Kinematic and anthropometric variables associated with temporal efficiency in elite judo techniques: a comparison of harai-goshi and uchi-mata

Variables cinemáticas y antropométricas asociadas a la eficiencia temporal en técnicas de judo de élite: una comparación entre harai-goshi y uchi-mata

Authors

Naiara Ribeiro Almeida [1]
Ignacio Roa Gamboa [1]
Lindsei Brabec Mota Barreto [2]
Felipe J. Aidar [3]
Otávio de Toledo Nóbrega [4]
Bianca Miarka [5]
Esteban Aedo Muñoz [6]
Ciro José Brito [7]

[1] Universidade Federal de Juiz de Fora (Brasil)
[2] Universidade Federal de Grande Dourados (Brasil)
[3] Universidade Federal de Sergipe (Brasil)
[4] Universidade de Brasilia (Brasil)
[5] Universidade Federal do Rio de Janeiro (Brasil)
[4] Universidad Metropolitana de Ciencias de la Educación (Chile)
[7] Universidade Federal de Viçosa (Brasil)

Corresponding author:
Ciro José Brito
ciro.jose@ufv.br

Received: 09-04-26
Accepted: 08-05-26

How to cite in APA

Ribeiro Almeida, N., Roa Gamboa, I., Mota Barreto, L. B., Aidar, F. J., Nóbrega, O. de T., Miarka, B., Aedo-Muñoz, E., & Brito, C. J. (2026). Kinematic and anthropometric variables associated with temporal efficiency in elite judo techniques: a comparison of harai-goshi and uchi-mata. *Retos, 82*, 787-799. https://doi.org/10.47197/retos.v82.119217

Abstract

Objective: To investigate the associations of anthropometric and kinematic variables with temporal efficiency in the *harai-goshi* and *uchi-mata* techniques in elite judokas, and to compare performance between sexes.
Methods: Forty elite judokas (12 women, 28 men) performed three maximal-speed repetitions of each technique in a motion capture. Kinematic variables (time, linear and angular velocities and accelerations of the foot, knee, and hip) were evaluated across the approach, turning, and throw phases. Anthropometric measures included body mass, height, body mass index (BMI), and lower-limb length. Two-way mixed ANOVA compared techniques and sexes, while Random Forest and multiple linear regression identified variables associated with total execution time.
Results: *Harai-goshi* was performed faster than *uchi-mata* in both men (0.9 ± 0.2 vs. 1.1 ± 0.2 s) and women (0.8 ± 0.2 vs. 1.2 ± 0.3 s; $p \leq 0.004$). Men showed higher foot velocities and accelerations in specific phases ($p \leq 0.04$), with no sex-by-technique interaction. Kinematic variables consistently showed stronger associations with execution time than anthropometric variables. For *uchi-mata*, hip angular velocity during the throw phase was the strongest predictor, whereas for *harai-goshi*, BMI, hip angular velocity during the turning phase, and foot linear velocity during the approach were most important.
Conclusions: Temporal efficiency in elite judo techniques was more strongly associated with kinematic than anthropometric variables. *Harai-goshi* was executed faster than *uchi-mata*, and the variables associated with execution time differed between techniques, highlighting the importance of optimizing movement velocity, coordination, and timing to improve technical performance.

Keywords

Judo, sport performance, elite athlete, task performance and analysis

Resumen

Objetivo: Investigar las asociaciones entre variables antropométricas y cinemáticas con la eficiencia temporal de las técnicas *harai-goshi* y *uchi-mata* en judocas de élite, y comparar el rendimiento entre sexos.
Métodos: Cuarenta judocas de élite (12 mujeres y 28 hombres) realizaron tres repeticiones de cada técnica a velocidad máxima mediante captura de movimiento. Se evaluaron variables cinemáticas (tiempo, velocidades y aceleraciones lineales y angulares del pie, la rodilla y la cadera) durante las fases de aproximación, giro y proyección. Las variables antropométricas incluyeron masa corporal, estatura, índice de masa corporal (IMC) y longitud de las extremidades inferiores. Un ANOVA mixto de dos vías comparó las técnicas y los sexos, mientras que los modelos de Random Forest y regresión lineal múltiple identificaron las variables asociadas con el tiempo total de ejecución.
Resultados: El *harai-goshi* fue más rápido que el uchi-mata en hombres (0.9 ± 0.2 vs. 1.1 ± 0.2 s) y mujeres (0.8 ± 0.2 vs. 1.2 ± 0.3 s; $p \leq 0.004$). Los hombres presentaron mayores velocidades y aceleraciones del pie en fases específicas ($p \leq 0.04$), sin interacción entre sexo y técnica. Las variables cinemáticas mostraron asociaciones más fuertes con el tiempo de ejecución que las antropométricas. En *uchi-mata*, la velocidad angular de la cadera durante la proyección fue el principal predictor; en *harai-goshi*, el IMC, la velocidad angular de la cadera durante el giro y la velocidad lineal del pie durante la aproximación fueron las variables más importantes.
Conclusiones: La eficiencia temporal de las técnicas de judo se asoció más con variables cinemáticas que antropométricas. El *harai-goshi* fue más rápido que *el uchi-mata*, y las variables asociadas con el tiempo de ejecución difirieron entre ambas técnicas, destacando la importancia de optimizar la velocidad, la coordinación y el tiempo del movimiento para mejorar el rendimiento técnico.

Palabras clave

Judo; rendimiento deportivo; atleta de elite, análisis y ejecución de tareas.

Introduction

The consistent demonstration of high strength and physical endurance in elite judokas is supported by studies showing superior upper body anaerobic power and grip strength compared to lower-level athletes (Branco et al., 2018; Torres-Luque, Hernández-García, Escobar-Molina, Garatachea, & Nikolaidis, 2016). While physical strength provides an advantage, small technical differences often determine match outcomes when physical attributes are similar, highlighting the importance of technical mastery and variability in techniques among elite judokas (Marcos, Rodríguez-Rodríguez, Alfaro-Saíz, Carballeira, & Marcos, 2021; Schoof, Sliedrecht, & Elferink-Gemser, 2024). Elite athletes exhibit greater technical proficiency and the ability to apply techniques in multiple directions, which distinguishes them from less skilled competitors (Hamaguchi, Liu, Shiokawa, & Deguchi, 2025; Ishii, Ae, Suzuki, & Kobayashi, 2018; Liu et al., 2021; Schoof et al., 2024). Specific performance traits such as distinct grip techniques in ground fighting and variations in attack frequency and technical variability have been observed across different nationalities. For example, Georgian judokas show greater technical variability, whereas Japanese judokas perform more frequent late-bout attacks (Engwerda, Lidor, & Elferink-Gemser, 2020). Neuromuscular performance assessments also reveal that top-elite judokas outperform elite peers in upper-body strength and explosive lower-limb actions, which are critical for success (Monteiro, Massuça, Ramos, & Garcia-Garcia, 2024). Overall, multidimensional analyses emphasize that both physiological capacities like grip strength and anaerobic power, alongside refined technical skills, are key factors differentiating elite judo performance levels (Schoof et al., 2024; Torres-Luque et al., 2016).

