The mechanical efficiency of the *o soto gari* technique when applied to judokas of different heights

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Abstract

Background and Study Aim: The biomechanical efficiency of judo throw techniques depends on the anthropometric characteristics of the opponent. This study aimed to evaluate the mechanical efficiency of the *o soto gari* technique when applied to judoists of different heights in relation to the thrower.

Material/Methods: The following factors were compared: the *tori* angular variation of knee, hip and trunk; the total and partial performance time and the displacement of the vertical trajectory of the *tori* center of mass (ΔCM). Three *uke* of shorter, similar and taller stature than the *tori* were kinematically analyzed performing ten *o soto gari* throws. The images were recorded at 180 Hz using the Peak Motus System 3D. The data were analyzed by descriptive statistics, ANOVA and *post-hoc Tukey* ($p \leq 0.05$).

Results: The mechanical efficiency of angular displacement was greater when the *tori* was throwing shorter *uke*; the throwing time was shorter against shorter *uke*; the *tori* ΔCM was greater when throwing shorter *uke*.

Conclusions: We conclude that the *o soto gari* technique is more efficient when applied to shorter opponents.

Key words: Judo • biomechanical efficiency • kinematic • body height

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Background

Judo – Japanese meaning "gentle way", is a modern martial art and combat sport created in Japan in 1882 by Kano Jigoro.

Biomechanical efficiency – better efficiency with less energy consumption.

Judo is a complex and physically demanding sport that includes many techniques and tactics for either throwing or immobilizing an opponent and simultaneously involves both cognitive and motor skills [1].

There have been few investigations about the **biomechanical efficiency** of judo throw techniques in the literature. For each throw technique (hand or arm, leg or foot, hip or sacrifice) different skills are required [2]. In theory, they were intended to be applied using *seiryoku zenyo*, which means better efficiency with less energy consumption.

However, the correct use of *seiryoku zenyo* depends on knowing what technique to apply at the right moment, adapting the movement to the anthropometric characteristics of the opponent. Otherwise, the maneuver would be successfully applied only if excessive force were used.

The efficiency of a technique, with regards to biomechanical aspects, is directly related to the biotype of the judoka and the use of leverage, timing and torque [3]. Thus, for techniques those use the hip as a support, a judoka (*tori*) with a trunk proportionally larger than his lower limbs would be able to produce higher torque, resulting in a greater velocity while spinning the opponent (*uke*), and thus, greater economy of effort.

According to Imamura, Hreljac, Escamilla and Edwards [4], unlike some hips and hand throws that incorporating an instantaneous "snap pull" with the pulling hand during *kuzushi* to create an opposite movement from *uke*, the *o soto gari* tosses the *uke* backwards.

In the *o soto gari* technique, the first phase (*kuzushi*), defined as breaking an opponent's balance, begins with the onset of *tori*'s leg drive from the sweeping (right) leg, which allows the supporting (left) leg to move towards *uke*, and ends with tori's sweeping leg approaching the *uke*'s body. The *tsukuri* phase (the process of fitting into the throw) immediately follows *kuzushi* and begins with *tori*'s sweeping leg passing toward *uke*'s body and ends when the *tori*'s sweeping leg makes contact. The falling phase (*kake*) begins when the tori's leg touch the *uke*'s body, sweeping the back of the thigh of the load-bearing member while creating a lever action with the hip as a fulcrum, and ends when any part of both legs strikes the ground [4].

Melo, Santos, Teixeira and Piucco [5] investigated the *harai goshi* throw technique and found higher mechanical efficiency in angular displacement and a shorter throw time when the *tori* threw *uke* taller than himself. Due to the great thrust required during the collision between *tori* and *uke*, the *harai goshi* and *o soto gari* are considered power throws, and well-suited for large and powerful individuals [4].

Due to the scarcity of research investigating judo throw techniques and mechanical efficiency, and assuming that the efficiency of a technique is dependent on the biotype of both the *uke* and *tori*, this study, whose general objective was to evaluate the mechanical efficiency of the *o soto gari* technique when applied to opponents of different heights, is justified. More specifically, this study's aim was to characterize and compare the angular variation (Δθ) of the *tori*'s knee and trunk, identify and compare the time necessary for each of the different phases of the technique (imbalance, fitting and fall) and to identify and compare the vertical displacement of center of mass trajectory (ΔCM) of the *tori* when throwing *uke* of different heights.

