc (D)	0.2	0.07	0.4	2.3	0.034	0.304
Hip angular acceleration	RFDecc (D)	11.4	3.8	0.5	3.0	0.006	0.206

*Note:* B: unstandardized coefficient; SE: standard error;  $\beta$ : standardized coefficient; RFDcon: concentric rate of force development; BM: body mass; ND: non-dominant; D: dominant; RFDecc: eccentric rate of force development.

#### 4. Discussion

This study analyzed the associations between variables of an explosive jump (DSJ) and a countermovement jump (ABK) and rear roundhouse kick performance. The main results showed that for the DSJ, RFDcon and takeoff peak force of the non-dominant lower limb were the primary variables associated with kick performance. For the ABK, the RFDecc variable of the dominant lower limb was the main associate for this kick in high-performance combat athletes. However, it is important to note that if the DSJ in our protocol is effectively performed at 90° of knee flexion without countermovement, it closely resembles a traditional SJ, which reduces the novelty of this approach and suggests that the findings may partly replicate previous SJ-related research.

3D motion capture systems, such as Vicon®, offer several advantages over 2D analysis, particularly in applications requiring a deeper understanding of human movement dynamics and biomechanics (Skalski et al., 2025; Windolf et al., 2008). One of the main advantages of 3D systems is the ability to capture movements in a more realistic and accurate way, since they provide a three-dimensional visualization that reflects the complexity of interactions in space (Merriault et al., 2017; Szcześna et al., 2021; Windolf et al., 2008). However, these systems require laboratory settings (Fiorentino et al., 2013) and entail high costs (Torvinen et al., 2024), hindering widespread implementation (Yeung et al., 2016). In this context, valid, field-applicable methods that allow coaches to estimate jump-related predictors without access to force platforms are particularly valuable, for example, by using simpler timing gates, smartphone-based motion analysis, or validated surrogate tests (Antonietto et al., 2024; Yan et al., 2021; Yeung et al., 2016). From a practical standpoint, although force platforms provide the most accurate measures of RFD and peak force, coaches without access to such equipment can approximate these metrics using more accessible technologies. For instance, smartphone-based video analysis apps (e.g., MyJump2) or wearable

inertial measurement units (IMUs) can estimate takeoff dynamics and flight time, which serve as indirect indicators of explosive power. Furthermore, by monitoring changes in jump height and execution velocity through linear position transducers or even high-speed video (available on most modern smartphones), practitioners can qualitatively assess improvements in the rapid force production qualities identified in this study as critical for roundhouse kick performance.

Similar to the present protocol, previous studies have also analyzed relationships between the roundhouse kick and biomechanical variables (Bercades & Pieter, 2012; de Oliveira Goulart et al., 2016; Estevan et al., 2013). In taekwondo athletes, Estevan et al. (2013) demonstrated significant correlations ( $r = 0.89$ ,  $p < 0.01$ ) between vertical force peak during the kick and execution time measured via 2D kinematic. Meanwhile, de Oliveira Goulart et al. (2016) reported a strong correlation between CMJ and roundhouse kick performance in taekwondo athletes; however, this jump showed limited predictive capacity for the kick. Unlike previous studies, our protocol introduces the novel aspect of using a force platform to measure jump performance, which offers advantages over contact mats (Bagchi et al., 2024; Plakoutsis et al., 2023), combined with 3D motion capture to quantify roundhouse kick performance, allowing for multi-joint and multidirectional analysis (Antonietto et al., 2024; Szczęśna et al., 2021).