Biomechanical analysis is a key method for comparing judokas' performance, employing various tools such as force platforms, isokinetic dynamometers, and kinematic analysis (Brito et al., 2025; Soto, Aedo-Muñoz, Brito, & Miarka, 2020). Force platforms have been used to assess balance and ground reaction forces during judo movements (Soto et al., 2020), while isokinetic dynamometers help evaluate muscle strength and joint torque relevant to judo techniques (Detanico, Ghedini Gheller, Saldanha Da Silva Athayde, & Lima Kons, 2024; Marcondes et al., 2019). Kinematic analysis is widely applied in judo research to capture motion characteristics such as angular velocities and movement directions. These measurements have been used to differentiate skill levels, with elite judokas exhibiting greater peak angular velocities and more efficient body rotations than less skilled athletes (Hamaguchi et al., 2025; Ishii et al., 2018; Liu et al., 2021). Despite many studies describing biomechanical parameters such as peak force and angular velocity, fewer have directly linked these factors to performance level distinctions among athletes (Hamaguchi et al., 2025; Teixeira, Rosa, Mello, & Nadal, 2021). Some research has begun identifying biomechanical and anthropometric variables that effectively separate national- from regional-level judokas, highlighting the potential of combined biomechanical assessments for performance classification (Engwerda et al., 2020; Hamaguchi et al., 2025; Teixeira et al., 2021). Overall, biomechanical methods provide detailed insights into judo technique performances, but further work is needed to clarify how specific biomechanical factors predict competitive success (Hamaguchi et al., 2025; Ishii et al., 2018; Liu et al., 2021; Teixeira et al., 2021).

The uchi-mata and harai-goshi techniques are among the most frequently used and successful throws in elite competitive judo, often being decisive in matches at World Championships and the Olympic Games (Adam, Wolska, Klimowicz, & Smaruj, 2013; Brito et al., 2025; Hamaguchi et al., 2025; Kajmović, 2021). More broadly, elite judo scoring is concentrated in a limited number of throwing techniques, and standing attacks are most often direct, forward throws, which helps explain the competitive relevance of trunk-leg techniques such as uchi-mata and harai-goshi (Martins et al., 2019). Both techniques are suitable for varied tactical situations because they require a combination of timing, stability, balance, leverage, inertia, and acceleration. In addition, successful execution relies on explosive lower-limb actions and rapid decision-making (Belkadi, Cherara, Beboucha, & Messaoudi, 2026; Monteiro et al., 2024; Pucsok, Nelson, & Ng, 2001).

Biomechanical studies further indicate that both techniques require substantial intersegmental coordination and lower-limb involvement. In uchi-mata, highly skilled judokas show greater body-center-of-mass velocity, greater angular velocity of the hips, shoulders, and arms, and better displacement and velocity control than less skilled or non-specialist athletes (Brito et al., 2025; Hamaguchi et al., 2025). Similarly, effective harai-goshi execution has been associated with horizontal force application, sweep-leg velocity, shorter execution time, lowering of the center of gravity during the turning phase, and rapid extension of the knee and hip (K.-S. Kim, Park, Lee, Chung, & Kim, 2011; Pucsok et al., 2001). Notational analyses also indicate that leg techniques are prominent scoring actions in competition, with uchi-mata specifically reported among the prevailing leg throws in World Championship datasets and as the most efficient technique in British championship analysis (Gutiérrez-Santiago, Gentico-Merino, & Prieto-Lage, 2019; Miller, Collins, Stewart, & Challis, 2015; Ojeda-Aravena, Moronta, Calvo-Rico, Azócar-Gallardo, & García-García, 2025).

Despite this practical prominence, scientific literature still lacks robust biomechanical investigations that directly compare these two techniques from a detailed kinematic and kinetic perspective (R. Imamura, Iteya, Hreljac, & Escamilla, 2007; Pucsok et al., 2001). Most existing research focuses on isolated analyses or on populations with heterogeneous technical skill levels, leaving a gap in understanding how specific anthropometric variables and acceleration patterns influence the temporal efficiency of elite athletes (Brito, Aedo-Muñoz, & Miarka, 2020; Hamaguchi et al., 2025; E.-H. Kim, Cho, & Kwon, 2002; Pucsok et al., 2001). Therefore, a comparative biomechanical study may help address this gap by providing information on the anthropometric and kinematic characteristics associated with the temporal efficiency of these techniques. Such information may also assist coaches in individualizing technical instruction and training according to athletes' morphological and movement characteristics.

Although a previous study explored the mechanical efficiency of harai-goshi in judo athletes of different heights (Melo, Teixeira, Santos, & Piucco, 2010) and highlighted biomechanical differences in specialists in uchi-mata compared to other athletes (Brito et al., 2025), investigations with an integrated focus on these aspects remain scarce. Understanding the biomechanical determinants of performance in judo throwing techniques remains limited, especially regarding their practical application in training (Brito et al., 2020; Brito et al., 2025). Accordingly, this study aimed to provide additional evidence regarding the anthropometric and kinematic factors associated with the temporal efficiency of harai-goshi and uchi-mata in elite judokas. By examining these factors and potential sex differences, the findings may contribute to a better understanding of technical performance and inform evidence-based training strategies. Furthermore, our study proposes a comparative and multidimensional biomechanical analysis between the two techniques in elite athletes, quantifying the relative contribution of anthropometric and kinematic variables to temporal efficiency. Thus, the objective of this study is to investigate the relative contribution of biomechanical and anthropometric variables to temporal efficiency in these techniques, providing support for evidence-based preparation. We hypothesize that specific kinematic variables will be more strongly associated with the temporal efficiency of both techniques, and that differences will be observed between techniques and between male and female athletes.

Method

Experimental approach

This comparative, quasi-experimental study aimed to analyze and contrast the biomechanical performance of the harai-goshi and uchi-mata throwing techniques in a group of elite judo athletes. Although visually similar, the differences between these techniques mainly involve leg action, hip positioning, and the axis of rotation. In harai-goshi, the lower limb attacks with the hip positioned in front of the opponent, generating a more horizontal rotation (R. Imamura et al., 2007). In turn, the lower limb attacks internally with greater hip insertion in uchi-mata, resulting in a more vertical rotation and forward projection (Brito et al., 2025).

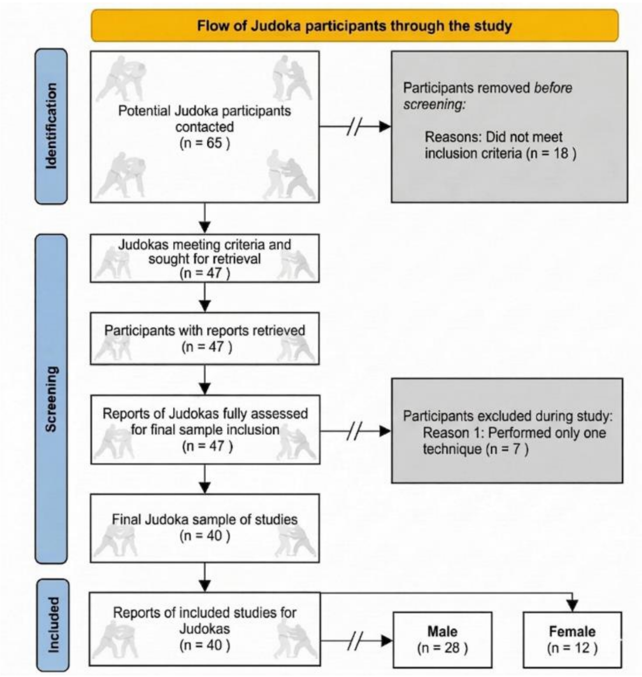
The investigation focused on a detailed analysis of the three phases of the movement (1. approach, 2. turning, and 3. attack) and their total sum, using videophotogrammetry to measure kinematic variables. The biomechanical variables analyzed included: time (s), hip angular velocity (°/s), knee angular velocity (°/s), foot linear velocity (m/s), hip angular acceleration (°/s^2), knee angular acceleration (°/s^2), and foot linear acceleration (m/s^2). Anthropometric variables such as height, body mass, body mass index (BMI), and leg length were additionally measured, considered potential determinants of technical performance.