Material and Methods

Four male judo athletes (one *tori* and three *uke*), all black belts and with a minimum of 10 years of training, participated in this study: one *tori* (height 1.71m, weight 78 kg, age 25, years of training 14) and three *uke*; one shorter than the *tori* (height 1.66 m, weight 62 kg, age 30 years, years of training 16), one of similar height (height 1.74 m, weight 78.6 kg, age 22 years, years of training 12), and one taller (height 1.84 m, weight 81.7 kg, age 23 years, years of training 13). All judokas reported no injuries in the six months prior to data collection.

This work was approved by Research Ethics Committee of Universidade do Estado de Santa Catarina (process number 021/06) and written informed consent was granted by all subjects. Data was collected via the following procedures: a) *Peak Motus* 3D (four cameras corresponding to 180 Hz) system calibration; b) placing reflective markers on joint axes, according to Kalfhues & Groh apud Riehle [6]; c) previous warm-up by the athletes; d) image acquisition of 10 *o soto gari* throws technique performances for each *uke* subject, at 180 Hz and data processing; e) image digitalization and data filtering using a third-order Butterworth filter; f) data calculation and value exportation to a database spreadsheet for further analysis; g) data normalization according to time values, considering that the repetitions were not of equal time or number of frames; h) selection of the angular variables for study, according to figure 1, including the maximum flexion angle of the attacking hip (right) (MFArH) during *tsukuri*, the maximum extension angle of the attacking knee (right) (MEArK) during *tsukuri*, maximum extension angle of the attacking hip (MEArH) during *kake*, maximum extension angle of the supporting knee (left) (MEAlK) during *kake*, maximum trunk flexion angle (MFAT) during *kake;* i) selection of temporal variables, including the execution of the *kuzushi*, *tsukuri* and *kake* phases and the total throw time; f) variation of the *tori*'s ΔCM while throwing *uke* of three different heights, based on 3D model.

Descriptive statistics were used to analyze the data and to compare the Δθ, the time spent performing each phase of the technique, the total performance time, and the ΔCM; one-way ANOVA was applied, followed by Tukey's post hoc test ($p \leq 0.05$).

Results

Initially, the *tori* knee, hip and trunk Δθ when throwing *uke* of different heights were compared. The value comparisons were made at specific stages of the technique, associating the statistical results with the graphic analysis. The results of these comparisons are shown in Table 1 and illustrated in Figures 1–4.

Figures 1–4 illustrate the Δθ of the variables analyzed and the results of the comparisons after application of the Tukey test.

It was observed (Table 1) that during each phase of the technique, in at least one of the different *uke* heights, the angular values of the *tori* body segments differed.

Table 1. Comparison of inter segmental maximum angle values of the *tori* throwing *uke* of different heights during the *tsukuri* and *kake* phases of the *o soto gari* technique.

Variable	Phase	Height	$\bar{X} \pm s$ (°)	F	p
MFArH	tsukuri	Taller Similar Shorter	88.51±1.20 101.51±1.76 110.34±106	639.822	0.000
MEArK	tsukuri	Taller Similar Shorter	135.31±1.23 141.38±1.58 160.55±1.08	1005.516	0.000
MEArH	kake	Taller Similar Shorter	133.85±1.31 130.91±1.22 148.19±1.28	531.458	0.000
MEAlK	kake	Taller Similar Shorter	153.44±1.51 155.77±1.23 147.16±0.99	124.683	0.000
MFAT	kake	Taller Similar Shorter	46.31±1.20 46.46±1.13 52.46±1.56	71.692	0.000

* Maximum flexion angle of the attacking hip (right) (MFArH); maximum extension angle of the attacking knee (right) (MEArK); maximum extension angle of the attacking hip (MEArH); maximum extension angle of the supporting knee (left) (MEAlK); maximum trunk flexion angle (MFAT).

