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 judokas 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 (ACM). 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* ≤ 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* ACM 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.

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 kazushi to create an opposite movement from uke, the o soto gari tosses the uke backwards.

In the o soto gari technique, the first phase (kazushi), 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 kazushi 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 throw 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 bio-type 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 falling) 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 1.71 m, 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 Kalhues & 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 supporting knee (left) (MEAIK) during kake, maximum trunk flexion angle (MFAT) during kake; i) selection of temporal variables, including the execution of the kazushi, tsukuri and kake phases and the total throw time; i) 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≤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.
Figures 2–5 illustrate the tori $D_q$ for the analyzed variables during the osoto 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 (153.44°) 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).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Phase</th>
<th>Height</th>
<th>$\bar{x} \pm s$ (°)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFArH</td>
<td>tsukuri</td>
<td>Taller</td>
<td>88.51±1.20</td>
<td>639.822</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Similar</td>
<td>101.51±1.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shorter</td>
<td>110.34±1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEArK</td>
<td>tsukuri</td>
<td>Taller</td>
<td>135.31±1.23</td>
<td>1005.516</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Similar</td>
<td>141.38±1.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shorter</td>
<td>160.55±1.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEArH</td>
<td>kake</td>
<td>Taller</td>
<td>133.85±1.31</td>
<td>531.458</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Similar</td>
<td>130.91±1.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shorter</td>
<td>148.19±1.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEAlK</td>
<td>kake</td>
<td>Taller</td>
<td>153.44±1.51</td>
<td>124.683</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Similar</td>
<td>155.77±1.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shorter</td>
<td>147.16±0.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFAT</td>
<td>kake</td>
<td>Taller</td>
<td>46.31±1.20</td>
<td>71.692</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Similar</td>
<td>46.46±1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shorter</td>
<td>52.46±1.56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 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).

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 osoto gari technique.

Figures 2–5 illustrate the tori $\Delta \theta$ for the analyzed variables during the osoto 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 (153.44°) 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).
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 (0.43 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
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 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≤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...
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 osoto 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 osoto 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 (MEA1K) 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 osoto gari technique would not be the most suitable for opponents taller than the tori, since the mechanical efficiency of the

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.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Height</th>
<th>$\bar{X} \pm s ,(s)$</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuzushi</td>
<td>Taller</td>
<td>0.65±0.0086</td>
<td>286.419</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Similar</td>
<td>0.73±0.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter</td>
<td>0.62±0.0095</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsukuri</td>
<td>Taller</td>
<td>0.45±0.0063</td>
<td>57.012</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Similar</td>
<td>0.47±0.0063</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter</td>
<td>0.44±0.0069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kake</td>
<td>Taller</td>
<td>0.88±0.0087</td>
<td>1184.203</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Similar</td>
<td>0.71±0.0086</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter</td>
<td>0.84±0.073</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time</td>
<td>Taller</td>
<td>1.98±0.0096</td>
<td>56.123</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Similar</td>
<td>1.90±0.0269</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter</td>
<td>1.91±0.0133</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. The tori’s CM behavior when throwing uke of different heights with the osoto gari technique.
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 katasashi 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 kaze 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 ACM 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 ACM 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
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, MEAIK, 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 soto gari technique is biomechanically more efficient when applied to opponents shorter than the attacker. Nevertheless, considering that this technique is relatively easy, is best suited for beginners with little mobility, and for heavier judokas who can generate great momentum after contact.

**REFERENCES:**