The research process began with one of the researchers directly contacting national judo federations, presenting the objectives and relevance of the study. After obtaining institutional approval, the research team contacted coaches and athletes who met the stringent inclusion criteria for elite judo athletes. Participants who agreed to take part in the study signed an informed consent form, and the assessments were conducted in a specialized biomechanics laboratory. This study was approved by the research ethics committee of the university responsible for data analysis (protocol: 275/2024).

Participants

The participant selection process began by contacting 65 athletes after obtaining authorization from the national judo federation. The minimum sample size was calculated based on previous kinematic judo studies (Brito et al., 2025; R. Imamura et al., 2007; E.-H. Kim et al., 2002; Melo et al., 2010) using Granmo 8.0 software. An estimated minimum of 32 participants was required (α = 0.05, two-tailed, power = 0.8). The inclusion of additional participants aimed to minimize losses and increase statistical strength. The inclusion criteria were: (a) being an active member of a national team; (b) having participated in international competitions in the previous year; (c) being in competitive training; and (d) having no injuries that would prevent the performance of the techniques. Of the 65 athletes, 47 judokas (12 women, 35 men) met the criteria and agreed to participate. Exclusion criteria were: (a) failures in kinematic analysis; (b) voluntary withdrawal; or (c) failure to perform both techniques. Due to the last criterion, 7 participants (all men) were excluded, resulting in a final sample of 40 judokas (12 women, 28 men). Figure 1 presents the PRISMA flowchart of the study sample composition.

Figure 1. Flowchart of participants selection. Gris box represents excluded participants.

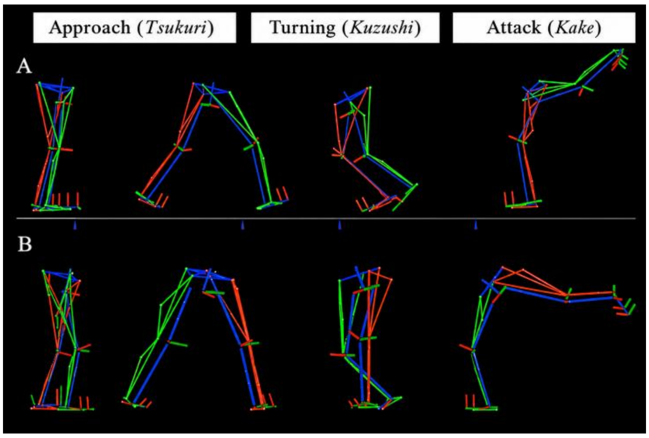


Procedures and kinematic analysis

All participants underwent an anamnesis before testing, during which they reported their preferred side for performing the techniques. Anthropometric measurements included body mass, measured using a Detecto® scale (339, Webb City, USA), and height, determined using a Welmy® stadiometer (W2000A, SP, Brazil). Lower limb length was measured using a non-elastic anthropometric tape (Sanny®, SP, Brazil). Kinematic analysis was obtained and analyzed using a three-dimensional system consisting of 10 cameras operating at an acquisition frequency of 200 Hz (Vicon® Motion Systems Ltd., Oxford, UK). The system was calibrated before each data collection session according to standards, with data residuals adjusted to a 2 mm threshold, following the recommendations of Merriaux, Dupuis, Boutteau, Vasseur, & Savatier (2017). Spherical reflective markers of 14 mm were positioned bilaterally on specific anatomical landmarks of the lower limbs, according to the manufacturer's guidelines (VICON, 2023): (a) anterior superior and posterior superior iliac spines; (b) lower and upper thirds of the lateral thigh surface; (c) lower and upper thirds of the left leg; (d) lateral femoral epicondyle; (e) lateral malleolus; (f) head of the second metatarsal; and (g) calcaneus.

For data collection, participants were paired based on body mass, allowing a maximum tolerance of 5% difference. During all trials, the uke cooperated with the execution of the techniques by maintaining a standardized posture and grip, without actively resisting or attempting to counter the throw. This procedure was adopted to ensure consistent testing conditions and to minimize variability unrelated to the tori's biomechanical performance. All judo athletes began the session with a standardized warm-up consisting of 5 minutes of stretching, 3 minutes of partial technique repetitions (uchi-komi – repetition training), and 2 minutes of ukemi (falling practice). Each tori (executant) performed three complete repetitions of each technique, with 1-minute intervals between attempts. The fastest valid trial of each technique was selected for all subsequent statistical analyses, as this approach best represented the athletes' maximal performance under the standardized testing conditions. All analyzed trials corresponded to successful throws. Because the participants were elite judokas, all techniques were successfully executed under the standardized testing conditions. For each technique, the fastest successful trial with complete kinematic data acquisition was selected for subsequent statistical analyses. Participants were instructed to perform the techniques at maximum speed, directing the throw toward their dominant side. For analysis purposes, the complete movement from the initial off-balancing to the throw completion was segmented into three distinct phases for both techniques: (a) Approach (Tsukuri): from the initial movement of the attacking leg to the beginning of the supporting leg rotation; (b) Turning (Kuzushi): from the beginning of the supporting leg rotation to the start of the attacking leg movement; and (c) Attack (Kake): from the beginning to the completion of the attacking leg movement. Figure 2 schematically illustrates these movement phases.

Figure 2. Sequency analysis of the uchi-mata (A) performed by a right-handed athlete; and the harai-goshi (B) performed by a left-handed participant, divided into the Approach, Turning, and Attack phases.



Next, the following kinematic variables were quantified for the comparative analysis of the harai-goshi and uchi-mata techniques in each of the three movement phases (approach, turning, and attack), as well as in their total sum: (a) Time (s); (b) Foot linear velocity (m/s) and foot linear acceleration (m/s^2); (c) Knee angular velocity (°/s) and knee angular acceleration (°/s^2); and (d) Hip angular velocity (°/s) and hip angular acceleration (°/s^2). Movement phase segmentation for uchi-mata was performed according to the recommendations of Windolf, Götzen, & Morlock (2008), while for harai-goshi we followed the previous analysis performed by R. Imamura et al. (2007). All measurements and calculations were performed in accordance with the manufacturer's guidelines (VICON, 2023) and processed using Nexus 1.8.5 software (Vicon® Motion Systems Ltd., Oxford, UK).