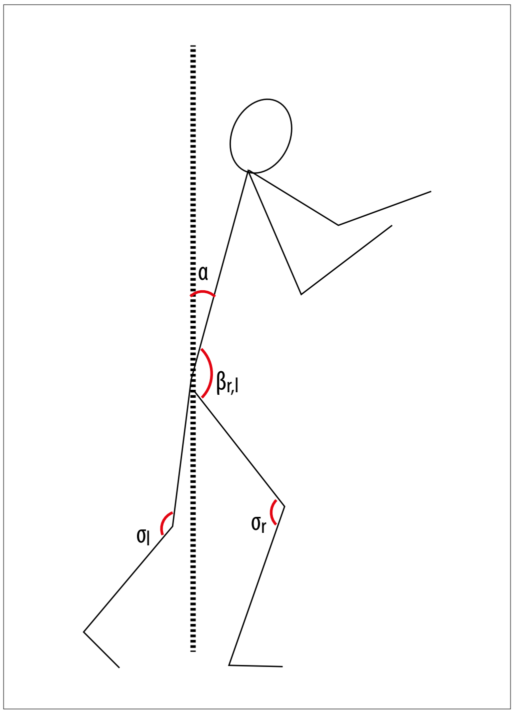

Figure 1. Angular variables: α) trunk flexion; β_r) right hip angle; β_l) left hip angle; σ_r) right knee angle; σ_l) left knee angle.

Figures 2–5 illustrate the *tori* Δθ for the analyzed variables during the *o soto gari* test throws and the results after the application of the Tukey test.

As demonstrated in Figure 2, it was found that both the *tori* MFArH (highlighted in circle) and the MEArH (highlighted in the square) in the *tsukuri* phase were different while throwing *uke* of different heights. The MFArH was greater (88.51°) while throwing the taller *uke* and smaller (110.34°) while throwing the shorter *uke*. The MEArH was greater (148.20°) while throwing the shorter *uke* and smaller (130.91°) while throwing the *uke* of similar height to the *tori*.

Figure 3, highlighted in the circle, shows that the variable MEArK of *tori* in the *tsukuri* phase was different when throwing *uke* of different heights. The value was smaller (135.31°) while throwing the taller *uke* and greater (160.55°) while throwing the *uke* of similar height to the *tori*.

Figure 4 shows that the variable MEAlK of *tori* in the *kake* phase was different when throwing *uke* of different statures. The value was greater (155.77°) while throwing the *uke* of similar height and smaller (147.16°) while throwing the shorter *uke*.

Figure 5 indicates that there were no differences in the *tori* MFAT in the *kake* phase while throwing taller *uke* (46.32°) and *uke* of similar height (46.46°). This angle was greater while throwing the shorter *uke* (52.46°) than the taller one (46.32°) and the *uke* of similar height (46.46°), respectively, as illustrated in Figure 5, highlighted in the circle.

Subsequently, the time spent in each phase of the technique spent was compared, as well as the total time spent performing the technique on *uke* of three different statures (Table 2).

