2024, Retos, 56, 597-606

Can the Countermovement Jump or Squat Jump predict the kinematic performance of the rear *Bandal Chagi* kick?

¿Puede el salto con contramovimiento o el squat jump predecir el rendimiento cinemático de la patada trasera de Bandal Chagi?

*Destter Álacks Antonietto, **,******Ignacio Roa Gamboa, , *Naiara Ribeiro, ***Ciro José Brito, *Cinthya Luiza Rezende Oliveira, ****Otávio de Toledo Nóbrega, *Lucio Marques Vieira-Souza, *****Bianca Miarka, ***Esteban Aedo-Muñoz
*Federal University of Juiz de Fora (Brazil), **Universidad Metropolitana de Ciencias de la Educación (Chile), ***Universidad de Santiago de Chile (Chile), ****University of Brasilia (Brazil), *****Federal University of Rio de Janeiro (Brazil), ******Instituto Nacional de Deportes (Chile)

Abstract. This study aimed to measure the associative and predictive strength of biomechanical variables of the countermovement jump (CMJ) and squat jump (SJ), and performance of the *bandal-chagi* kick performed with the dominant (D) rear lower limb in elite Taekwondo Athletes. For this, a total of 27 international level athletes (15 males and 12 females) performed the CMJ and SJ on two force platforms. The *bandal-chagi* was monitored using a motion capture system (VICON). The main results indicated that non-dominant (ND) Stiffness for the CMJ showed predictive power alone (p=0.048) or in combination with eccentric breaking rating of force development (RFD) (p=0.031) for total hip angular speed. Takeoff peak force/BM for the SJ predicted total time (p=0.002). Concentric RFD/BM predicted total linear foot acceleration, either alone (p=0.001) or with vertical speed at takeoff (p=0.042). The total hip angular acceleration predictor was takeoff peak force D alone (p=0.019) or in combination with peak power/BM (p=0.041). In conclusion, CMJ and SJ tests showed specific associations with TKD kick performance. These analyses in this study indicated that they are good predictors for TKD athletes, producing results consistent with the participants' levels.
Keywords: Martial arts, Biomechanical Phenomena, Time-motion studies, Kinanthropometry, Motion Capture.

Resumen. Este estudio tuvo como objetivo medir la fuerza asociativa y predictiva de las variables biomecánicas del salto con contramovimiento (CMJ) y el squat jump (SJ), y el rendimiento de la patada *bandal-chagi* realizada con el miembro inferior trasero dominante (D) en atletas de taekwondo de élite. Para esto, un total de 27 atletas de nivel internacional (15 hombres y 12 mujeres) realizaron el CMJ y SJ en dos plataformas de fuerza. El *bandal-chagi* fue monitoreado mediante un sistema de captura de movimiento (VICON). Los principales resultados indicaron que la rigidez no dominante (ND) para el CMJ mostró poder predictivo solo (p=0,048) o en combinación con la tasa de desarrollo de fuerza en el frenado excéntrico (RFD) (p=0,031) para la velocidad angular total de la cadera. En el SJ, la fuerza máxima de despegue/MC para el tiempo total previsto (p=0,002). RFD/MC concéntrica predijo la aceleración lineal total del pie, sola (p=0,001) o con velocidad vertical en el despegue (p=0,042). El predictor de aceleración angular total de la cadera fue la fuerza máxima de despegue D sola (p=0,019) o en combinación con la potencia máxima/MC (p=0,041). En conclusión, las pruebas CMJ y SJ mostraron asociaciones específicas con el rendimiento de la patada de TKD. Estos análisis en este estudio indicaron que son buenos predictores para los atletas de TKD, produciendo resultados consistentes con los niveles de los participantes.
Palabras clave: Artes marciales, Fenómenos Biomecánicos, Estudios de tiempo-movimiento, Cineantropometría, Captura de Movimiento.

Fecha recepción: 23-01-24. Fecha de aceptación: 19-04-24
Ciro José Brito
cirojbrito@gmail.com

Introduction

Taekwondo (TKD) is an Olympic combat sport (Santos et al., 2014). To win a bout, athletes strive to score points while avoiding counterattacks from their opponents (da Silva Santos, Loturco, & Franchini, 2018). It is consequently crucial that offensive actions, such as punches and kicks, are swift and accurate (da Silva Santos et al., 2018; Falco et al., 2009). Scoring criteria are according to competitive rules, and vary based on the applied technique and targeted body area (Santos et al., 2014). Athletes often opt for kicks since they generally score higher than punches (Kwok, 2012), with the *bandal-chagi* (roundhouse kick) being the most frequent choice (Ha, Choi, & Kim, 2009; Sousa, Puerto, Beltrán, Louro, & Godoy, 2024). Moreover, proficiency in executing this kick correlates with competitive success; medalist athletes use this kick more frequently, as noted by Kwok (2012).

Given that the technique is adaptable to an athlete's morphology (Falco et al., 2009), some studies (Gavagan & Sayers, 2017; Ha et al., 2009) have delved into understanding how anthropometric and biomechanical variables can aid coaches in enhancing fighter performance (Ojeda-Aravena, Azócar-Gallardo, Hérnandez-Mosqueira, & Herrera-Valenzuela, 2020). Certain technical-tactical and biomechanical analysis studies (Estevan, Alvarez, Falco, Molina-García, & Castillo, 2011; Falco et al., 2009) have identified kick application speed as a determinant of competitive success in TKD. However, it is essential to understand that a comprehensive analysis of *bandal-chagi* performance necessitates kinematic monitoring due to the technique's angular nature (Falco et al., 2009). The advent of camera capture systems has ushered in an era of refined precision in assessing sports techniques (Windolf, Götzen, & Morlock, 2008). Accordingly, using such equipment has deepened our understanding of the biomechanical variables integral to this kick (Estevan, Jandacka, & Falco, 2013; Gavagan & Sayers, 2017; Kim, Kim, & Im, 2011). For instance, Kim et al. (2011) documented an angular velocity of 56.6g/s in hip flexion-extension movements, while the knee average was 95.5g/s. Gavagan and Sayers (2017) reported 341g/s and 943g/s for the hip and knee angular velocities, respectively, and 14.66 m/s for linear velocity in a stationary position. Similarly, experienced athletes in a study by Estevan et al. (2013) exhibited an average foot speed of 9.90 m/s. In relation to kicks, da Silva, Misuta, Silvatti, Mercadante, and Barros (2011) observed an average foot acceleration of 127.65 m/s^2 and 421 rad/s^2 for the knee joint.