Data analysis

Descriptive statistics (mean ± standard deviation) were calculated for all anthropometric, demographic (age), training, and biomechanical variables. Data normality was assessed using the Shapiro–Wilk test

($p > 0.05$ for all dependent variables) and confirmed by visual inspection of Q–Q plots. Homogeneity of variances was verified using Levene's test ($p > 0.05$ for all comparisons). The assumption of sphericity was not applicable for the kinematic variables, as the within-subject factor (technique) included only two levels.

A two-way mixed-design ANOVA was performed to examine the effects of sex and technique on each kinematic variable (time, velocity, and acceleration), with sex as the between-subject factor and technique as the within-subject factor. When significant main effects or interactions were identified, post hoc analyses were conducted using paired-samples t-tests (to compare techniques within each sex) and independent-samples t-tests (to compare sexes within each technique). A Bonferroni correction was applied for post-hoc tests to control for multiple comparisons across the three movement phases and seven kinematic variables. Effect sizes for the ANOVA are reported as partial eta squared (ηp^2), interpreted as small (0.01), medium (0.06), and large (0.14). Cohen's d was calculated for pairwise comparisons using the pooled standard deviation and interpreted according to Fröhlich, Emrich, Pieter, & Stark (2009) for elite athletes: trivial (<0.25), small (0.25–0.50), moderate (0.50–1.0), and large (>1.0).

Pearson product–moment correlation coefficients were computed to investigate the relationships between anthropometric variables (body mass, height, BMI, and lower limb length) and total time for each technique. The relative importance of each anthropometric predictor was subsequently evaluated using a Random Forest regression model (500 trees), with mean decrease in impurity used as the importance metric. To ensure model robustness and assess predictive performance, a 5-fold cross-validation procedure was implemented, with Mean Absolute Error and R^2 reported as performance metrics. In addition, an R^2 decomposition approach using Relative Weight Analysis was applied to quantify the percentage contribution of each predictor to the total explained variance. RWA was specifically chosen for its ability to provide stable estimates of predictor importance in the presence of multicollinearity by transforming predictors into an orthogonal space before calculating their contribution to the model R^2.

Multiple linear regression analyses were performed to estimate the association between selected anthropometric and kinematic variables (i.e., approach-phase variables that showed significant correlations) on total time for each technique. Prior to these analyses, multicollinearity was assessed using the Variance Inflation Factor (VIF), with a threshold of <10 used to ensure the stability of the regression coefficients. The Enter method (standard entry) was selected for these analysis procedures to produce a more robust and theoretically grounded evaluation of the biomechanical system. This approach enables simultaneous assessment of all predictors, controlling for their mutual influence and avoiding the potential instability and sampling bias often associated with stepwise selection in smaller, elite-level samples. Standardized beta coefficients (β) are reported to facilitate comparison of predictor strength. All statistical analyses were conducted using Python (version 3.12) with the Pandas, NumPy, SciPy, Scikit-learn, and Statsmodels libraries. The significance level was set at $p \leq 0.05$.

Results

Anthropometric characteristics (height, body mass, BMI, and leg length), age, and weekly training hours were collected for all participants, as detailed in Table 1. Males had greater body mass, height, and lower limb length ($p \leq 0.005$).

Table 1. Age, training and anthropometric characteristics of participants.

Measures	Male (n=28)	Female (n=12)	P; effect size	95%CI for difference
Age (years)	22.6±3.6	25.5±6.2	p=0.072; d=0.64	-2.9 [-6.65; 0.87]
Body mass (kg)	71.1±9.4[a]	62.5±5.4	p=0.005; d=1.03	8.6 [4.04; 13.24]
Height (cm)	172.5±7.[a]	159.8±2.2	p≤0.001; d=2.10	12.8 [9.88; 15.69]
BMI (Kg/m^2)	23.9±3.2	24.5±1.8	p=0.592; d=0.19	-0.5 [-2.12; 1.04]
LL height (cm)	90.0±4.2[a]	83.6±1.0	p≤0.001; d=1.78	6.4 [4.77; 8.09]
Training (h/wk.)	18.1±2.5	18.5±2.2	p=0.6; d=0.1	-0.1 [-0.3; 0.05]

Note: BMI – Body mass index. LL – lower limbs. P – P calculated. CI – confidence interval. [a] p≤0.002 vs. female.

Table 2 presents the kinematic analysis of the techniques for the male and female athletes. There was a significant main effect of technique regarding time during approach ($F = 24.003$, $p \leq 0.001$, $\eta p^2 = 0.255$).

Male athletes perform harai-goshi faster ($p \leq 0.001$) than uchi-mata. Similar results were observed during attack ($F = 22.924$, $p \leq 0.001$, $\eta p^2 = 0.247$) and total time ($F = 34.971$, $p \leq 0.001$, $\eta p^2 = 0.333$). Males ($p \leq 0.002$) and females ($p \leq 0.004$) performed the harai-goshi faster than the uchi-mata.

There was a significant main effect of sex for foot velocity during turning ($F = 4.387$, $p = 0.04$, $\eta p^2 = 0.059$), with females demonstrating higher velocities than males (2.96 ± 1.14 m/s vs 2.51 ± 0.82 m/s). Significant main effects were found during attack for sex ($F = 4.397$, $p = 0.04$, $\eta p^2 = 0.059$) and technique ($F = 21.351$, $p \leq 0.001$, $\eta p^2 = 0.234$). Males showed higher velocity in the uchi-mata (2.36 ± 0.90 m/s) than females (1.85 ± 0.52 m/s, $p = 0.038$). The uchi-mata was faster than the harai-goshi in both sexes ($p = 0.01$).

Significant main effects were observed regarding foot linear acceleration during approach for sex ($F = 7.856$, $p = 0.007$, $\eta p^2 = 0.101$) and technique ($F = 4.377$, $p = 0.040$, $\eta p^2 = 0.059$). Males showed higher acceleration in the harai-goshi ($p = 0.012$) than females, and males showed higher acceleration in this technique than uchi-mata ($p = 0.032$). There was a significant main effect of technique during attack ($F = 10.727$, $p = 0.002$, $\eta p^2 = 0.133$). The harai-goshi presented significantly higher acceleration in males than the uchi-mata ($p = 0.005$). Moreover, significant main effects were found for knee angular acceleration during approach for sex ($F = 6.905$, $p = 0.011$, $\eta p^2 = 0.09$) and technique ($F = 7.110$, $p = 0.01$, $\eta p^2 = 0.092$). Males exhibited higher acceleration in the harai-goshi ($p = 0.009$) vs. female, and males showed higher acceleration in harai-goshi ($p = 0.003$) than uchi-mata.

Table 2. Kinematic analysis for uchi-mata and harai-goshi performed by the groups.