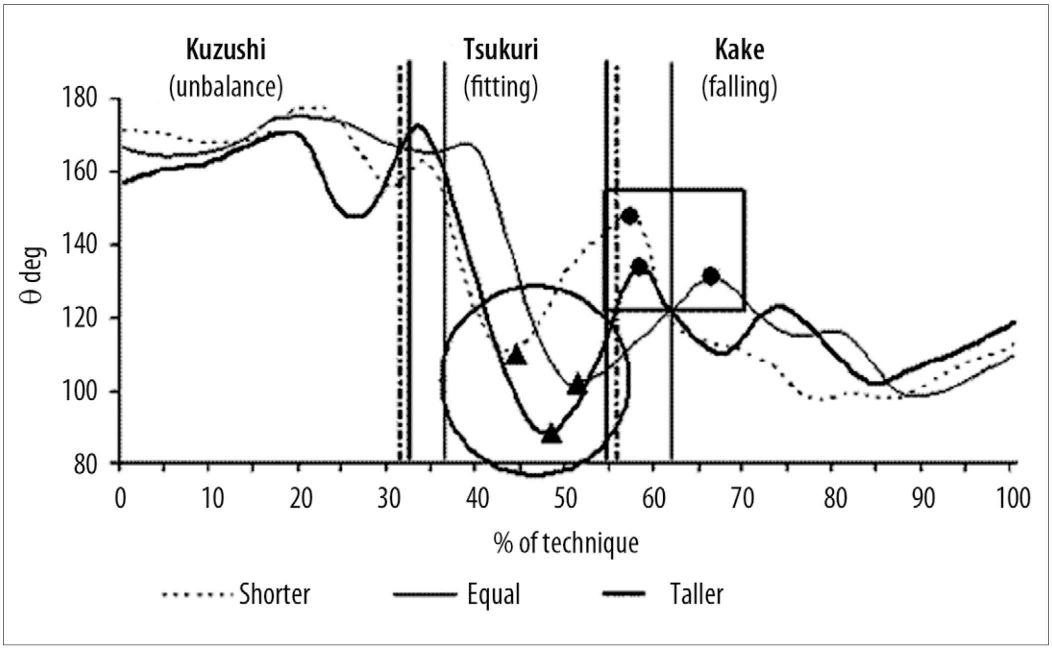

Figure 2. Attacking hip (right) Δθ, where ▲ = maximum flexion of the attacking hip; • = maximum extension of the attacking hip.

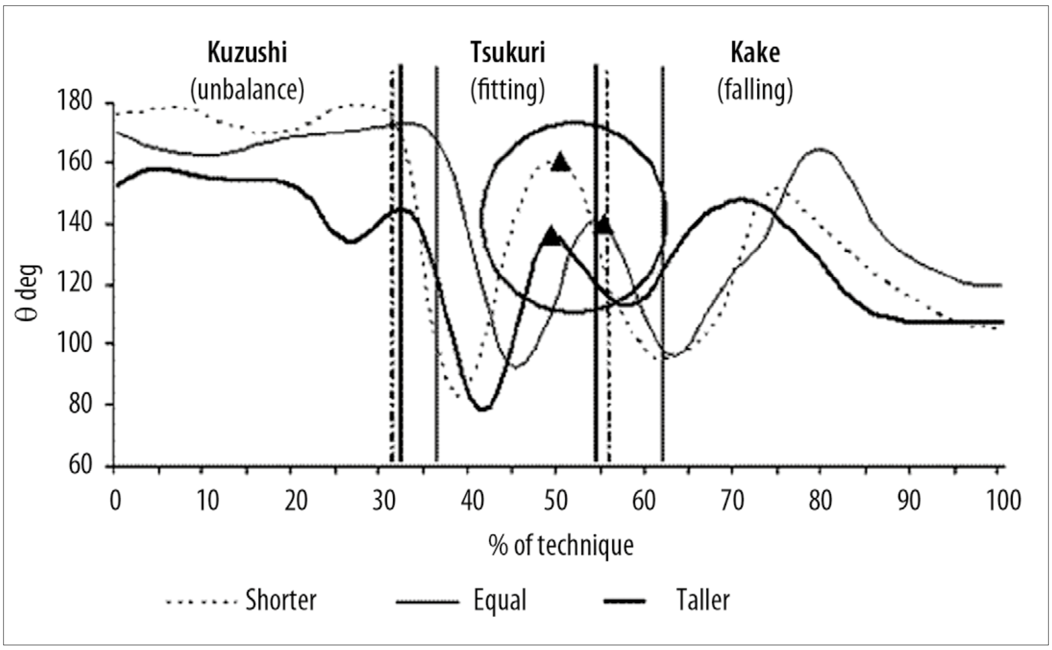

Figure 3. Attacking knee (right) Δθ, where ▲ = maximum extension of the attacking knee.

Based on the results of Table 2, it was determined that in every phase of the technique, for at least one of the different *uke* heights, the time it took the *tori* to complete the throw differed.