An important consideration to highlight is that while motion capture systems boast advanced capabilities, they often lack portability and cost-effectiveness (Fiorentino, Uva, Foglia, & Bevilacqua, 2013). Consequently, there is a growing interest in exploring alternative methods that bridge the gap between the technical insights provided by motion capture and the more accessible biomechanical tests. In this regard, jump tests have emerged as a viable option for evaluating TKD fighters (Avci & Celik, 2023; Chiodo et al., 2012; da Silva Santos, Herrera-Valenzuela, Ribeiro da Mota, & Franchini, 2016; Norjali Wazir et al., 2019). Considering the dominance of lower limb attacks in the sport (Ha et al., 2009), both the countermovement jump (CMJ) and squat jump (SJ) tests have been leveraged to forecast kicking prowess in TKD (Chiodo et al., 2012; da Silva Santos et al., 2016; Norjali Wazir et al., 2019). However, existing knowledge regarding these jumps' utility in TKD remains limited, predominantly because evaluators have primarily gauged jump height as the sole performance indicator (Ojeda-Aravena et al., 2023). The prevalent use of contact mats instead of force platforms partly explains this restricted perspective (Chiodo et al., 2012; da Silva Santos et al., 2016; Norjali Wazir et al., 2019). Indeed, force platforms offer a wider array of measurable variables, delivering invaluable biomechanical insights (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015), such as the rate of force development (RFD) (Kavvoura et al., 2018). Hence, this study aims to ascertain the associative and predictive strength of CMJ and SJ tests concerning *bandal-chagi* performance. If a connection emerges between the jump variables and the kick's kinematics, coaches could implement this study's findings to steer athlete selection, discern competitive tiers, project sports performance, and design training regimens. Given this context, our primary objective is to determine the associative and predictive strength of standard biomechanical variables from CMJ and SJ tests, and the spatiotemporal aspects of the *bandal-chagi* kick executed with the rear dominant lower limb in elite TKD athletes. We posit that both tests will successfully predict the performance of spatiotemporal components of the *bandal-chagi* as measured by kinematic analysis.

Materials and methods

Experimental approach

The present study follows a cross-sectional design in which a group of elite TKD athletes were analyzed in a biomechanics laboratory. They underwent anthropometric measurements, two jump tests, and a kick monitored by a kinematic device. We initially reached out to the National Federation and coaches to explain the objectives of this protocol. After obtaining permission from the relevant authorities, athletes meeting the inclusion criteria were contacted. Those who agreed and provided signed informed consent were included in the study. All measurements were performed in a single visit to the laboratory, following this sequence: 1) anthropometry, 2) warm-up, 3) CMJ, 4) SJ, 5) kinematic test. The ethics committee of the University approved this study (Protocol 71430923.4.0000.5546).

Participants

Elite athletes of both sexes participated in this study. The inclusion criteria were: a) ≥18 years old; b) ≥5 years of continuous competitive TKD training; c) black belt status; d) at least one National Championship title. Exclusion criteria included: a) injuries that could affect test performance; b) errors during signal capture; or c) withdrawal from the study. A total of 56 out of 120 athletes initially met the inclusion criteria. Among these, 28 (16 men and 12 female) agreed to participate. However, one athlete was excluded due to an error during the kinematic capture, resulting in a final sample of 27 athletes (15 men and 12 female). Their achievements include 11 national championships, 8 South American medals, and 8 Pan-American medals (from the year 2022). Table 1 presents other participant characteristics.

Anthropometric measures

Height was measured to the nearest centimeter, and body mass to the nearest 100 grams (using Detecto®, 339, USA). Body fat was estimated using the Jackson and Pollock 7-skinfold protocol for men (Jackson & Pollock, 1978) and women (Jackson, Pollock, & Ward, 1980).

Jump tests

Participants warmed up for about 10 minutes, consisting of joint mobility exercises, moderate-intensity running, specific strength movements, and three practice attempts for each jump. After the warm-up, participants performed three CMJ attempts as described by Slinde, Suber, Suber, Edwén, and Svantesson (2008). After the CMJ, the participants performed three SJ attempts based on the method described by Markovic, Dizdar, Jukic, and Cardinale (2004). Both CMJ and SJ results were evaluated using the best result calculated by the ratio between flight time to contraction time (or time to take-off) and the reactive strength index modified according to McMahon, Lake, and Comfort (2018). All jumps were executed on two monoaxial force platforms (type: PS-2142; sampling: 50-1000Hz; Range: -1000 to 4400N over 6600N; Resolution: 0.34N; dimensions 350mm x 350mm, Pasco® CI-6461, Pasco Scientific, USA). The sampling was set at 1000Hz, since it has shown good reliability in force-time variables (Dos' Santos et al., 2018).

Kinematics of Bandal-chagi

2024, Retos, 56, 597-606

Kinematic measurements utilized a photogrammetry video capture system (Vantage V5, VICON® Motion Systems Ltd., Oxford, UK) with ten cameras capturing movements at a frequency of 200Hz. Prior calibration ensured residuals were adjusted to 2mm (Merriaux, Dupuis, Boutteau, Vasseur, & Savatier, 2017). Reflective and deformable sensors, 14mm in diameter, were placed at specific anatomical points (plug in gate lower limbs model), according the standard recommendations. All data were analyzed by Nexus Software 1.8.5 (VICON® Motion Systems Ltd., Oxford, UK). To a measure in the software, the sensor's movement needs to be simultaneously captured by a minimum of two cameras.

Variables measured during the test

For the *bandal-chagi* analysis, we adopted the kinematic division proposed by Kim, Kwon, Yenuga, and Kwon (2010), dividing the kick into three phases: a) Toe-off; b) Maximum Knee Flexion; and c) Impact. Athletes practiced ten *bandal-chagi* kicks, with at least two at maximum intensity. All kicks targeted a specific TKD mitt, with each athlete choosing the distance for the mitt. They delivered three kicks with a 14-second interval, which reflects the average attack time in international competitions (Santos et al., 2014). All kicks utilized the rear leg, based on data from Gutiérrez-Santiago, Pereira-Rodríguez, and Prieto-Lage (2020) indicating its effectiveness in scoring during competitions. Figure 1 provides a model derived from the kinematic analysis of a kick by a female athlete.

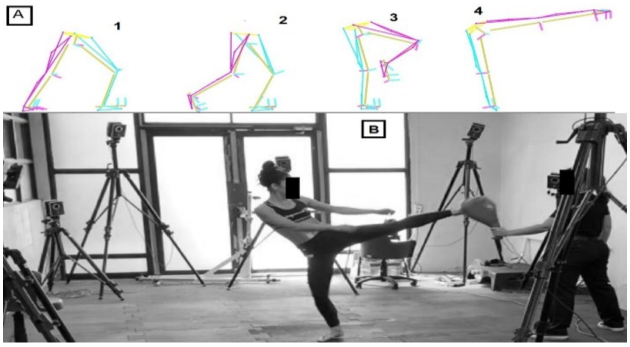

Figure 1. A. *Bandal-chagi* kinematic analysis. 1 – Start position, 2 – Toeoff, 3 - Maximum Knee Flexion, 4 – Impact. B. Example of a female rear kick.