Technique	Phase	Male	Female	Difference [95%CI]
		Time (s)		
Uchi-mata	Approach	0.4±0.1[a]	0.4±0.2	0.1 (-0.2; 0.2)
	Turning	0.2±0.1	0.3±0.1	-0.1 (-0.1; 0.1)
	Attack	0.5±0.1[a]	0.5±0.1[a]	0.1 (-0.1; 0.1)
	Total	1.1±0.2[a]	1.2±0.3[a]	-0.1 (-0.3; 0.2)
Harai-goshi	Approach	0.3±0.1	0.3±0.2	-0.03 (-0.1; 0.1)
	Turning	0.2±0.1	0.2±0.1	-0.01 (-0.1; 0.03)
	Attack	0.4±0.1	0.3±0.1	0.1 (-0.0; 0.1)
	Total	0.9±0.2	0.8±0.2	0.1 (-0.1; 0.2)
		Foot linear velocity (m/s)		
Uchi-mata	Approach	1.5±0.8[b]	1.4±1.2	0.1 (-0.7; 1.0)
	Turning	3.0±1.1[b]	2.5±0.8	0.5 (-0.3; 1.2)
	Attack	2.4±0.9[a]	1.9±0.5	0.5 (0.0; 1.0)
Harai-goshi	Approach	1.2±0.7	1.8 ± 0.7	-0.6 [-1.1; -0.1]
	Turning	3.1±1.0[b]	2.5±0.7	0.6 (-0.1; 1.2)
	Attack	1.4±0.4	1.5±0.6	-0.1 (-0.5; 0.3)
		Foot linear acceleration (m/s²)		
Uchi-mata	Approach	21.3±12.5[a]	14.9±14.5	6.4 (-4.4; 17.1)
	Turning	27.6±10.0	22.4±5.6	5.2 (-0.5; 10.8)
	Attack	15.8±3.9[a]	17.6±6.0	-1.7 (-5.9; 2.5)
Harai-goshi	Approach	29.1±12.5[b]	17.8±11.7	11.3 (2.1; 20.6)
	Turning	30.5±9.0	26.6±11.8	3.9 (-4.6; 12.4)
	Attack	21.7±9.1	23.2±10.8	-1.6 (-9.5; 6.4)
		Knee angular velocity (°/s)		
Uchi-mata	Approach	218.5±77.7	196.3±102.1	22.2 (-51.1; 95.5)
	Turning	315.7±114.2	313.6±92.9	2.1 (-75.4; 79.6)
	Attack	177.3±123.4	152.4±79.4	24.8 (-49.3; 98.9)
Harai-goshi	Approach	248.9±93.5	209.9±107.6	39.0 (-40.8; 118.8)
	Turning	280.4±80.4	263.2±103.7	17.2 (-57.6; 92.0)
	Attack	185.5±55.2	183.8±55.2	1.7 (-41.0; 44.4)
		Knee angular acceleration (°/s²)		
Uchi-mata	Approach	4181.1±2038.3[a]	3644.4±2118.7	536.8 (-1081.0; 2154.5)
	Turning	5894.9±3534.0	5736.0±2639.3	158.9 (-2128.5; 2446.2)
	Attack	4699.0±4602.0	4142.1±3449.9	556.9 (-2427.8; 3541.6)
Harai-goshi	Approach	6240.2±2628.3[b]	3765.5±2293.4	2474.7 (614.1; 4335.3)
	Turning	5824.8±2297.2	5233.9±1796.3	590.9 (-934.0; 2115.8)
	Attack	4847.8±1607.5	4564.3±1674.8	283.5 (-994.4; 1561.5)
		Hip angular velocity (°/s)		
Uchi-mata	Approach	125.0±32.1	134.1±61.2	-9.2 (-50.6; 32.3)
	Turning	123.7±54.2	110.6±50.2	13.1 (-26.7; 53.0)
	Attack	156.0±57.2	177.1±71.0	-21.2 (-72.8; 30.5)
Harai-goshi	Approach	113.9±44.6	113.2±49.6	0.7 (-36.4; 37.8)
	Turning	141.7±73.5	122.4±48.5	19.3 (-25.4; 63.9)
	Attack	205.1±80.6	170.1±58.5	35.1 (-16.3; 86.4)
		Hip angular acceleration (°/s²)		

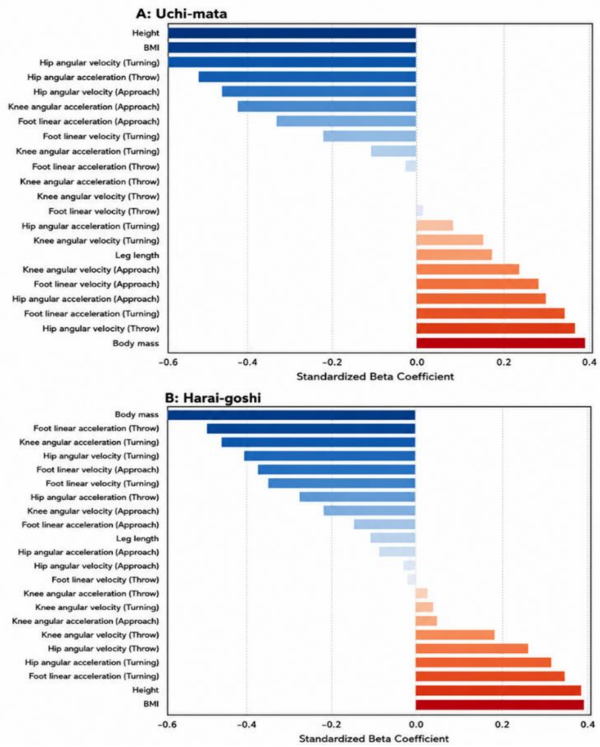
	Approach	2048.6±1864.3	2028.2±1037.1	20.4 (-1032.0; 1072.9)
Uchi-mata	Turning	2764.2±1453.0	2399.3±1037.5	365.0 (-553.5; 1283.5)
	Attack	2893.9±1528.7	3354.6±2800.2	-460.8 (-2363.0; 1441.4)
	Approach	2547.2±3660.4	1587.5±777.7	959.7 (-725.7; 2645.1)
Harai-goshi	Turning	3145.6±1447.7	2679.2±1060.1	466.4 (-460.8; 1393.7)
	Attack	3627.8±1735.8	2790.1±916.3	837.8 (-122.9; 1798.4)

Note: Data present by Mean ± Standard deviation and 95% Conffidence Interval. [a] p≤0.01 vs. harai-goshi. [b] p≤0.038 vs. female.

The relative importance of anthropometric and kinematic variables associated with total execution time differed between techniques. For uchi-mata, kinematic variables from the throw phase and anthropometric characteristics showed the greatest relative importance, with hip angular velocity during the throw phase accounting for 41.2% of the explained variance, followed by height (36.1%) and body mass (33.2%). For harai-goshi, BMI showed the highest relative importance (105.7%), followed by hip angular velocity during the turning phase (27.6%) and foot linear velocity during the approach phase (25.4%). The value exceeding 100% reflects the redistribution of shared variance among correlated predictors in the Relative Weight Analysis rather than an isolated contribution of BMI. Figure 4 presents the relative importance of the anthropometric and kinematic variables for each technique.

Multiple linear regression analyses identified different patterns of association between anthropometric and kinematic variables and total execution time for each technique. For uchi-mata, greater height ($\beta = -1.17$), higher BMI ($\beta = -1.03$), and greater hip angular velocity during the turning phase ($\beta = -0.74$) were associated with shorter execution time, whereas greater body mass ($\beta = 1.52$) and higher hip angular velocity during the throw phase ($\beta = 0.79$) were associated with longer execution time. For harai-goshi, greater body mass ($\beta = -3.19$), higher foot linear acceleration during the throw phase ($\beta = -0.48$), and higher knee angular acceleration during the turning phase ($\beta = -0.46$) were associated with shorter execution time. In contrast, higher BMI ($\beta = 2.59$) and greater height ($\beta = 2.30$) were associated with longer execution time. Figure 3 illustrates the standardized beta coefficients derived from the regression models for uchi-mata (A) and harai-goshi (B).