The Tukey post hoc test showed that: a) the time spent performing the *kuzushi* phase was shorter while throwing the shorter *uke* (0.62 s), intermediate while throwing the taller *uke* (0.65 s) and longer while throwing the *uke* of similar height (0.72 s); b) the time spent performing the *tsukuri* was shorter while throwing the shorter *uke* (0.44 s), intermediate while throwing the taller *uke* (0.45 s) and longer while throwing the *uke* of similar height (0.47 s); c) the time spent performing the *kake* phase was shorter while throwing the *uke* of similar height (0.71 s), intermediate while throwing the shorter *uke* (0.84 s) and longer while throwing the taller *uke* (0.88 s).

The total throw time for the taller *uke* (1.98 s) was significantly longer than for the *uke* of similar (1.90 s) and

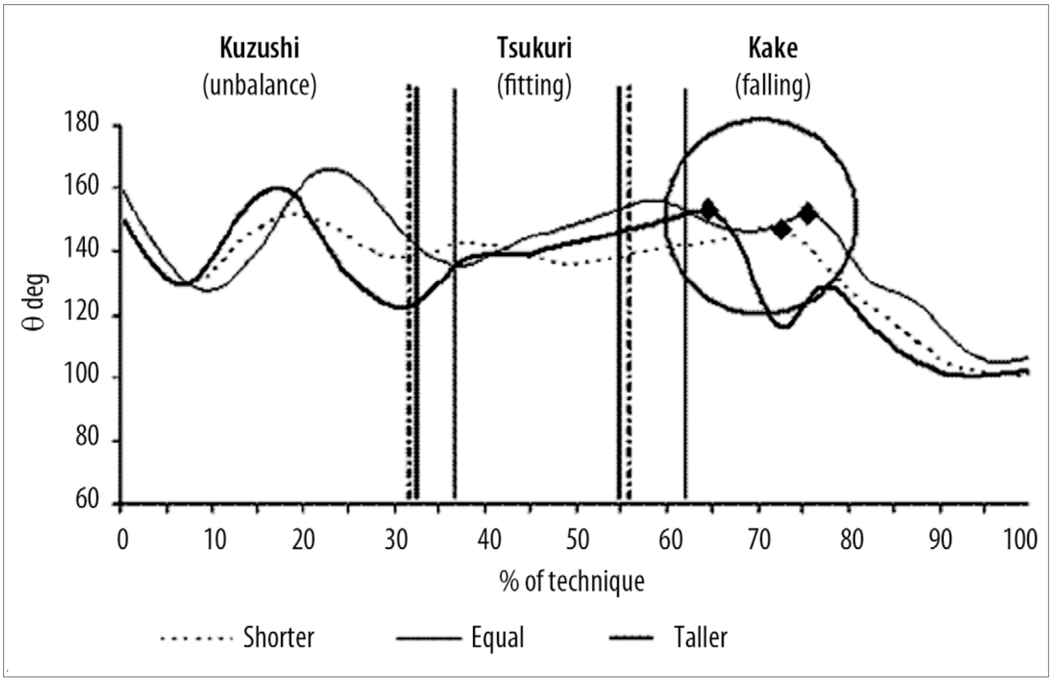

Figure 4. Supporting knee (left) Δθ, where ◆ = maximum extension of the supporting knee.