Statistical analysis

Data normality was initially assessed using the Kolmogorov-Smirnov test. One-way ANOVA was used for comparisons among men, women, and the total group. Pearson's correlation was performed to assess the strength of association between jump and kicking performance. This evaluated potential associations between CMJ and SJ variables with kinematic measures. A linear regression was also conducted using the stepwise method to determine the predictive power of the jumps. All analyses were executed using the SPSS software program (version 25.0). A significance level of $p \leq 0.05$ was set for all tests.

Results

Table 1 shows the anthropometric measures of the participants and performance of sit-and-reach test.

Table 1.
Anthropometric characteristics of participants and the performance of sit-and-reach test.

Measure	Male	Female	Total
Age (years)	20.9±3.1	22.6±3.8	21.6±3.5
Experience (years)	11.7±3.1	12.1±2.3	11.9±2.7
Body mass (kg)	69.9±8.7[a]	55.2±4.4	62.8±9.8
Body fat (%)	4.6±1.9[a]	14.9±3.0	9.1±5.7
Height (m)	1.8±0.1[a]	1.6±0.1	1.7±0.1
Side domain	11 R and 4 L	11 R and 1 L	22 R and 5 L

Note: Data present by mean ± standard deviation. R – right lower limb domain. L – left lower limb domain. [a] $p \leq 0.026$ vs. female.

In comparing males, females, and the total participants, no significant differences were observed in the means presented in Table 1 for the variables of age ($F=0.823$; $p=0.445$; $\eta p^2=0.019$) and experience ($F=0.077$; $p=0.926$; $\eta p^2=0.01$). Differences were noted for the other variables between the means presented by men and women; however, the averages for men did not differ from the overall average. These variables include body mass ($F=8.436$; $p=0.001$; $\eta p^2=0.45$), height ($F=10.601$; $p \leq 0.001$; $\eta p^2=0.51$), and fat percentage ($F=17.958$; $p \leq 0.001$; $\eta p^2=0.064$). The results of the CMJ are presented in Table 2.

Table 2.
Countermovement jump variables results by the athletes.

Measure	Male	Female	Total
Stiffness [N/m]	5,136.0±1,461.0	4,782.1±839.6	4,978.7±1,216.4
Concentric time [ms]	284.3±33.0	272.7±40.1	279.1±36.1
Concentric Peak Force/BM [N/kg]	23.9±1.4	23.0±1.5	23.5±1.5
Concentric Peak Velocity [m/s]	2.6±0.3	2.6±0.2	2.6±0.3
Eccentric Breaking RFD/BM [N/s/kg]	73.8±17.8	73.6±24.7	73.7±20.7
Eccentric Breaking RFD-100ms/BM [N/s/kg]	48.4±25.3	64.1±36.2	55.4±31.0
Eccentric Deceleration RFD/BM [N/s/Kg]	87.1±20.2	81.0±30.2	84.4±24.8
Eccentric Duration [ms]	457.1±50.2	439.0±80.8	449.1±64.8
Eccentric Peak Force/BM [N/kg]	23.6±1.8	22.3±2.3	23.0±2.1
Flight Time [ms]	492.9±47.5	506.3±39.9	498.9±44.0
Jump Height [cm]	30.1±5.8	31.6±5.1	30.8±5.4
Peak Power/BM [W/kg]	45.8±7.8	46.7±5.2	46.2±6.7
Vertical Velocity at Takeoff (m/s)	2.5±0.3	2.4±0.2	2.4±0.3
Limb Stiffness (ND) [N/m]	2,589.9±756.7	2,387.6±394.0	2,500.0±620.0
Limb Stiffness (D) [N/m]	2,564.5±712.2	2,425.7±462.4	2,502.8±607.1
Concentric Peak Force (ND) [N]	797.5±156.9	721.9±134.6	763.9±149.6
Concentric Peak Force (D) [N]	784.5±132.3	738.3±109.2	763.9±122.6

Eccentric Breaking RFD (ND) [N/s]	2,423.3±483.3	2,304.3±683.7	2,370.4±572.0
Eccentric Breaking RFD (D) [N/s]	2,388.5±355.8	2,259.3±706.3	2,331.1±532.4
Eccentric Breaking RFD-100ms (ND) [N/s]	1,604.6±612.2	2,077.7±875.2	1,814.9±765.4
Eccentric Breaking RFD-100ms (D) [N/s]	1,629.9±775.1	1,889.8±1,023	1,745.4±885.2
Takeoff Peak Force (ND) [N]	800.2±157.3	722.7±134.7	765.7±150.1
Takeoff Peak Force (D) [N]	791.7±133.2	740.3±109.5	768.8±123.7

Note: Data present by mean ± standard deviation. RFD – rating of force development. BM – body mass. D – dominant lower limb. ND – non-dominant lower limb.

There were no significant differences ($p>0.05$) in comparing male, female and the total participants for the means in Table 2. Table 3 shows the results for SJ. In comparing males, females, and the total participants, significant differences in the means presented in Table 3 were observed for: peak takeoff acceleration ($F=3.192$; $p=0.049$; $\eta p^2=0.29$) and takeoff peak force/BM ($F=3.233$; $p=0.48$; $\eta p^2=0.32$). There were significant differences for these variables between males and females ($p=0.044$ for peak takeoff acceleration and $p=0.042$ for takeoff peak force/BM). Table 4 shows the results of the kinematic analysis of *bandal-chagi* performed by the athletes.

Table 3.
Squat jump results by the athletes.

Measure	Male	Female	Total
Concentric Mean Power/BM [W/kg]	15.6±3.0	16.4±2.4	16.0±2.7
Concentric Peak Velocity [ms]	2.4±0.2	2.4±0.2	2.4±0.2
Concentric RFD/BM [N/s/kg]	44.3±18.1	56.4±15.6	49.7±17.8
Contraction Time [ms]	425.9±106.2	374.4±70.9	403.1±94.2
Flight Time [ms]	576.8±45.9	487.0±41.3	476.3±44.2
Jump Height (Flight Time) [cm]	27.1±5.3	29.2±5.1	28.0±5.2
Peak Power/BM [W/kg]	45.3±5.6	47.8±6.4	46.4±6.0
Peak Takeoff Acceleration [m/s²]	12.6±1.4[a]	14.5±2.2	13.5±2.0
Take off Peak Force/BM (N/Kg)	22.4±1.4[a]	24.3±2.2	23.3±2.0
Vertical Velocity at Takeoff [m/s]	2.3±0.2	2.3±0.2	2.3±0.2
Concentric RFD (ND) [N/s]	1,444.0±516.7	1,785.8±542.1	1,595.9±545.9
Concentric RFD (D) [N/s]	1,410.2±519.9	1,752.3±516.7	1,572.3±537.1
Concentric RFD – 100ms (ND) [N/s]	716.1±163.3	706.1±138.9	711.6±150.2
Concentric RFD – 100ms (D) [N/s]	679.5±142.8	704.1±117.2	690.4±130.2
Force at Peak Power (ND) [N]	761.0±182.9	772.0±150.8	765.9±166.3
Force at Peak Power (D) [N]	746.3±172.3	769.7±131.1	756.7±152.9

Note: Data present by mean ± standard deviation. RFD – rating of force development. BM – body mass. D – dominant lower limb. ND – non-dominant lower limb. [a] $p\leq0.044$ vs. female.