Furthermore, we are unaware of any studies applying the DSJ and ABK to striking combat athletes. As Vizcaya et al. (2009) note, many athletic movements are performed without a countermovement, suggesting the DSJ may serve as a relevant assessment tool for monitoring specific explosive qualities. However, this jump is more commonly applied as a training exercise than an evaluative measure (Soriano et al., 2024; Vizcaya et al., 2009). Soriano et al. (2024) demonstrated that the DSJ is strongly associated with performance in Olympic weightlifters (68.1%) due to its biomechanical similarity to the snatch and clean and jerk. Although the specific striking technique in our study differs biomechanically from the DSJ, two variables of this jump showed significant associations with roundhouse kick performance, suggesting practical value for athlete monitoring and individualized training. Our results identified RFDcon and takeoff peak force in the non-dominant lower limb as the primary variables related to roundhouse kick performance. RFDcon was the main variable associated with foot acceleration and velocity. This latest variable has been shown higher values in the roundhouse kick compared to other kick techniques such as the front kick in high-level athletes (Vagner et al., 2023), which also explains its high eligibility in taekwondo competitions (Avakian et al., 2021), emphasizing the importance of these findings regarding the association between RFDcon and athletic performance.

In relation to this measure, a study involving physically active college students linked this variable to explosive force production (Mirkov et al., 2004). Indeed, the DSJ; initiated from a static squat position without countermovement; qualifies as an explosive ballistic movement (Soriano et al., 2024). In line with our results, prior researches highlight the critical role of supporting lower limb in generating velocity and power during roundhouse kicks (R. Huang et al., 2025; Robalino et al., 2025; Vagner et al., 2023). Notably, athletes in our study executed kicks exclusively with their dominant lower limb; future studies should examine both limbs to enhance generalizability.

The ABK test not only assesses explosiveness but also harnesses the elastic energy stored in the tendons and requires coordination between the trunk and upper limbs (Lago-Peñas et al., 2011; Miguel-Ortega et al., 2023; Ruiz et al., 2006). Its application as an athlete assessment tool benefits from incorporating the arm-swing motion, which resembles technical movements in basketball and volleyball (Miguel-Ortega et al., 2023, 2025). Unlike the DSJ, the primary variable associated with kick performance for the ABK is associated with the kicking limb, where RFD<sub>decc</sub> emerges as the key predictor of hip acceleration and velocity during the roundhouse kick, an indicator linked to lower-limb explosive strength (Merino-Muñoz et al., 2020). Supporting this relationship, systematic reviews indicate that eccentric forces during the CMJ (as measured by RFD-100 ms) are associated with the reactive strength index (Nishiumi et al., 2023). Therefore, athletes with better RFD<sub>decc</sub> performance are expected to exhibit superior reactive force during kick performance. This correlation aligns with studies directly linking eccentric braking to countermovement performance (Krzyszowski et al., 2022; Nishiumi et al., 2023). Krzyszowski et al. (2022) suggest that strategies to enhance the RFD<sub>decc</sub> may improve athletic performance.



## 5. Limitations

Despite its valuable contributions, this study presents several limitations that warrant consideration. Firstly, the relatively small sample size ( $n = 27$ ) and the exclusive focus on elite taekwondo athletes restrict the generalizability of these findings to other striking sports or broader athletic populations. Future research should aim for larger and more diverse samples to enhance external validity. Secondly, the analysis was not stratified by sex, which may obscure potential sex-specific relationships between jump metrics and kick kinematics, suggesting a need for future studies to explore these differences. Additionally, only the rear lower limb was analyzed, further limiting the extrapolation of results to bilateral or other unilateral actions. A methodological limitation concerning the DSJ protocol also needs to be acknowledged: while the initial knee angle ( $\sim 120^\circ$ ) was verified during warm-up, it was not systematically monitored during each official trial. Relying on participants to self-replicate the starting position may have introduced variability in the initial knee angle across attempts. Given that the starting joint angle can influence force production and jump mechanics, this lack of continuous objective verification should be considered when interpreting the DSJ-derived variables and their predictive relationship with kick performance. Finally, although a standardized kick mitt was used and held by the same trained evaluator in a fixed position, slight variations in target handling cannot be completely ruled out, which may have introduced minimal variability in the kinematic measures.

## 6. Conclusion

Based on the established aims, applied methods, and obtained results, the present study observed significant associations between specific variables from DSJ and ABK and roundhouse kick performance in elite striking athletes. When evaluating athletes, the main variables to be observed are RFDcon and takeoff peak force of the non-dominant lower limb for DSJ, and RFDecc for ABK.