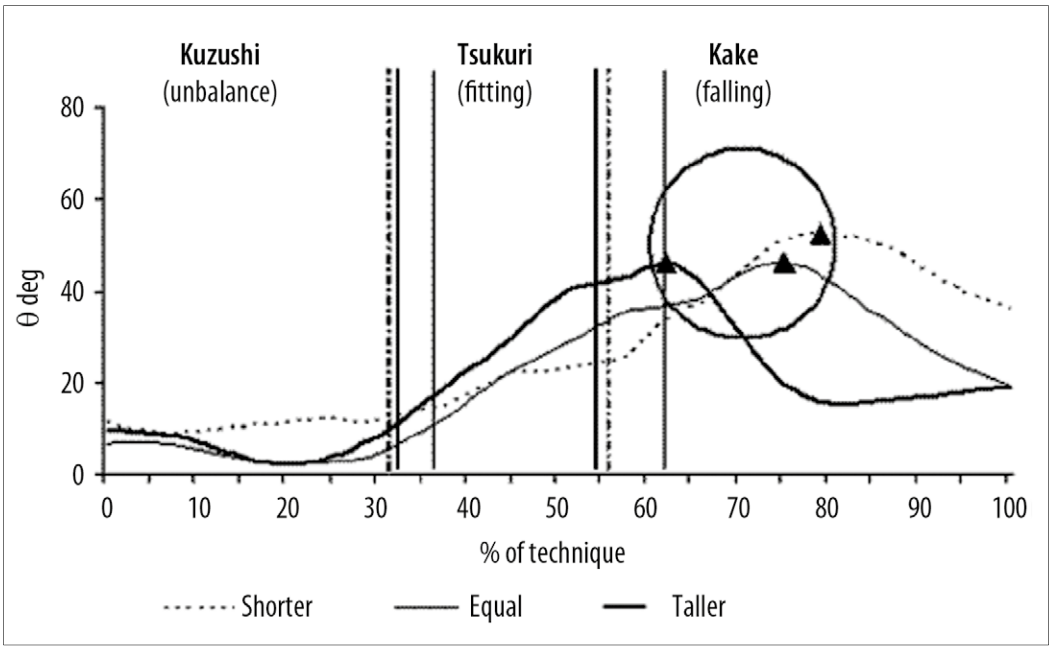

Figure 5. Trunk Δθ, where ▲ = maximum trunk flexion.

shorter (1.91 s) stature. There was no significant difference in the time it took to throw the *uke* of similar (1.90 s) or shorter (1.91 s) stature.

Finally, the *tori's* CM behavior and variation when throwing *uke* of different heights was analyzed (Figure 6).

Figure 6 demonstrates that during performance of the *o soto gari* technique, the *tori* CM height was similar while throwing the *uke* of similar and taller stature, and was lower while throwing the shorter *uke*. There was no significant difference ($p \leq 0.01$) in *tori* ΔCM when throwing the *uke* of similar (0.603 m), taller (0.0993 m) or shorter (0.26 m) stature.

Discussion

Regarding the variables *maximum angle of flexion of the attacking hip* (MAFrH) and *maximum extension angle of the attacking knee* (MEArK) during the *tsukuri* phase, it was

Table 2. A comparison of the time spent in each phase of the technique and the total time spent performing the technique on *uke* of three different statures.

Phase	Height	$\bar{X} \pm s$ (s)	F	p
Kuzushi	Taller Similar Shorter	0.65±0.0086 0.73±0.011 0.62±0.0095	286.419	0.000
Tsukuri	Taller Similar Shorter	0.45±0.0063 0.47±0.0063 0.44±0.069	57.012	0.000
Kake	Taller Similar Shorter	0.88±0.0087 0.71±0.0086 0.84±0.073	1184.203	0.000
Total time	Taller Similar Shorter	1.98±0.0096 1.90±0.0269 1.91±0.0133	56.123	0.000