Table 4.
Bandal-chagi kinematic analysis separated by kick phase.

Measure	Male	Female	Total
Time 1st phase (s)	0.12±0.04	0.14±0.03	0.13±0.04
Time 2nd phase (s)	0.13±0.02	0.13±0.01	0.13±0.02
Time 3rd 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 1st phase (m/s)	2.2±0.7	2.0±0.4	2.1±0.6
Foot linear speed 2nd phase (m/s)	9.8±1.3	9.4±1.3	9.6±1.3
Foot linear speed 3rd phase (m/s)	13.2±1.4	12.1±1.8	12.7±1.7
Total Foot linear speed (m/s)	25.3±2.5	23.5±2.8	24.5±2.7
Knee angular speed 1st phase (g/s)	657.1±145.8	676.7±123.9	665.8±134.3
Knee angular speed 2nd phase (g/s)	937.0±278.3	261.3±169.4	903.4±235.2
Knee angular speed 3rd phase (g/s)	1,746.1±357.2	1,6686.6±230.3	1,719.6±303.4
Total Knee angular speed (g/s)	3,340.2±650.6	3,224.5±338.5	3,288.8±529.0
Hip angular speed 1st phase (g/s)	261.2±61.5	271.8±112.2	265.9±58.9
Hip angular speed 2nd phase (g/s)	476.2±96.4	440.6±89.7	460.4±93.4
Hip angular speed 3rd phase (g/s)	611.5±166.1	603.1±223.8	607.7±189.9
Total Hip angular speed (g/s)	1,348.8±180.6	1,315.5±344.3	1,334.0±260.8
Foot acceleration 1st phase (m/s2)	72.0±25.0	59.4±11.6	66.4±20.8
Foot acceleration 2nd phase (m/s2)	128.9±31.7	120.5±37.0	125.2±33.7
Foot acceleration 3rd phase (m/s2)	362.2±83.2	308.0±67.8	338.1±80.1
Total Foot acceleration (m/s2)	563.1±114.2	488.0±87.0	529.7±108.0
Knee acceleration 1st phase (m/s2)	11,977.7±2,198.2	12,648.7±3,232.9	12,276.0±2,671.9
Knee acceleration 2nd phase (m/s2)	21,780.3±10,146.5	17,845.4±5,097.8	20,031.4±8,390.5
Knee acceleration 3rd phase (m/s2)	41,394.2±19,577.2	41,159.6±12,291.2	41,298.9±16,440.9
Total Knee acceleration (m/s2)	77,152.2±29,619.89	71,653.7±16,167.0	73,597.3±24,210.1
Hip acceleration 1st phase (m/s2)	6,940.1±1,431.0	8,463.4±3,498.4	7,617.1±2,622.1
Hip acceleration 2nd phase (m/s2)	6,575.9±1,820.3	6,143.5±1,490.4	6,361.5±1,662.4
Hip acceleration 3rd phase (m/s2)	24,579.8±16,164.4	25,930.1±10,477.7	25,180.0±13,690.5
Total Hip acceleration (m/s2)	38,055.8±17,240.2	40,537.1±13,184.1	39,1458.6±15,335.0

Note: Data present by mean ± standard deviation.

No significant differences were observed ($p>0.05$) in comparing men, women, and the total sample in Table 4. The correlations between typical CMJ variables and the kinematic analysis of *bandal-chagi* are presented in Table 5.

2024, Retos, 56, 597-606

Only significant correlations are presented to better organize the results. Stiffness demonstrated a direct relationship with hip angular velocity in the second (r=0.527; p=0.05) and third phases of the kick (r=0.464; p=0.015), as well as with total speed (r=0.485; p=0.01). Stiffness showed an inverse relationship for angular acceleration during the first phase of knee acceleration (r=-0.414; p=0.032), and a direct relationship during the second (r=0.427; p=0.026) and third hip phases of the kick. Similar correlations were observed for acceleration in the third phase (r=0.458; p=0.016) and for total acceleration (r=0.474; p=0.012). The concentric phase of the jump had an inverse association with hip angular velocity during the kick's second phase (r=-0.404; p=0.037). Analyzing by D and ND lower limbs separately, Stiffness ND directly correlated with hip angular speed in the second (r=0.526; p=0.005) and third phases of the kick (r=0.471; p=0.013), and with total speed (r=0.504; p=0.007). Similar results were found for hip angular acceleration in the second (r=0.453; p=0.018) and third phases (r=0.463; p=0.015), and for total acceleration (r=0.486; p=0.01). Stiffness for the D lower limb directly correlated with hip speed in the second (r=0.537; p=0.004) and third phases (r=0.451; p=0.018), and with total speed (r=0.474; p=0.013). It also showed an inverse correlation with knee angular acceleration during the kick's first phase (r=-0.43; p=0.025).

The concentric peak force of the ND lower limb positively correlated with foot acceleration during the first (r=0.388; p=0.045) and third phases (r=0.441; p=0.021), and total acceleration (r=0.395; p=0.042). The D lower limb had significant correlations with foot acceleration during the first (r=0.423; p=0.028) and third phases (r=0.456; p=0.017) and total hip acceleration (r=0.397; p=0.04). Eccentric braking RFD rate negatively correlated with the first phase of hip angular velocity for both the non-dominant (r=-0.458; p=0.016) and dominant (r=-0.415; p=0.031) legs. The relative RFD-100ms of the ND lower limb negatively correlated with the foot's linear acceleration during the third (r=-0.496; p=0.008) and total phases (r=-0.479; p=0.011). Positive correlations for peak force during takeoff were observed with foot linear acceleration in the first phase for both ND (r=0.407; p=0.035) and D (r=0.429; p=0.026). The peak takeoff force for both D and ND positively correlated with the hip's angular acceleration during the third and total phases. Table 6 shows the correlations between the SJ variables and the kinematics of the *bandal-chagi*.

Table 5.
Significant correlations between countermovement jump and kinematic measures of bandal-chagi performed by athletes.