## References

- Ahmadi, A., Rowlands, D., & James, D. (2009). Deriving upper arm rotation from Vicon to enhance the first serve in tennis. *Journal of Science and Medicine in Sport*, 12, S29-S30. <https://doi.org/10.1016/j.jsams.2008.12.069>
- Albuquerque, M. R., Tavares, L. D., Longo, A. R., Caldeira Mesquita, P. H., & Franchini, E. (2021). Relationship between Indirect Measures of Aerobic and Muscle Power with Frequency Speed of Kick Test Multiple Performance in Taekwondo Athletes. *International Journal of Sports Medicine*, 43(03), 254-261. <https://doi.org/10.1055/a-1546-9221>
- Antonietto, D. Á., Roa Gamboa, I., Ribeiro, N., Brito, C. J., Rezende Oliveira, C. L., Nóbrega, O. d. T., Vieira-Souza, L. M., Miarka, B., & Aedo-Muñoz, E. (2024). Can the Countermovement Jump or Squat Jump predict the kinematic performance of the rear Bandal Chagi kick? *Retos*, 56, 597-606. <https://doi.org/10.47197/retos.v56.104129>
- Arede, J., Esteves, P., Ferreira, A. P., Sampaio, J., & Leite, N. (2019). Jump higher, run faster: effects of diversified sport participation on talent identification and selection in youth basketball. *Journal of Sports Sciences*, 37(19), 2220-2227. <https://doi.org/10.1080/02640414.2019.1626114>
- Avakian, P., Frezza, D. A., Pinho, B. G., Junior, A. A., Aedo-Munoz, E., Perez, D. I. V., Antonietto, D. A., Brito, C. J., & Miarka, B. (2021). Development and reliability of technical-tactical and time-motion real-time analysis in the World Taekwondo Grand Prix. *Idō Movement for Culture*, 21(4). <https://doi.org/0.14589/ido.21.4.4>
- Bagchi, A., Raizada, S., Thapa, R. K., Ștefănică, V., & Ceylan, H. İ. b. (2024). Reliability and Accuracy of Portable Devices for Measuring Countermovement Jump Height in Physically Active Adults: A Comparison of Force Platforms, Contact Mats, and Video-Based Software. *Life*, 14(11), 1394. <https://doi.org/10.3390/life14111394>
- Bazanov, B., Pedak, K., & Rannama, I. (2019). Relationship between musculoskeletal state and vertical jump ability of young basketball players. *Journal of Human Sport and Exercise*, 14(4proc), S718-S725. <https://doi.org/10.14198/jhse.2019.14.Proc4.33>
- Bercades, L. T., & Pieter, W. (2012). A Biomechanical Analysis of the Modified Taekwondo Axe Kick. *Revista de Artes Marciales Asiáticas*, 2(1), 28-39. <https://doi.org/10.18002/rama.v2i1.282>