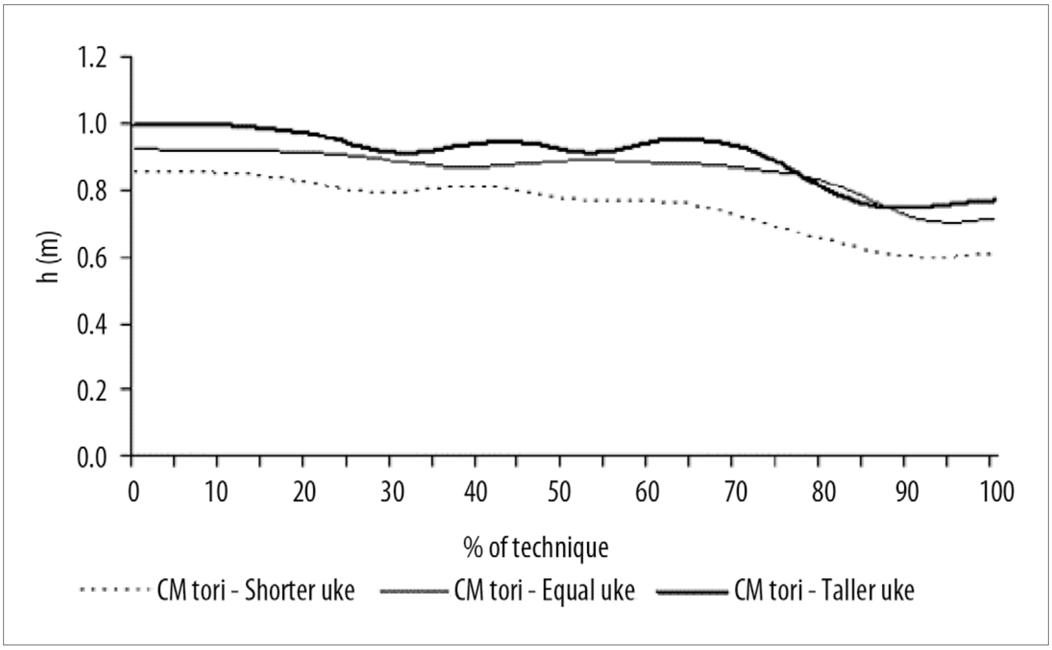

Figure 6. The *tori*'s CM behavior when throwing *uke* of different heights with the *o soto gari* technique.

observed that the *tori* performed greater hip and knee flexion when throwing taller *uke*, and lower hip and knee flexion when throwing shorter *uke*. Both leg elevation and attacking knee extension during the *tsukuri* phase are very important in the *o soto gari* technique, because the higher the elevation of the leg, the greater the distance the *tori* will have to develop speed for reaching the supporting leg of *uke*, which will generate greater impact. Moreover, the lower hip and knee flexion employed while throwing a shorter *uke* demonstrates the lower stress demanded and, thus, the shorter time necessary for throwing relatively shorter opponents.

The variables *maximum extension angle of the attacking hip* (MEArH) and *maximum flexion angle of the trunk* (MFAT) during the *kake* phase, which are associated variables, were greater when throwing the shorter *uke*. Imamura and Johnson [7] demonstrated that the front-to-back forward trunk flexion, attack hip extension, chest-to-chest contact and angular velocity of the *tori*'s trunk are very important aspects of *o soto gari* because they generate angular momentum that, upon collision with the supporting leg of *uke*, promote an efficient throw.

The variable *maximum extension angle of the supporting knee* (MEAlK) during the *kake* phase was greater when throwing *uke* of taller or similar stature, which demonstrates the need for greater effort, given that the extension of the *tori*'s support knee during the *kake* phase expedites the lifting of the attacking hip and leg.

These results reinforce the concept that the *o soto gari* technique would not be the most suitable for opponents taller than the *tori*, since the mechanical efficiency of the technique would decrease. According to Robert [8], for increased mechanical efficiency, relatively lower power consumption is necessary, and improvement in biomechanical movement can help preserve both bone and joint by avoiding overload [9].

In summary, it can be confirmed that for all angular variables investigated (MFArH, MEArK, MEArH, MEAlK, MFAT) in the respective phases of the technique analyzed, the *tori* required smaller motion amplitudes to throw the shorter *uke* efficiently. These results agree with other authors, such as Kudo [10], Tegner [2] and Figueroa [11], who point out that taller judokas found it easier to apply leg techniques to shorter *uke*. Thus, the angular values found in this study indicated greater efficiency for throwing *uke* who were shorter than *tori*.

No other studies with **kinematics** analysis of judo leg techniques that account the anthropometric characteristics of uke where found in literature. Melo, Santos, Teixeira and Piucco [5] investigated these same variables for *harai goshi* technique and observed that the mechanical efficiency was greater when the technique was applied to *uke* taller than the *tori* because it was easier to perform the hip entrance in preparation for the throw. The didactic judo literature only describes the technical details of movements considered essential, such as knee flexion during the fitting phase and forward trunk flexion during the fall, whereas other studies like that of Imamura, Hreljac, Escamilla and Edwards [4] and Imamura, Iteya, Hreljac, and Escamilla [12] analyze the *tori*'s CM during the throw in different techniques or during training and competition, but do not mention kinematic data related to throwing *uke* of different heights.

Regarding the total time it took to perform the *o soto gari* technique, it was demonstrated that the *tori* threw the *uke* of shorter of similar stature in a shorter time, which indicates a faster throw when the defenders are the same height or shorter than the attacker.