CMJ/Kinematic	Time 3rd phase	Total Knee angular speed	Hip angular speed 1st phase	Hip angular speed 2nd phase	Hip angular speed 3rd phase	Total Hip angular speed	Foot acceleration 1st phase	Foot acceleration 3rd phase	Total Foot acceleration	Knee angular acceleration 1st phase	Hip angular acceleration 2nd phase	Hip angular acceleration 3rd phase	Total Hip angular acceleration
Stiffness				r=0.527; p=0.005	r=0.464; p=0.015	r=0.485; p=0.01				r=-0.414; p=0.032	r=0.427; p=0.026	r=0.458; p=0.016	r=0.474; p=0.012
Concentric time				r=-0.404; p=0.037									
Eccentric Deceleration RFD/BM			r=--0.42; p=0.029										
Eccentric Duration	r=0.418; p=0.03												
Eccentric Peak Force/BM			r=-0.432; p=0.024										
Peak Power/BM		r=0.4; p=0.039									r=-0.434; p=0.024		r=-0.385; p=0.048
Limb Stiffness (ND)				r=0.526; p=0.005	r=0.471; p=0.013	r=0.504; p=0.007					r=0.453; p=0.018	r=0.463; p=0.015	r=0.486; p=0.01
Limb Stiffness (D)				r=0.537; p=0.004	r=0.451; p=0.018	r=0.474; p=0.013				r=-0.43; p=0.025	r=0.409; p=0.034	r=0.447; p=0.019	r=0.462; p=0.015
Concentric Peak Force (ND)							r=0.388; p=0.045					r=0.441; p=0.021	r=0.395; p=0.042
Concentric Peak Force (D)							r=0.423; p=0.028					r=0.456; p=0.017	r=0.397; p=0.04
Eccentric Breaking RFD (ND)										r=-0.458; p=0.016			
Eccentric Breaking RFD (D)										r=-0.415; p=0.031			
Eccentric Breaking RFD-100ms (ND)								r=-0.496; p=0.008	r=-0.479; p=0.011				
Takeoff Peak Force (ND)							r=0.407; p=0.035					r=0.449; p=0.019	r=0.403; p=0.037
Takeoff Peak Force (D)							r=0.429; p=0.026					r=0.45; p=0.018	r=0.393; p=0.043

Note: CMJ – countermovement jump. RFD – rating of force development. BM – body mass. D – dominant lower limb. ND – non-dominant lower limb.

2024, Retos, 56, 597-606

Jump height directly correlated with the duration of the third phase of the kick (r=0.385; p=0.048). Peak Power/BM positively correlated with the duration of the third phase of the kick (r=0.44; p=0.022) and negatively with the angular velocity of the knee in the second phase (r=-0.407; p=0.035). The peak acceleration at takeoff positively correlated with the time spent kicking in the first (r=0.407; p=0.035), second (r=0.493; p=0.009), and the total kick duration (r=0.558; p=0.003). This variable also negatively correlated with the total linear foot speed (r=-0.387; p=0.046), foot acceleration in the third phase (r=-0.411; p=0.033), and total acceleration (r=-0.417; p=0.031). The peak force during takeoff positively correlated with the time spent kicking in the first (r=0.406; p=0.035), second phase (r=0.494; p=0.009), and the total duration (r=0.558; p=0.002). This variable also negatively correlated with the total linear foot speed (r=-0.39; p=0.044), foot acceleration in the third phase (r=-0.411; p=0.033), and total acceleration (r=-0.418; p=0.03). The vertical speed at takeoff showed a direct correlation with the duration of the kick in the third phase (r=0.4; p=0.039).

For analysis separated by D and ND: the Concentric RFD of the ND lower limb had a positive correlation with the time in the second phase of the kick (r=0.609; p=0.001) and negative correlations with foot speed in the third phase (r=-0.556; p=0.003), total speed (r=-0.473; p=0.013), foot acceleration in the third phase (r=-0.659; p≤0.001), and total acceleration (r=-0.558; p=0.002). Similar results were observed for the Concentric RFD of the D lower limb. The Force at Peak Power of the D lower limb directly correlated with hip acceleration in the third phase of the kick (r=0.432; p=0.024). The Takeoff Peak Force for both D and ND limbs showed a positive correlation with hip acceleration in the third phase of the kick (r=0.424; p=0.027 for ND and r=0.5; p=0.008 for D). Only the D limb showed a correlation in total acceleration (r=0.448; p=0.019).

Table 6.
Correlation between squat jump and kinematic measures of *bandal-chagi*.

SJ/Kin	Time 1st phase	Time 2nd phase	Time 3rd phase	Total Time	Linear foot speed 3rd phase	Total linear foot speed	Angular knee speed 2nd phase	Linear foot acceleration 1st phase	Linear foot acceleration 3rd phase	Total Linear foot acceleration	Angular hip acceleration 3rd phase	Total Angular hip acceleration
Concentric Mean Power/BM								r=-0.383; p=0.049	r=-0.397; p=0.04	r=-0.43; p=0.025	r=-0.423; p=0.028	
Concentric Peak Speed			r=0.385; p=0.047									
Concentric RFD/BM		r=0.659; p≤0.001			r=-0.546; p=0.003	r=-0.501; p=0.008			r=-0.66; p≤0.001	r=-0.582; p=0.001		
Contraction Time									r=0.546; p=0.003	r=0.484; p=0.011	r=0.381; p=0.05	
Jump Height			r=0.385; p=0.048									
Peak Power			r=0.44; p=0.022				r=-0.407; p=0.035					
Peak Takeoff Acceleration	r=0.407; p=0.035	r=0.493; p=0.009		r=0.558; p=0.003		r=-0.387; p=0.046			r=-0.411; p=0.033	r=-0.417; p=0.031		
Peak Takeoff force	r=0.406; p=0.035	r=0.494; p=0.009		r=0.558; p=0.002		r=-0.39; p=0.044			r=-0.411; p=0.033	r=-0.418; p=0.03		
Vertical speed at Takeoff			r=0.4; p=0.039									
Concentric RFD (ND)		r=0.609; p=0.001			r=-0.556; p=0.003	r=-0.473; p=0.013			r=-0.659; p≤0.001	r=-0.558; p=0.002		
Concentric RFD (D)		r=0.653; p≤0.001			r=-0.58; p=0.002	r=-0.526; p=0.005			r=-0.644; p≤0.001	r=-0.558; p=0.002		
Force at Peak Power (D)											r=0.432; p=0.024	
Takeoff Peak Force (ND)											r=0.424; p=0.027	
Takeoff Peak Force (D)											r=0.5; p=0.008	r=0.448; p=0.019

Note: SJ – squat jump. RFD – rating of force development. BM – body mass. D – dominant lower limb. ND – non-dominant lower limb.

Table 7 shows the linear regression for CMJ and SJ measures of the participants and performance in *bandal-chagi*.

Table 7.
Linear regression for countermovement and squat jump to predict bandal-chagi performance.