- Cárdenas, D. V., Díaz, R. C., Mons, V., Badilla, P. V., Pichon, A., Aguilar, D. C., Albuquerque, M. R., da Silva Santos, J. F., & Valenzuela, T. H. (2019). Physical and physiological profile in youth elite Chilean wrestlers. *Archives of Budo*, *15*, 249-257.
- Chaabène, H., Hachana, Y., Franchini, E., Mkaouer, B., & Chamari, K. (2012). Physical and Physiological Profile of Elite Karate Athletes. *Sports Medicine*, *42*(10), 829-843. <https://doi.org/10.1007/BF03262297>
- Chavda, S., Lake, J. P., Comfort, P., Bishop, C., Joffe, S. A., & Turner, A. N. (2025). Relationship Between Kinetic and Kinematic Measures of the Countermovement Jump and National Weightlifting Performance. *Journal of Science in Sport and Exercise*, *7*(1), 50-62. <https://doi.org/10.1007/s42978-023-00245-w>
- Chiang, C.-Y., Chiang, Y.-C., Lin, H.-Y., Tseng, H.-C., Chu, M.-Y., & Chang, J.-S. (2025). Lower Extremity Stretch-Shortening Cycle Performance in the Vertical and Horizontal Direction as Key Determinants of Success in Collegiate Male Taekwondo. *Journal of Functional Morphology and Kinesiology*, *10*(1), 15. <https://doi.org/10.3390/jfmk10010015>
- Corcoran, D., Climstein, M., Whitting, J., & Del Vecchio, L. (2024). Impact Force and Velocities for Kicking Strikes in Combat Sports: A Literature Review. *Sports*, *12*(3), 74. <https://doi.org/10.3390/sports12030074>
- de Oliveira Goulart, K. N., Corgosinho, R. F., Rodrigues, S. A., Drummond, M. D. M., Flor, C. A. G., Goncalves, R., Szmuchrowski, L. A., & Couto, B. P. (2016). Correlation between roundhouse kick and countermovement jump performance. *Archives of Budo*, *12*, 125-131.
- Diniz, R., Del Vecchio, F. B., Schaun, G. Z., Oliveira, H. B., Portella, E. G., da Silva, E. S., Formalioni, A., Campelo, P. C. C., Peyré-Tartaruga, L. A., & Pinto, S. S. (2021). Kinematic Comparison of the Roundhouse Kick Between Taekwondo, Karate, and Muaythai. *The Journal of Strength & Conditioning Research*, *35*(1), 198-204. <https://doi.org/10.1519/JSC.0000000000002657>
- Estevan, I., Álvarez, O., Falcó, C., & Castillo, I. (2014). Self-efficacy and performance of the roundhouse kick in taekwondo. *Revista de Artes Marciales Asiáticas*, *9*(2), 97-105. <https://doi.org/10.18002/rama.v9i2.1323>
- Estevan, I., Jandacka, D., & Falco, C. (2013). Effect of stance position on kick performance in taekwondo. *Journal of Sports Sciences*, *31*(16), 1815-1822. <https://doi.org/10.1080/02640414.2013.803590>
- Fiorentino, M., Uva, A. E., Foglia, M. M., & Bevilacqua, V. (2013). Asymmetry measurement for vibroactive correction in lower limbs mobility. *Computer Science and Information Systems*, *10*(3), 1387-1406. <https://doi.org/10.2298/CSIS120516054F>
- Gavagan, C. J., & Sayers, M. G. L. (2017). A biomechanical analysis of the roundhouse kicking technique of expert practitioners: A comparison between the martial arts disciplines of Muay Thai, Karate, and Taekwondo. *Plos One*, *12*(8), e0182645. <https://doi.org/10.1371/journal.pone.0182645>
- Huang, R., Ma, Y., Lin, S., Zheng, W., Liu, L., & Jia, M. (2025). Research on the biomechanical laterality of athletes' lower limbs during side kick in the competitive Taekwondo. *Scientific Reports*, *15*(1), 10180. <https://doi.org/10.1038/s41598-025-94516-x>
- Huang, T. Y., Tang, W. T., Liu, T. T., Hamill, J., & Hu, C. (2025). Kinematic and kinetic demands on better roundhouse kick performances. *Sports Biomechanics*, *24*(2), 425-439. <https://doi.org/10.1080/14763141.2022.2122862>
- Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition*, *40*(3), 497-504. <https://doi.org/10.1079/BJN19780152>
- Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise*, *12*(3), 175-181.
- Jia, M., Liu, L., Huang, R., Yong, Lin, S., Peng, Q., Xiong, J., Wang, Z., & Zheng, W. (2024). Correlation analysis between biomechanical characteristics of taekwondo double roundhouse kick and effective scoring of electronic body protector. *Frontiers in Physiology*, *14*. <https://doi.org/10.3389/fphys.2023.1269345>
- Jia, M., Yong, Huang, R., Liu, L., Wang, Z., Lin, S., Peng, Q., Xiong, J., & Zheng, W. (2024). Correlation analysis between biomechanical characteristics of lower extremities during front roundhouse kick in Taekwondo and effective scores of electronic protectors. *Frontiers in Bioengineering and Biotechnology*, *12*. <https://doi.org/10.3389/fbioe.2024.1364095>