Figure 3. Standardized beta coefficients for the multiple linear regression models of total execution time in uchi-mata (A) and harai-goshi (B).



Discussion

The present study aimed to investigate the associations of anthropometric and kinematic variables with total execution time in the uchi-mata and harai-goshi techniques among elite judokas, as well as to compare performance between sexes and techniques. Our findings indicate that temporal efficiency was associated with distinct anthropometric and kinematic characteristics according to the technique performed. For uchi-mata, stature, BMI, and hip angular velocity during the throw phase showed the strongest associations with execution time. In contrast, for harai-goshi, body mass and hip angular velocity during the turning phase showed greater relative importance. These biomechanical differences between techniques, together with the varying contribution of anthropometric characteristics, suggest that technique-specific training approaches may be beneficial. Rather than adopting a universal strategy, coaches may consider emphasizing hip rotation and explosive movement according to the mechanical demands of each throwing technique (Brito et al., 2025; K.-S. Kim et al., 2011).

Although anthropometric characteristics may be associated with the selection and adaptation of techniques, the present findings suggest that their contribution is smaller when considered alongside kinematic variables. Unlike a previous study that primarily evaluated anthropometric characteristics in isolation (Melo et al., 2010), our integrated analysis suggests that temporal efficiency is more closely associated with the combined contribution of morphological characteristics and coordinated movement execution. Specifically, although stature and BMI showed relatively strong associations with execution time in the uchi-mata model, their relative importance was lower than that of key kinematic variables. These findings may help coaches identify movement characteristics associated with more efficient technique execution and support the development of training strategies tailored to the mechanical demands of these fundamental judo throwing techniques (Brito et al., 2020; Pucsok et al., 2001).

Our results suggest that the approach phase may play an important role in the temporal efficiency of both techniques, consistent with previous evidence indicating that movement preparation (approach and turning) is associated with successful attack execution. Three-dimensional biomechanical studies have shown that momentum and impulse generation occur predominantly during these early phases, emphasizing the importance of establishing favorable mechanical conditions before contact with the opponent (R. Imamura et al., 2007; R. T. Imamura, Hreljac, Escamilla, & Edwards, 2006). Likewise, studies on uchi-mata have reported that higher-level judokas exhibit greater center-of-mass velocities and higher segment angular velocities during the preparatory phase, characteristics that may facilitate energy transfer during the throwing movement (Brito et al., 2025; Hamaguchi et al., 2025).

For uchi-mata, hip angular velocity during the throw phase showed the greatest relative importance (41.2%), suggesting that faster trunk and hip rotation during the final execution phase is closely associated with shorter execution time (Lozado Campoverde, Bravo-Navarro, Aldas-Arcos, & Ávila-Mediavilla, 2024; Suarez, Davila, & Puche, 2002). Although approach-phase variables, such as knee angular velocity and foot linear acceleration, also showed meaningful associations with execution time, hip angular velocity during the throw phase exhibited the highest relative importance in the integrated model. These findings are consistent with previous studies reporting greater velocities and displacements of distal segments in expert athletes, particularly during the preparatory and final phases of the technique (Brito et al., 2025; Dimitrova, 2017). In addition, greater lower-limb angular velocity has been associated with increased angular momentum transferred to the uke (person being thrown) during the throwing movement (E.-h. Kim, Kim, & Chung, 2005), reflecting the coordinated kinetic chain typically observed in highly skilled athletes (Hamaguchi et al., 2025). Rather than establishing a causal relationship, the present findings extend previous evidence by identifying the kinematic variables most strongly associated with temporal efficiency in elite judokas.

The high relative importance of hip angular velocity during the turning phase of harai-goshi suggests that trunk rotation and hip motion are closely associated with temporal efficiency in this technique. In the present study, hip angular velocity during the turning phase and foot linear acceleration during the throw showed strong associations with execution time. Previous kinetic and kinematic investigations have reported that greater sweeping-leg velocity is associated with higher ground reaction forces, while advanced judokas typically exhibit greater horizontal force production and higher leg sweep velocities than less experienced athletes (Pucsok et al., 2001). Likewise, rapid trunk rotation, particularly forward rotation initiated by the head, has been associated with greater sweeping-leg velocity through improved whole-body coordination (R. Imamura et al., 2007; Liu et al., 2021). High-level judokas have also been reported to demonstrate better temporal synchronization and intersegmental coordination by producing greater forces earlier in the movement (Hamaguchi et al., 2025). Together, these findings are consistent with the present results, suggesting that coordinated trunk rotation and lower-limb acceleration are important biomechanical characteristics associated with the temporal efficiency of harai-goshi (R. Imamura et al., 2007; K.-S. Kim et al., 2011).

Taken together, our biomechanical analyses are consistent with the classic judo principle of maximum efficiency with minimum effort, as temporal efficiency was more strongly associated with movement timing and segmental velocity than with anthropometric characteristics (R. Imamura et al., 2007; R. T. Imamura et al., 2006). Previous studies have suggested that effective force application depends on the timing and direction of force production (Zaggelidis & Lazaridis, 2012), while analyses of the center of mass indicate that efficient manipulation of the uke's movement begins before the attack phase (R. T. Imamura et al., 2006). In agreement with these findings, the present results suggest that generating high velocities and accelerations at specific phases of the movement is closely associated with shorter execution time (Ishii et al., 2018). Likewise, the lower relative importance of anthropometric variables observed in this study agrees with previous research indicating that, although morphological characteristics may be associated with technique selection, temporal efficiency is more closely related to coordination, timing, and movement execution (Brito et al., 2020; Marcos et al., 2021; Melo et al., 2010). These findings suggest that athletes with different anthropometric profiles may achieve similar levels of technical performance through efficient movement coordination and technique-specific execution.

Regarding sex-related differences, although total execution time did not differ significantly between elite male and female judokas, differences were observed in specific kinematic variables (K. Sterkowicz-Przybycień, Miarka, & Fukuda, 2017). Men exhibited greater foot linear acceleration and knee angular acceleration during the approach phase of harai-goshi, whereas women demonstrated higher foot linear velocity during the turning phase. In contrast, men achieved higher foot linear velocity during the throw phase of uchi-mata (Šimenko & Pori, 2026; Katarzyna Sterkowicz-Przybycień & Fukuda, 2016). However, the absence of a significant sex-by-technique interaction suggests that the overall biomechanical patterns of these techniques were similar between sexes, despite differences in specific kinematic variables. These findings indicate that the movement characteristics associated with temporal efficiency may be largely shared by elite male and female judokas, although sex-specific differences in movement execution should also be considered (Katarzyna Sterkowicz-Przybycień & Fukuda, 2016; K. Sterkowicz-Przybycień et al., 2017). Likewise, the lower relative importance of anthropometric variables observed when analyzed together with kinematic variables suggests that movement coordination and execution may be more closely associated with temporal efficiency than morphological characteristics alone (Brito et al., 2020).