Countermovement Jump								
Total Knee angular speed								
Model		NSC		SC	t	Sig.	95%CI expected for B	
		B	Error	Beta			Upper limit	Lower limit
1	Constant	4701.898	684.721		6.867	≤0.001	3291.687	6112.108
	Peak Power / BM	-30.592	14.677	-0.385	-2.084	0.048	-60.820	-0.363
Total hip angular speed								
1	Constant	8040.046	186.929		4.301	≤0.001	419.059	1189.034
	Stiffness (ND)	0.214	0.073	0.504	2.918	0.007	0.063	0.364

2	(Constante)	1144.036	227.432		5.030	≤0.001	674.640	1613.431
	Stiffness (ND)	0.241	0.069	0.569	3.511	0.002	0.099	0.383
	Eccentric Breaking RFD (ND)	-0.174	0.076	-0.373	-2.298	0.031	-0.330	-0.018
Total foot linear acceleration								
1	Constant	656.172	49.902		13.149	≤0.001	553.397	758.947
	Eccentric Breaking RFD-100ms (ND)	-0.069	0.025	-0.479	-2.732	0.011	-0.121	-0.017
Total angular hip acceleration								
1	Constant	9115.216	11124.986		0.819	0.420	-13797.122	32027.555
	Stiffness (ND)	12.108	4.356	0.486	2.779	0.010	3.136	21.080
Squat Jump								
Total time								
1	Constant	0.065	0.087		0.748	0.462	-0.114	0.244
	Take off Peak Force/BM	0.013	0.004	0.558	3.362	0.002	0.005	0.020
Total linear foot speed								
1	Constant	28.518	1.375		20.745	≤0.001	25.687	31.350
	Concentric RFD (D)	-0.003	0.001	-0.526	-3.096	0.005	-0.004	-0.001
Total foot linear acceleration								
1	Constant	704.700	51.911		13.575	≤0.001	597.787	811.612
	Concentric RFD/BM	-3.523	0.986	-0.582	-3.574	0.001	-5.552	-1.493
2	Constant	1160.653	218.141		5.321	≤0.001	710.432	1610.874
	Concentric RFD/BM	-4.331	0.996	-0.715	-4.350	≤0.001	-6.386	-2.276
	Vertical speed at Takeoff	-178.901	83.446	-0.352	-2.144	0.042	-351.124	-6.677
Total hip angular acceleration								
1	Constant	5407.495	13727.146		0.394	0.697	-22864.090	33679.081
	Takeoff Peak Force (D)	44.603	17.789	0.448	2.507	0.019	7.966	81.240
2	Constant	42268.234	21347.500		1.980	0.059	-1790.842	86327.309
	Takeoff Peak Force (D)	54.667	17.255	0.549	3.168	0.004	19.055	90.278
	Peak Power/BM	-958.994	444.089	-0.374	-2.159	0.041	-1875.548	-42.440

Note: NSC – Non-standardized coefficient; SC – Standardized coefficient.

In linear regressions where CMJ variables were used to predict *bandal-chagi* kinematic measurements, Peak Power/BM was found to be predictive of total knee angular speed. Stiffness ND exhibited predictive power either on its own (p=0.048) or in conjunction with eccentric breaking RFD (p=0.031) for total hip angular speed. The total foot linear acceleration was predicted by the eccentric breaking RFD-100ms ND (p=0.011). Additionally, Stiffness ND served as a predictor for total angular hip acceleration (p=0.01).

Regarding the measurements obtained from the SJ, Takeoff peak force/BM predicted total kick time (p=0.002). Concentric RFD D was a predictor for total linear foot speed (p=0.005). Concentric RFD/BM predicted total linear foot acceleration both independently (p=0.001) and in combination with vertical speed at takeoff (p=0.042). Finally, takeoff peak force D was predictive for total hip angular acceleration either on its own (p=0.019) or in combination with peak power/BM (p=0.041).

Discussion

This study measures the associative and predictive power of biomechanical variables of the CMJ and SJ for spatiotemporal variables of the *bandal-chagi* kick performed with the dominant rear lower limb in elite athletes. The main results indicated that both jumps can predict the technical performance of *bandal-chagi*, thereby corroborating our hypothesis. Stiffness (specially of ND lower limb) was the variable which showed the most correlations and was the main predictor variable for the CMJ. In turn, Concentric RFD/BM and Takeoff Peak Force (D) were the main predictor variables for SJ. The capture system enables precise movement analysis of the kicking technique performed by the athlete (Ha et al., 2009), however, it is expensive equipment and requires the use of a specific laboratory (Fiorentino et al., 2013), Thus, it is interesting that there are indirect indicators that can predict the athlete's technical performance. The results of the present study can be used by coaches to evaluate athletes through a simple jump test and that have predictive the kick performance.

CMJ is not specific to combat sports, however this jump is capable of estimating the specific performance of TKD athletes (Chiodo et al., 2012; da Silva Santos et al., 2016). In our study, the main predictor variable of CMJ was Stiffness of the ND lower limb. Stiffness is associated with the ability to accumulate elastic energy in the lower limbs, which enhances jumping performance (Struzik & Zawadzki, 2013). In this sense, the energy transfer from the lead limb (i.e., ND) appears to be decisive for *bandal-chagi* performance, as this variable is directly associated with hip speed when performing the kick. Estevan et al. (2013) observed that the efficiency of the *bandal-chagi* is associated with the push of the support leg against the ground, in the opposite direction to the proximal segment of the lead leg. Furthermore, studies have shown that a higher Stiffness increases the performance of muscular strength and power (Papla, Ewertowska, & Krzysztofik, 2023; Struzik & Zawadzki, 2013). In fact, speed, reaction time and kick power are physical strengths that determine success in combat (Moreira, Goethel, & Gonçalves, 2016; Wąsik, Mosler, Ortenburger, Góra, & Cholewa, 2021).

The main predictor variables for SJ were Concentric RFD/BM and Takeoff Peak Force. The force development rate is an important indicator of lower limb power (Maffiuletti et al., 2016), as previous studies had already measured this variable in TKD athletes (Kavvoura et al., 2018; Moreira et al., 2016; Moreira, Paula, & Veloso, 2015). In a kinematic analysis study of *bandal-chagi* by

Moreira et al. (2016), the RFD/ BM (calculated during the preparation phase for the kick) is capable of distinguishing elite and sub-elite athletes, with RFD being higher in elite athletes. However, our data contradict these previous findings, as the RFD/BM measured in the SJ was inversely associated with the linear foot speed during the kick. A possible explanation for this difference in results is possibly associated with the body mass of the lower limbs. When analyzing the body mass of the lower limbs of TKD fighters, Kavvoura et al. (2018) observed that the lean mass of the lower limbs is directly related to RFD. Another point to be considered is the diversity of methods used to measure the RFD, which generates doubts in the interpretation of the results (Wąsik et al., 2021). Moreira et al. (2015) observed a strong correlation between the RFD obtained in an isometric leg-press test and the peak hip velocity when performing the *bandal-chagi* kick (r=0.89).

Takeoff Peak Force expresses the maximum force applied at the moment the feet lose contact with the force platform, and constitutes an important variable in the jump test to determine the efficiency of muscle strength and power (Amasay & Suprak, 2022). Our results show that a higher the reactive ground force against the platform results in a higher hip angular speed. Similar results were observed by Moreira et al. (2015), which showed that the reactive ground force in the CMJ showed a strong association (r=0.9) with the hip peak force during the *bandal-chagi*. A previous study with isokinetic analysis showed that the ability to produce force with the hip combined with the angular velocity of the knee are decisive in differentiating competitive levels in TKD athletes (Moreira et al., 2021).