- Joffe, S. A., Price, P., Chavda, S., Shaw, J., & Tallent, J. (2023). The Relationship of Lower-Body, Multijoint, Isometric and Dynamic Neuromuscular Assessment Variables With Snatch, and Clean and Jerk Performance in Competitive Weightlifters: A Meta-Analysis. *Strength & Conditioning Journal*, 45(4), 411-428. <https://doi.org/10.1519/SSC.0000000000000755>
- Kim, J.-W., Kwon, M.-S., Yenuga, S. S., & Kwon, Y.-H. (2010). The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kicks. *Sports Biomechanics*, 9(2), 98-114. <https://doi.org/10.1080/14763141003799459>
- Krzyszczkowski, J., Chowning, L. D., & Harry, J. R. (2022). Phase-Specific Predictors of Countermovement Jump Performance That Distinguish Good from Poor Jumpers. *The Journal of Strength & Conditioning Research*, 36(5), 1257-1263. <https://doi.org/10.1519/JSC.0000000000003645>
- Lago-Peñas, C., Casais, L., Dellal, A., Rey, E., & Domínguez, E. (2011). Anthropometric and Physiological Characteristics of Young Soccer Players According to Their Playing Positions: Relevance for Competition Success. *The Journal of Strength & Conditioning Research*, 25(12), 3358-3367. <https://doi.org/10.1519/JSC.0b013e318216305d>
- Li, X., Fan, D., Feng, J., Lei, Y., Cheng, C., & Li, X. (2025). Systematic review of motion capture in virtual reality: Enhancing the precision of sports training. *Journal of Ambient Intelligence and Smart Environments*, 17(1), 5-27. <https://doi.org/10.3233/AIS-230198>
- Liu, L., Jia, M., Ma, Y., Lin, S., Peng, Q., Xiong, J., & Zheng, W. (2023). Biomechanics research on laterality effect between dominant and non-dominant during double roundhouse kick in the competitive taekwondo. *Heliyon*, 9(10), e20843. <https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e20843>
- Merino-Muñoz, P., Pérez-Contreras, J., Aedo-Muñoz, E., & Bustamante-Garrido, A. (2020). Relationship between jump height and rate of braking force development in professional soccer players. *Journal of Physical Education and Sport*, 20(6), 3614-3621. <https://doi.org/10.7752/jpes.2020.06487>
- Merriault, P., Dupuis, Y., Bouteau, R., Vasseur, P., & Savatier, X. (2017). A study of vicon system positioning performance. *Sensors*, 17(7), 1591. <https://doi.org/10.3390/s17071591>
- Miguel-Ortega, Á., Calleja-González, J., & Mielgo-Ayuso, J. (2023). Comparison of Sports Performance and Kinanthropometric Profiles of Elite Female Basketball and Volleyball Players over the Course of a Competitive Season. *Applied Sciences*, 13(14), 8267. <https://doi.org/10.3390/app13148267>
- Miguel-Ortega, Á., Calleja-González, J., & Mielgo-Ayuso, J. (2025). Longitudinal comparison of the relationship of energy intake with body composition and physical performance in elite female basketball and volleyball players. *Sport Sciences for Health*, 21(1), 301-319. <https://doi.org/10.1007/s11332-024-01261-1>
- Mirkov, D. M., Nedeljkovic, A., Milanovic, S., & Jaric, S. (2004). Muscle strength testing: evaluation of tests of explosive force production. *European Journal of Applied Physiology*, 91(2), 147-154. <https://doi.org/10.1007/s00421-003-0946-8>
- Miziara, I. M., da Silva, B. G., Marques, I. A., de Sá, A. A. R., Oliveira, I. M., Pereira, A. A., & Naves, E. L. M. (2019). Analysis of the biomechanical parameters of high-performance of the roundhouse kicks in Taekwondo athletes. *Research on Biomedical Engineering*, 35(3), 193-201. <https://doi.org/10.1007/s42600-019-00022-1>
- Moenig, U. (2012). The Evolution of Kicking Techniques in Taekwondo. *Revista de Artes Marciales Asiáticas*, 6(1), 117-140. <https://doi.org/10.18002/rama.v6i1.87>
- Nishiumi, D., Nishioka, T., Saito, H., Kurokawa, T., & Hirose, N. (2023). Associations of eccentric force variables during jumping and eccentric lower-limb strength with vertical jump performance: A systematic review. *Plos One*, 18(8), e0289631. <https://doi.org/10.1371/journal.pone.0289631>
- Norton, K. I. (2018). Standards for anthropometry assessment. In K. Norton & R. Eston (Eds.), *Kinanthropometry and exercise physiology* (Vol. 4, pp. 68-137). Routledge.
- Plakoutsis, G., Zapantis, D., Panagiotopoulou, E.-M., Paraskevopoulos, E., Moutzouri, M., Koumantakis, G. A., & Παπανδρέου, Μ. (2023). Reliability and Validity of the Portable KForce Plates for Measuring Countermovement Jump (CMJ). *Applied Sciences*, 13(20), 11200. <https://doi.org/10.3390/app132011200>