The practical implications of this study should be interpreted within the context of its observational design. The findings suggest that coaches may consider emphasizing different movement characteristics according to the technique performed. For uchi-mata, greater attention may be given to hip rotation during the throw phase and explosive knee and foot actions during the approach, whereas for harai-goshi, training may emphasize hip rotation during the turning phase and foot acceleration during the throw. In addition, the greater relative importance of specific kinematic variables compared with anthropometric characteristics in the integrated models (e.g., BMI accounting for only 1.3% of the relative importance in the uchi-mata model) suggests that movement coordination, velocity, and timing may be more closely associated with temporal efficiency than anthropometric characteristics alone.

Despite these contributions, this study has several limitations. First, the analysis was restricted to two throwing techniques, which may limit the generalizability of the findings to other techniques. Second, muscle strength was not directly assessed, precluding examination of its association with the observed kinematic variables. Third, the biomechanical analysis focused primarily on lower-limb movements and did not include the contribution of the upper limbs and trunk, which also play important roles in throwing performance. Future research could investigate a broader range of throwing techniques and weight categories, incorporate electromyographic assessments to examine muscle activation patterns, include direct measures of muscle strength (e.g., isokinetic or maximal dynamic testing), and evaluate upper-limb and trunk biomechanics. In addition, machine learning approaches and longitudinal studies may further improve the understanding of the biomechanical factors associated with technical development and temporal efficiency in judokas.

Conclusions

Based on the aims, methods, and findings of this study, temporal efficiency in the uchi-mata and harai-goshi techniques was more strongly associated with kinematic than anthropometric variables in elite judokas. Harai-goshi was executed faster than uchi-mata in both sexes. Although male athletes exhibited greater foot linear acceleration and knee angular acceleration during the approach phase of harai-goshi, the absence of a significant sex-by-technique interaction suggests that the overall biomechanical patterns of these techniques were similar between sexes. Hip angular velocity during the throw phase showed the greatest relative importance for uchi-mata, whereas hip angular velocity during the turning phase and foot acceleration during the throw were the variables most strongly associated with temporal efficiency in harai-goshi. Overall, these findings are consistent with the principle of maximum efficiency with minimum effort, suggesting that movement timing and segmental velocity may be more closely associated with temporal efficiency than anthropometric characteristics alone.

Acknowledgements

Naiara Ribeiro Almeida received a "*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*" Sandwich Scholarship (#88881.218726/2025-01). Ignacio Roa-Gamboa received post-graduate Scholarship from Federal University of Juiz de Fora (#705).

Financing

The authors acknowledge the financial support provided by the Fundação de Apoio à Pesquisa do Distrito Federal (FAPDF), process no. 00193-00001790/2023-99, TOA 274/2023, associated with Otávio de Toledo Nóbrega (CPF: 645.971.481-91).

References

Adam, M., Wolska, B., Klimowicz, P., & Smaruj, M. (2013). Characteristics of technical-tactical preparation of Russian men's judo representation during the Olympic Games in London in 2012. *Baltic Journal of Health and Physical Activity, 5*(4), 3.

Belkadi, A., Cherara, L., Beboucha, W., & Messaoudi, K. (2026). Establishing Model Characteristics for Optimising Special Physical and Technical-Tactical Preparation in Elite Judo Athletes. *Studia sportiva*. doi:10.5817/sts2026-1-10

Branco, B. H. M., Andreato, L. V., Ribeiro, E. D., de Oliveira, H. G., Almeida, F. N., & Junior, N. N. (2018). Development of tables for classifying judo athletes according to maximal isometric strength and muscular power, and comparisons between athletes at different competitive levels. *Sport Sci Health, 14*(3), 607-614. doi:10.1007/s11332-018-0469-7

Brito, C. J., Aedo-Muñoz, E., & Miarka, B. (2020). Judo performance: kinanthropometric importance for technical tactical and biomechanics. *Braz J kinanthrop Hum Perform, 22*, e76584. doi:10.1590/1980-0037.2020v22e76584

Brito, C. J., Almeida, N. R., Roa-Gamboa, I., Barreto, L. B. M., Fernandes, J., Vieira-Souza, L. M., . . . Aedo-Muñoz, E. (2025). Kinematic Analysis of the Lower Limb in Uchi-Mata: Comparison Between Elite Athletes Specializing and Non-Specializing. *Journal of Functional Morphology and Kinesiology, 10*. doi:10.3390/jfmk10040378

Detanico, D., Ghedini Gheller, R., Saldanha Da Silva Athayde, M., & Lima Kons, R. (2024). Shoulder rotator strength in judo athletes: A cross-sectional study with different experience levels. *Isokinetics and Exercise Science, 32*(1), 21-27.

Dimitrova, N. (2017). Biomechanical assessment of the physical activities of the technique Uchi-mata in judo sport. *Act Phys Educ Sport, 7*, 180-181.

Engwerda, I., Lidor, R., & Elferink-Gemser, M. (2020). Performance characteristics of top-level youth judokas in light- and heavy-weight categories. *International Journal of Sports Science & Coaching, 15*, 783-792. doi:10.1177/1747954120945160

Fröhlich, M., Emrich, E., Pieter, A., & Stark, R. (2009). Outcome effects and effects sizes in sport sciences. *Int J Sports Sci Eng, 3*(3), 175-179.

Gutiérrez-Santiago, A., Gentico-Merino, L., & Prieto-Lage, I. (2019). Detection of the technical-tactical pattern of the scoring actions in judo in the men's category of –73 kg. *International Journal of Performance Analysis in Sport, 19*, 778-793. doi:10.1080/24748668.2019.1655934

Hamaguchi, K., Liu, L., Shiokawa, M., & Deguchi, T. (2025). A biomechanical study of judo uchimata: a comparison of judokas with different skill levels. *Sports Biomech*, 1-16. doi:10.1080/14763141.2025.2474515

Imamura, R., Iteya, M., Hreljac, A., & Escamilla, R. (2007). A Kinematic Comparison of the Judo Throw Harai-Goshi during Competitive and Non-Competitive Conditions. *J Sports Sci Med, 6*(Cssi-2), 15-22.

Imamura, R. T., Hreljac, A., Escamilla, R. F., & Edwards, W. B. (2006). A three-dimensional analysis of the center of mass for three different judo throwing techniques. *J Sports Sci Med, 5*(CSSI), 122.

Ishii, T., Ae, M., Suzuki, Y., & Kobayashi, Y. (2018). Kinematic comparison of the seoi-nage judo technique between elite and college athletes. *Sports Biomech, 17*(2), 238-250. doi:10.1080/14763141.2017.1284256

Kajmović, H. (2021). Comparison of Unsuccessfully Performed Throwing Techniques Between Male and Female Judo Competitors. *The Arts and Sciences of Judo, 1*(1), 51-59.