The temporal values related to the execution of each phase of the technique demonstrated that the *kuzushi* and *tsukuri* phases were faster when throwing the shorter *uke*. These two phases are considered both essential and prerequisite for a proper application of the technique, while the *kake* phase is merely consequential to the earlier phases [11]. According to Imamura, Hreljac, Escamilla and Edwards [4], for the performance of the *o soto gari* technique, the *uke*'s body moves toward *tori*'s pulling movement, resulting in the greatest moment of force during the *tsukuri*. Therefore, this phase tends to be particularly important. In light of this fact, the data found in this study regarding time spent indicate that the *o soto gari* technique is most effective when applied to uke shorter than the tori.

No studies investigating the relationship between judo leg techniques, speed of application and throw efficiency were found that involved different judo athletes during different phases of a technique. Authors like Kudo [10] and Carvalho [13] emphasize the importance of speed during judo technique performance, but they did not mention speed differences with respect to judokas of different heights, which highlights the need for major studies that might improve judoka performance.

Regarding the CM analysis, it was determined that the *tori's* CM dropped when throwing the shorter *uke*, although there were no differences when throwing the *uke* of similar or taller stature. The *tori*'s maximum and minimum ΔCM were similar when throwing the *uke* of similar or taller stature, although a larger value variance occurred when throwing the shorter *uke*.

These same results were found by Melo, Santos, Teixeira and Piucco [5] regarding the *harai goshi* technique, confirming the judo literature, which states that the *tori* must position his trunk below the *uke* in order to perform hip techniques with greater efficiency [2,10,14,15]. For leg judo techniques, such as the one investigated in this study, the need to drop the *tori*'s CM is probably related to the need to "sweep" the *uke*'s posterior load-bearing thigh, while generating a lever movement with the hip as a fulcrum [4].

Other studies that have considered the relationship between stature and the preferred technique of judokas revealed that hand techniques predominated among *tori* of shorter or similar stature than the *uke*, while the taller judokas preferred leg techniques [16–20].

A principal limitation of this study is that unfortunately, it is impossible to find *uke* who represents the same weight category, but considerably different in **body height**. However, this condition does not interfere in the angular values and *tori's* ΔCM found, regarding that these variables are not dependent of *uke* body weight during *o soto gari* technique, based on 3D model. Differently of the hip judo throw techniques, the *o soto gari* do not need that *tori* raise the *uke* from the ground, what implies that the *uke* body weight did not change the angular positioning and CM trajectory of *tori* during all the investigated phases, instead the *uke* height is the most important variable for observed results.

On the other hand, temporal kinematics variables like angular and linear velocities and kinects variables like momentum and impulse are directly associated to the body weight [3] and then, could be influenced by the *uke* body weight.

However, the results finding are important to improve the mechanical efficiency of judokas not only during

Kinematic – is the branch of classical mechanics that describes the motion of bodies (objects) and systems (groups of objects) without consideration of the forces that cause the motion.

Body height – is the distance from the bottom of the feet to the top of the head in a human body standing erect.

competitions, but also in judo training or open category fights. Further studies should be conducted to investigate both the linear and angular kinematics variables of *tori* in greater detail by applying different kinds of throw techniques to opponents of different heights.

Conclusions

In spite of the limitations of this study, it can be stated that for all angular variables investigated (MFArH, MEArK, MEArH, MEAlK, MFAT) in the three phases of the technique, the *tori* performed better when throwing the shorter *uke*.

The performance times were quicker for throwing the shorter *uke* in the *kuzushi* and *tsukuri* phases, which are the most important steps for the successful application of this technique.

The greatest variation in the *tori*'s CM occurred while throwing the shorter *uke*, probably indicating that a greater effort was necessary to throw shorter *uke* with efficiency.

Finally, it can be affirmed that the temporal and angular values found in this study indicate that the *o soto gari* technique is biomechanically more efficient when applied to opponents shorter than the attacker. Nevertheless, considering that this technique is relatively easy, it is best suited for beginners with little mobility, and for heavier judokas who can generate great momentum after contact.

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