- Pojskić, H., Papa, E. V., Wu, S. S. X., & Pagaduan, J. (2022). Validity, reliability, and usefulness of jump performance from a low-cost contact mat. *Journal of Human Sport and Exercise*, 17(2), 261-271. <https://doi.org/10.14198/jhse.2022.172.03>
- Rafael, M. A., Del Olmo, M. F., González, O. V., Jodar, X. A., & Pérez, F. J. V. (2008). DSJ (salto vertical sin contramovimiento desde flexión de rodillas mayor de 120º) y carrera de velocidad de 30m desde parado. *Fitness & Performances Journal*, 7(5), 319-325. <https://doi.org/10.3900/fpj.7.5.319.s>
- Robalino, J., Sérvio José da Silva, T., Fernandes, S., Franchini, E., Mezêncio, B., & Ferreira, J. C. (2025). Reliability of a kinetic and kinematic assessment procedure for kicks in combat sports. *International Journal of Performance Analysis in Sport*, 25(1), 69-80. <https://doi.org/10.1080/24748668.2024.2386834>
- Ruiz, J. R., Ortega, F. B., Gutierrez, A., Meusel, D., Sjöström, M., & Castillo, M. J. (2006). Health-related fitness assessment in childhood and adolescence: a European approach based on the AVENA, EYHS and HELENA studies. *Journal of Public Health*, 14(5), 269-277. <https://doi.org/10.1007/s10389-006-0059-z>
- Sáez de Villarreal, E., Suarez-Arrones, L., Requena, B., Haff, G. G., & Ferrete, C. (2015). Effects of Plyometric and Sprint Training on Physical and Technical Skill Performance in Adolescent Soccer Players. *The Journal of Strength & Conditioning Research*, 29(7), 1894-1903. <https://doi.org/10.1519/JSC.0000000000000838>
- Santos, E. J. A. M., & Janeira, M. A. A. S. (2008). Effects of complex training on explosive strength in adolescent male basketball players. *Journal of strength and conditioning research*, 22(3), 903-909. <https://doi.org/10.1519/jsc.0b013e31816a59f2>
- Santos, V. G. F., de Oliveira Pires, F., Bertuzzi, R., Frachini, E., da Silva-Cavalcante, M. D., Kiss, M. A. P. D. M., & Lima-Silva, A. E. (2014). Relationship between attack and pause in world taekwondo championship contests: effects of gender and weight category. *Muscles, Ligaments and Tendons Journal*, 4(2), 127-131. <https://doi.org/10.11138/mltj/2014.4.2.127>
- Skalski, D., Prończuk, M., Stastny, P., Łosińska, K., Drozd, M., Toborek, M., Aschenbrenner, P., & Maszczyk, A. (2025). Evaluation of the Impact of External Conditions on Arm Positioning During Punches in MMA Fighters: A Comparative Analysis of 2D and 3D Methods. *Sensors*, 25(11), 3270. <https://doi.org/10.3390/s25113270>
- Soriano, M. A., Flores, F. J., Lama-Arenales, J., Fernández-del-Olmo, M., & Comfort, P. (2024). Neuromuscular Capabilities in Top-Level Weightlifters and Their Association with Weightlifting Performance. *Applied Sciences*, 14(9), 3762. <https://doi.org/10.3390/app14093762>
- Szczęsna, A., Błaszczyszyn, M., & Pawlyta, M. (2021). Optical motion capture dataset of selected techniques in beginner and advanced Kyokushin karate athletes. *Scientific Data*, 8(1), 13. <https://doi.org/10.1038/s41597-021-00801-5>
- Tabben, M., Chaouachi, A., Mahfoudhi, M., Aloui, A., Habacha, H., Tourny, C., & Franchini, E. (2014). Physical and physiological characteristics of high-level combat sport athletes. *Journal of Combat Sports and Martial Arts*, 5(1), 1-5. <https://doi.org/10.5604/20815735.1127445>
- Torvinen, P., Ruotsalainen, K. S., Zhao, S., Cronin, N., Ohtonen, O., & Linnamo, V. (2024). Evaluation of 3D Markerless Motion Capture System Accuracy during Skate Skiing on a Treadmill. *Bioengineering*, 11(2). <https://doi.org/10.3390/bioengineering11020136>
- Vagner, M., Cleather, D. J., Olah, V., Vacek, J., & Stastny, P. (2023). A systematic review of dynamic forces and kinematic indicators of front and roundhouse kicks across varied conditions and participant experience. *Sports*, 11(8), 141. <https://doi.org/10.3390/sports11080141>
- Vargas-Molina, S., Manuel, G.-S., B., K. R., Enrique, S., L., P. J., Javier, B.-P., & and Bonilla, D. A. (2022). A randomized open-labeled study to examine the effects of creatine monohydrate and combined training on jump and scoring performance in young basketball players. *Journal of the International Society of Sports Nutrition*, 19(1), 529-542. <https://doi.org/10.1080/15502783.2022.2108683>
- VICON. (2023). *VICON: Plug-in Gait kinematic and kinetic calculation* (Vol. 1). Nexus.
- Vizcaya, F. J., Viana, O., del Olmo, M. F., & Acero, R. M. (2009). Could the deep squat jump predict weightlifting performance? *The Journal of Strength & Conditioning Research*, 23(3), 729-734. <https://doi.org/10.1519/JSC.0b013e3181a04dc3>