For the present study we chose to only analyze the rear limb of *bandal-chagi*, which is due to the effectiveness of this type of attack (Gutiérrez-Santiago et al., 2020). When analyzing TKD combats, a higher frequency of attacks made with the *bandal-chagi* performed with the lead limb can be seen (Gutiérrez-Santiago et al., 2020; Kwok, 2012), and a higher frequency of using the front leg has been observed after the insertion of electronic protectors in sport since the 2016 Olympic games (Márquez, López-Gullón, Menescardi, & Falcó, 2022). However, the rear leg is more effective in generating points (Casolino et al., 2012; Gutiérrez-Santiago et al., 2020). In this line, a study of technical-tactical analysis in university athletes by Falco, Estevan, Álvarez, Morales-Sánchez, and Hernández-Mendo (2014) observed that winners perform fewer direct attacks, however they perform more counterattacks simultaneously and subsequent to the attacks and anticipatory counterattacks, which are predominantly performed with the rear leg. This fact reinforces our findings on the importance of transferring strength from the supporting leg to the rear leg when performing the *bandal-chagi* in a counterattack.

Although jump height is considered the most effective measure of CMJ and SJ (Struzik & Zawadzki, 2013), our results show that these variables do not have great predictive capacity for kicking performance. In fact, this has been the main variable when evaluating the performance of TKD fighters in jump tests (Chiodo et al., 2012; da Silva Santos et al., 2016; Norjali Wazir et al., 2019). This limitation is possibly associated with the equipment used, as most studies have used mats to measure performance in the SJ and CMJ (Bridge, Ferreira da Silva Santos, Chaabene, Pieter, & Franchini, 2014; Ojeda-Aravena et al., 2020). Therefore, based on our results, it is recommended to use force platforms to obtain kinetic and kinematic measurements (McErlain-Naylor, King, & Pain, 2014), as these may have greater predictive capacity for the fighter's competitive performance. The results of the present study were observed in elite athletes, and so future studies can analyze whether the same predictors occurred in non-elite athletes. It should be noted that elite athletes perform better in CMJ and SJ when compared to non-elite athletes (Norjali Wazir et al., 2019). Another limitation of the present study is the single analysis between men and women, although no differences were observed in terms of kinematic variables (Table 4); thus, it would be interesting that future studies explore this analysis separately.

Conclusion

This study underscores the significant association between the biomechanical variables of the CMJ and SJ tests and the performance of the *bandal-chagi* kick in TKD. Remarkably, to our knowledge, this is the first study which concurrently analyzes the influence of both CMJ and SJ on *bandal-chagi* performance. Through our findings, we have identified predictors that offer valuable insights for TKD coaches and practitioners. These reliable indicators are consistent with the elite status of the participating athletes. From a practical standpoint, the emphasis lies on the stiffness, particularly of the ND lower limb in CMJ, and Concentric RFD/BM in SJ as pivotal in enhancing *bandal-chagi* kick performance. Rather than resorting to costly movement analysis tools, coaches can then leverage the simple CMJ and SJ tests to predict technical prowess in *bandal-chagi*. Furthermore, it is advisable to tailor exercises that specifically focus on enhancing stiffness and accumulating elastic energy in the lower limbs, optimizing *bandal-chagi* performance. This study also highlights the strategic advantage of utilizing the rear limb for *bandal-chagi*, given its proven effectiveness in scoring points. Force platforms stand out as the preferred choice over mats for accurate jump test measurements. These insights not only help to distinguish between elite and sub-elite athletes for talent identification, but also pave the way for future studies that might explore potential gender-specific variations, even though none were observed in the current study. Finally, by understanding the biomechanics of CMJ and SJ, there is an opportunity to design training regimens which not only accentuate performance, but also prioritize athlete safety. In its entirety, our study serves as a comprehensive guide for coaches, shaping TKD training, assessment, and the strategic nuances of competition decisions.

Acknowledgment

Agradecimientos al Proyecto POSTDOC_DICYT, Código 022304AM_Postdoc, Vicerrectoría de Investigación, Desarrollo e Innovación.

Conflict of interest

The authors declare no conflicts of interest.

References

Amasay, T., & Suprak, D. N. (2022). Predicting Time to Take-Off in a Countermovement Jump for Maximal Quickness From Upright and Squat Starting Positions. Journal of Human Kinetics, 84(1), 53-63.

Avci, B., & Celik, A. (2023). Age-related differences in the specific test on taekwondo players. Scientific Journal of Sport and Performance, 2(2), 198-207.

Bridge, C. A., Ferreira da Silva Santos, J., Chaabene, H., Pieter, W., & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes. Sports Medicine, 44, 713-733.

Casolino, E., Lupo, C., Cortis, C., Chiodo, S., Minganti, C., Capranica, L., & Tessitore, A. (2012). Technical and tactical analysis of youth taekwondo performance. The Journal of Strength & Conditioning Research, 26(6), 1489-1495.

Chiodo, S., Tessitore, A., Lupo, C., Ammendolia, A., Cortis, C., & Capranica, L. (2012). Effects of official youth taekwondo competitions on jump and strength performance. European Journal of Sport Science, 12(2), 113-120.

da Silva, A. J., Misuta, M. S., Silvatti, A. P., Mercadante, L. A., & Barros, R. M. (2011). Kinematical analysis of bandal and dolyo taekwondo kicks of a high level female athlete. Paper presented at the ISBS-Conference Proceedings Archive.

da Silva Santos, J. F., Herrera-Valenzuela, T., Ribeiro da Mota, G., & Franchini, E. (2016). Influence of half-squat intensity and volume on the subsequent countermovement jump and frequency speed of kick test performance in taekwondo athletes. Kinesiology, 48(1.), 95-102.

da Silva Santos, J. F., Loturco, I., & Franchini, E. (2018). Relationship between frequency speed of kick test performance, optimal load, and anthropometric variables in black-belt taekwondo athletes. Ido Movement for Culture. Journal of Martial Arts Anthropology, 18(1), 39-44.

Dos' Santos, T., Thomas, C., Comfort, P., McMahon, J. J., Jones, P. A., Oakley, N. P., & Young, A. L. (2018). Between-session reliability of isometric midthigh pull kinetics and maximal power clean performance in male youth soccer players. The Journal of Strength & Conditioning Research, 32(12), 3364-3372.

Estevan, I., Alvarez, O., Falco, C., Molina-García, J., & Castillo, I. (2011). Impact force and time analysis influenced by execution distance in a roundhouse kick to the head in taekwondo. The Journal of Strength & Conditioning Research, 25(10), 2851-2856.

Estevan, I., Jandacka, D., & Falco, C. (2013). Effect of stance position on kick performance in taekwondo. Journal of sports sciences, 31(16), 1815-1822.