Kim, E.-H., Cho, D.-H., & Kwon, M.-S. (2002). A kinematic analysis of uchi-mata (inner thigh reaping throw) by kumi-kata types in judo. *Korean J Sport Biomech, 12*(1), 63-87. doi:10.5103/KJSB.2002.12.1.063

Kim, E.-h., Kim, S.-s., & Chung, C.-W. (2005). A case study of angular momentum of trunk and lower extremity when performing uchimata by posture and voluntary resistance levels of Uke in Korean Judo Olympian. *Korean J Sport Biomech, 15*(4), 191-203. doi:10.5103/KJSB.2005.15.4.191

Kim, K.-S., Park, C., Lee, E.-K., Chung, N.-J., & Kim, D.-H. (2011). A Kinematic Analysis of Harai-Goshi(Hip Throw) in Judo. *Korean Journal of Sport Biomechanics, 21*, 47-55. doi:10.5103/kjsb.2011.21.1.047

Liu, L., Deguchi, T., Shiokawa, M., Ishii, T., Oda, Y., & Shinya, M. (2021). A biomechanics analysis of the judo osoto-gari technique: comparison of black belt and white belt judokas. *Sports Biomechanics, 23*, 2021-2033. doi:10.1080/14763141.2021.1990993

Lozado Campoverde, N. C., Bravo-Navarro, W. H., Aldas-Arcos, H., & Ávila-Mediavilla, C. M. (2024). Análisis de la aceleración, fuerza y velocidad de la técnica Uchi Mata mediante sensores inalámbricos. In J. Erazo-Álvarez & C. Narváez-Zurita (Eds.), *Transitar desde los estudios de posgrado en la investigación multidisciplinar científica* (Vol. 1, pp. 87-111). Azuay: Perspectivas Globales.

Marcondes, F. B., Castropil, W., Schor, B., Miana, A., Vasconcelos, R., & Etchebehere, M. (2019). Shoulder isokinetic performance in healthy professional judo athletes: normative data. *Acta Ortop Bras, 27*, 308-312. doi:10.1590/1413-785220192706223708.

Marcos, S. U., Rodríguez-Rodríguez, R., Alfaro-Saíz, J., Carballeira, E., & Marcos, M. U. (2021). Improving on Half-Lightweight Male Judokas' High Performance by the Application of the Analytic Network Process. *Frontiers in Psychology, 12*. doi:10.3389/fpsyg.2021.621454

Martins, F. P., De Souza, L. S. D. P., De Campos, R. P., Bromley, S., Takito, M., & Franchini, E. (2019). Techniques utilised at 2017 Judo World Championship and their classification: comparisons between sexes, weight categories, winners and non-winners. *Ido Movement for Culture. Journal of Martial Arts Anthropology, 19*, 58-65. doi:10.14589/ido.19.1.6

Melo, S. I. L., Teixeira, J. S., Santos, S. G., & Piucco, T. (2010). Eficiência mecânica do harai goshi em judocas com diferentes estaturas. *Motriz Revista de Educação Física*, 50-58.

Merriaux, P., Dupuis, Y., Boutteau, R., Vasseur, P., & Savatier, X. (2017). A study of vicon system positioning performance. *Sensors, 17*(7), 1591.

Miller, G. A., Collins, N. A., Stewart, M. J., & Challis, D. G. (2015). Throwing Technique and Efficiency in the 2013 British Judo Championships. *Int J Perform Anal Sport, 15*(1), 53-68. doi:10.1080/24748668.2015.11868776

Monteiro, L., Massuça, L. M., Ramos, S., & Garcia-Garcia, J. (2024). Neuromuscular Performance of World-Class Judo Athletes on Bench Press, Prone Row and Repeated Jump Tests. *Appl Sci, 14*(7). doi:10.3390/app14072904

Ojeda-Aravena, A., Moronta, D., Calvo-Rico, B., Azócar-Gallardo, J., & García-García, J. (2025). Decisive Techniques for Ippon in Elite Women's Judo: A Tactical Analysis from the Rio 2016 and Tokyo 2020 Olympic Games. *Applied Sciences*. doi:10.3390/app15137455

Pucsok, J. M., Nelson, K., & Ng, E. (2001). A kinetic and kinematic analysis of the harai-goshi judo technique. *Acta Physiol Hung, 88*(3-4), 271-280. doi:10.1556/APhysiol.88.2001.3-4.9.

Schoof, S., Sliedrecht, F., & Elferink-Gemser, M. T. (2024). Throwing it out there: Grip on multidimensional performance characteristics of judoka – a systematic review. *Int J Sports Sci Coach, 19*(2), 908-928. doi:10.1177/17479541231223160

Šimenko, J., & Pori, P. (2026). Morphological Asymmetries and Their Relationship to Judo-Specific Performance in Youth Judokas. *Applied Sciences, 16*(2), 894.

Soto, D. A. S., Aedo-Muñoz, E., Brito, C. J., & Miarka, B. (2020). Comparisons of Motor Actions and Biomechanical Assessments of Judo Techniques Between Female Weight Categories. *Journal of Human Kinetics, 75*, 247-255. doi:10.2478/hukin-2020-0053

Sterkowicz-Przybycień, K., & Fukuda, D. H. (2016). Sex differences and the effects of modified combat regulations on endurance capacity in judo athletes: A meta-analytic approach. *Journal of Human Kinetics, 51*, 113-120. doi:10.1515/hukin-2015-0175

Sterkowicz-Przybycień, K., Miarka, B., & Fukuda, D. (2017). Sex and Weight Category Differences in Time-Motion Analysis of Elite Judo Athletes: Implications for Assessment and Training. *Journal of Strength and Conditioning Research, 31*, 817. doi:10.1519/jsc.0000000000001597

Suarez, G. R., Davila, M. G., & Puche, P. P. (2002). *Análisis de factores biomecánicos y comportamentales relacionados con la efectividad del uchi mata, ejecutado por judokas de alto rendimiento.* (Doctorate). Universidad de Granada, Granada. (87601)

Teixeira, F., Rosa, P., Mello, R., & Nadal, J. (2021). Biomechanical and Anthropometric Factors That Differentiate National- and Regional-Level Judo Players. *International journal of sports physiology and performance*, 1-7. doi:10.1123/ijspp.2020-0756

Torres-Luque, G., Hernández-García, R., Escobar-Molina, R., Garatachea, N., & Nikolaidis, P. T. (2016). Physical and physiological characteristics of judo athletes: An update. *Sports, 4*(1), 20. doi:10.3390/sports4010020

VICON. (2023). *VICON: Plug-in Gait kinematic and kinetic calculation* (Vol. 1): Nexus.

Windolf, M., Götzen, N., & Morlock, M. (2008). Systematic accuracy and precision analysis of video motion capturing systems—exemplified on the Vicon-460 system. *J Biomech, 41*(12), 2776-2780. doi:10.1016/j.jbiomech.2008.06.024

Zaggelidis, G., & Lazaridis, S. (2012). Evaluation of vertical ground reaction forces in three different judo hip throwing techniques in novice and advanced Greek athletes. *Med Dello Sport, 65*(1), 29-36.

Authors' and translators' details:

Naiara Ribeiro Almeida	naiara.ribeiro@ufjf.br	Author
Ignacio Roa Gamboa	ignacio.roa@estudante.ufjf.br	Author
Lindsei Brabec Mota Barreto	lindseibarreto@ufgd.edu.br	Author
Felipe J. Aidar	fjaidar@gmail.com	Author
Otávio de Toledo Nóbrega	otavionobrega@unb.br	Author
Bianca Miarka	biancamiarka@eefd.ufrj.br	Author
Esteban Aedo Muñoz	esteban.aedo@umce.cl	Author
Ciro José Brito	ciro.brito@ufjf.br	Author
Christopher J. Quinn	englishconsultingbrazil@gmail.com	Translator