- Windolf, M., Götzen, N., & Morlock, M. (2008). Systematic accuracy and precision analysis of video motion capturing systems—exemplified on the Vicon-460 system. *Journal of Biomechanics*, 41(12), 2776-2780. <https://doi.org/10.1016/j.jbiomech.2008.06.024>
- Wood, G. A., & Marshall, R. N. (1986). The accuracy of DLT extrapolation in three-dimensional film analysis. *Journal of Biomechanics*, 19(9), 781-785. [https://doi.org/10.1016/0021-9290\(86\)90201-0](https://doi.org/10.1016/0021-9290(86)90201-0)
- Yan, L., Wei, G., Hu, Z., Xiu, H., Wei, Y., & Ren, L. (2021). Low-Cost Multisensor Integrated System for Online Walking Gait Detection. *Journal of Sensors*, 2021(1), 6378514. <https://doi.org/10.1155/2021/6378514>
- Yeung, M.-Y., Fu, S. C., Chua, E. N., Mok, K.-M., Yung, P. S. H., & Chan, K.-M. (2016). Use of a Portable Motion Analysis System for Knee Dynamic Stability Assessment in Anterior Cruciate Ligament Deficiency During Single-Legged Hop Landing. *Asia-Pacific Journal of Sports Medicine Arthroscopy Rehabilitation and Technology*, 5, 6-12. <https://doi.org/10.1016/j.asmart.2016.06.002>

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