Falco, C., Alvarez, O., Castillo, I., Estevan, I., Martos, J., Mugarra, F., & Iradi, A. (2009). Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. Journal of biomechanics, 42(3), 242-248.

Falco, C., Estevan, I., Álvarez, O., Morales-Sánchez, V., & Hernández-Mendo, A. (2014). Tactical analysis of the winners' and non-winners' performances in a Taekwondo University Championship. International Journal of Sports Science & Coaching, 9(6), 1407-1416.

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.

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. International journal of sports physiology and performance, 10(1), 84-92.

Gavagan, C. J., & Sayers, M. G. (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.

Gutiérrez-Santiago, A., Pereira-Rodríguez, R., & Prieto-Lage, I. (2020). Detection of the technical and tactical motion of the scorable movements in taekwondo. Physiology & behavior, 217, 112813.

Ha, C.-S., Choi, M.-H., & Kim, B.-G. (2009). The Kinematicall Anallysis of the Taekwondo Sparring Players' Bandal Chagi in Kinematics. International Journal of Applied Sports Sciences, 21(1), 115-131. doi:10.24985/KJSS.2008.19.3.22

Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. British journal of nutrition, 40(3), 497-504.

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.

Kavvoura, A., Zaras, N., Stasinaki, A.-N., Arnaoutis, G., Methenitis, S., & Terzis, G. (2018). The importance of lean body mass for the rate of force development in taekwondo athletes and track and field throwers. Journal of Functional Morphology and Kinesiology, 3(3), 43.

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.

Kim, Y. K., Kim, Y. H., & Im, S. J. (2011). Inter-joint coordination in producing kicking velocity of Taekwondo kicks. Journal of sports science & medicine, 10(1), 31.

Kwok, H. H. M. (2012). Discrepancies in fighting strategies between Taekwondo medalists and non-medalists. Journal of human Sport and Exercise, 7(4), 806-814.

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. European journal of applied physiology, 116, 1091-1116.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. The Journal of Strength & Conditioning Research, 18(3), 551-555.

Márquez, J. J., López-Gullón, J. M., Menescardi, C., & Falcó, C. (2022). Comparison between the KPNP and Daedo Protection Scoring Systems through a Technical-Tactical Analysis of Elite Taekwondo Athletes. Sustainability, 14(4), 2111.

McErlain-Naylor, S., King, M., & Pain, M. T. G. (2014). Determinants of countermovement jump performance: a kinetic and kinematic analysis. Journal of sports sciences,

32(19), 1805-1812.
McMahon, J. J., Lake, J. P., & Comfort, P. (2018). Reliability of and relationship between flight time to contraction time ratio and reactive strength index modified. Sports, 6(3), 81. doi:10.3390/sports6030081
Merriaux, P., Dupuis, Y., Boutteau, R., Vasseur, P., & Savatier, X. (2017). A study of vicon system positioning performance. Sensors, 17(7), 1591.
Moreira, P. V. S., Falco, C., Menegaldo, L. L., Goethel, M. F., De Paula, L. V., & Gonçalves, M. (2021). Are isokinetic leg torques and kick velocity reliable predictors of competitive level in taekwondo athletes? PloS one, 16(6), e0235582.
Moreira, P. V. S., Goethel, M. F., & Gonçalves, M. (2016). Neuromuscular performance of Bandal Chagui: Comparison of subelite and elite taekwondo athletes. Journal of Electromyography and Kinesiology, 30, 55-65.
Moreira, P. V. S., Paula, L., & Veloso, A. P. (2015). Segmental kick velocity is correlated with kick specific and nonspecific strength performance in a proximodistal sequence. Archives of Budo, 11, 271-276.
Norjali Wazir, M. R. W., Van Hiel, M., Mostaert, M., Deconinck, F. J., Pion, J., & Lenoir, M. (2019). Identification of elite performance characteristics in a small sample of taekwondo athletes. PloS one, 14(5), e0217358.
Ojeda-Aravena, A., Herrera-Valenzuela, T., Valdés-Badilla, P., Báez-San Martín, E., Thapa, R. K., & Ramirez-Campillo, R. (2023). A Systematic Review with Meta-Analysis on the Effects of Plyometric-Jump Training on the Physical Fitness of Combat Sport Athletes. Sports, 11(2), 33.
Ojeda-Aravena, A. P., Azócar-Gallardo, J., Hérnandez-Mosqueira, C., & Herrera-Valenzuela, T. (2020). Relación entre la prueba de agilidad específica en taekwondo (tsat), la fuerza explosiva y la velocidad líneal en 5-m atletas de taekwondo de ambos sexos (Relationship between the specific agility test in taekwondo (tsat), explosive strength and 5-m linea. Retos, 39, 84-89. doi:10.47197/retos.v0i39.78395
Papla, M., Ewertowska, P., & Krzysztofik, M. (2023). Acute Effects of Complex Conditioning Activities on Athletic Performance and Achilles Tendon Stiffness in Male Basketball Players. Journal of sports science & medicine, 22(2), 281.
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.
Slinde, F., Suber, C., Suber, L., Edwén, C. E., & Svantesson, U. (2008). Test-retest reliability of three different countermovement jumping tests. The Journal of Strength & Conditioning Research, 22(2), 640-644.
Sousa, J., Puerto, J. M. G., Beltrán, V. H., Louro, H., & Godoy, S. J. I. (2024). Effective techniques analysis in taekwondo: A systematic review. Retos: nuevas tendencias en educación física, deporte y recreación(53), 78-90. doi:10.47197/retos.v53.102399
Struzik, A., & Zawadzki, J. (2013). Leg stiffness during phases of countermovement and take-off in vertical jump. Acta of Bioengineering and Biomechanics, 15(2), 113--118.
Wąsik, J., Mosler, D., Ortenburger, D., Góra, T., & Cholewa, J. (2021). Kinematic Effects of the Target on the Velocity of Taekwon-Do Roundhouse Kicks. Journal of Human Kinetics, 80(1), 61-69.
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.

Datos de los/as autores/as:

Destter Álacks Antonietto	destter@gmail.com	Autor/a
Ignacio Roa Gamboa	ignacio.roa.27@gmail.com	Autor/a
Naiara Ribeiro	profa.naiara.ribeiro@gmail.com	Autor/a
Ciro José Brito	cirojbrito@gmail.com	Autor/a
Cinthya Luiza Rezende Oliveira	Cinthya.rezende@hotmail.com	Autor/a
Otávio de Toledo Nóbrega	otavionobrega@unb.br	Autor/a
Lucio Marques Vieira-Souza	profedf.luciomarkes@gmail.com	Autor/a
Bianca Miarka	miarkasport@hotmail.com	Autor/a
Esteban Aedo-Muñoz	esteban.aedo@usach.cl	Autor/a
Christopher James Quinn	quinneroma@hotmail.com	Traductor/a