BIOMECHANICAL ANALYSIS OF JUDOKAS`THROWING TECHNIQUES: FOCUS ON THE PREPARATION PHASE

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The purpose of this study was to compare the Judo throwing technique "uchimata" (inner thigh throw) between high and low skilled judokas during the preparation phase. Fourteen male judokas participated in this research. Kinematic data were collected using three-dimensional motion capture system. During the analysis of the thrower's (tori's) angular velocity and the receiver's (uke's) angular momentum in the preparation phase, it was observed that high skilled judoka exhibited a very larger positive correlation between the peak angular velocity of the tori's legs and the peak angular momentum of the uke's trunk. Additionally, the peak tori's centre of mass (COM) velocity in the front-back direction was significantly higher for high skilled judoka. These findings suggest that, for the effective execution of the uchimata technique, rapidly advancing towards the opponent is crucial.

KEYWORDS: judo, nage-waza, motion analysis, angular velocity, angular momentum.

INTRODUCTION: Judo, a traditional Japanese martial art established by Jigoro Kano in 1882, has undergone a contemporary metamorphosis, evolving into an internationally embraced competitive pursuit. The uchimata, a hip-throwing technique, is one of the most effective foot techniques (ashi-waza) among the various throwing techniques used in judo (Miyake et al., 2014) and is frequently used in judo matches and practice. This technique requires that the thrower break the opponent's balance, then sweep the opponent's inner thigh with their legs to execute the throw by raising the thigh on their hips (Daigo, 1999), and is supported by a single leg during the throw. Notably during the preparation phase, tori initiates facing uke, yet, upon conclusion, executes a 180-degree torsional pivot of the hips, thus redirecting movement trajectory and facilitating the throw. During the preparation phase, it is imperative for tori to induce forward motion in the opponent, thereby ensuring a smooth and stable execution of the throw in the throwing phase. Imamura et al. (2007) assert that the efficacy of a throwing technique is contingent upon the opponent's movements, suggesting that investigating the interplay between tori and uke during the preparation phase could enhance throwing success. Recent years have witnessed a proliferation of biomechanical studies scrutinizing judo throwing techniques (Liu et al., 2022; Ishii et al., 2018). However, prevailing research predominantly focuses on the entirety of the technique, neglecting the preparation phase. Furthermore, conventional judo instruction relies heavily on intuition and past experiences, devoid of scientific foundations. Given the biomechanical discrepancies in uchimata techniques correlated with judokas' proficiency levels, it becomes crucial to contemplate quantitative standards for evaluating their proficiency. Thus, the primary purpose of this study was to compare uchimata technique between high and low skilled judokas during the preparation phase. Additionally, we hypothesized that the angular momentum of uke's trunk is contingent upon the angular velocity of tori's arms.

METHODS: The subjects were 14 male judokas belonging to a local university judo club, seven of whom had participated in national tournaments (hereafter referred to as "High skilled") (body mass: 79.2± 8.5 kg, body height: 1.71 ± 0.1 m, judo experience: 13.9 ± 2.6 years, age: 20.6 ± 0.9 years) and seven of whom had not participated in national tournaments (hereafter referred

Figure 1: Experimental circumstances

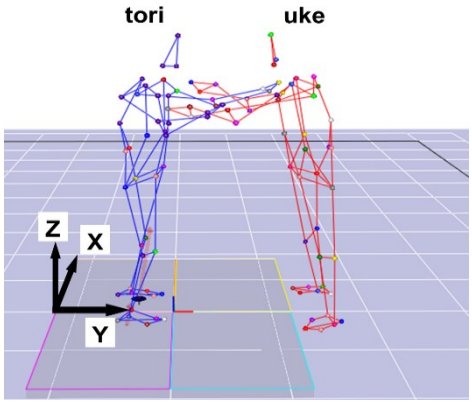

Figure 2: Experimental scenario in three dimensions

to as "Low skilled") (body mass: 77.2± 9.6 kg, body height: 1.71 ± 0.2 m, judo experience: 12.6 ± 3.4 years, age: 21.0 ± 1.8 years). The recipient of the techniques (uke) was a single individual with judo experience (mass: 78 kg, height: 1.70m, age: 25 years), whose physical attributes differed little from those of the judoka who applied the techniques (tori).

The three-dimensional marker trajectory data of the tori and uke were recorded using a 14-camera Mac3D motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA) with a sampling rate of 250 Hz. Marker trajectory data were filtered using a fourth-order Butterworth filter with a cut-off frequency of 12 Hz. 47 reflective markers were attached to each subject. Ground reaction forces acting on the feet during the movements were measured using a force plate (Advanced Mechanical Technology, Inc., Watertown, MA, USA) (1000 Hz).

The uke wore specially designed judogi and was instructed to maintain a natural posture and adhere to the basic stance of judo. During the measurements, the tori executed the throw with peak effort to ensure smooth execution, and the uke was instructed not to resist. After each technique attempt, tori self-assessed their performance using a 5-point scale, assigning a rating of 5 if they believed they had executed the best technique with proper throwing motion, drawing on previous studies (Ishii et al., 2018). The study was approved by Hiroshima university ethics committee.

The preparation phase started when the tori's lead leg (i.e., the left foot of a left-handed participant) lifted off the force plate, which was identified when the vertical position of the toe marker was higher than 0.05 cm. The end of the preparation phase was defined when the pivot foot landed, and the toe marker was higher than 0.05 cm immediately the sweeping foot lifted on the ground. The throwing phase was defined as the period between the end of the preparation phase and the moment the uke touched the tatami mat. The moment was confirmed using the ground reaction force data (the threshold value was set to 5N). Each phase was normalised to 100%. This study centered its attention on the preparation phase.

The estimation of the centre of mass (COM) for tori was conducted utilizing the 14-segment rigid body model designed for Japanese athletes (Ae, 1996). The three-dimensional velocity of the COM in the front-back direction was computed by differentiating its displacement over time. The angular velocities of the tori's arms and legs was calculated based on the

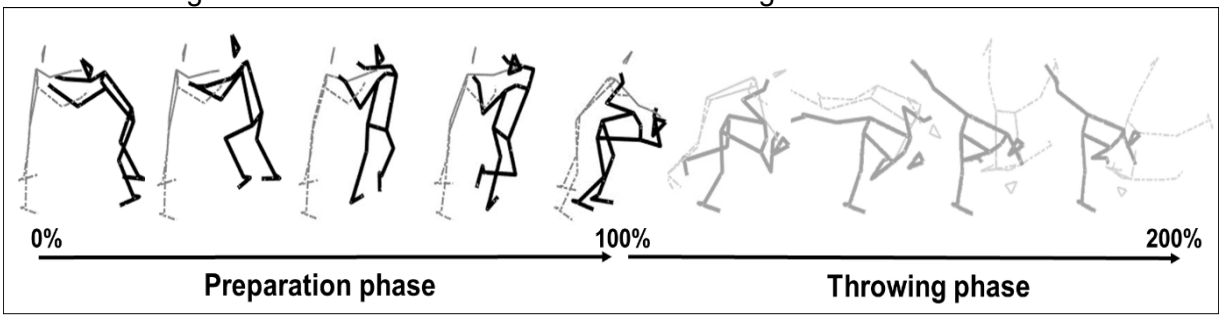

Figure 3: The phase of uchimata

methodology outlined by Ishii et al (2018), and the angular momentum of the uke's trunk was computed using a customized MATLAB program (MathWorks Inc., MA, USA) following the procedures described by Koshida et al (2016).
The data are expressed as the mean ± standard deviation for each item. Statistical processing was performed using SPSS Statistics (version 27; IBM Corp., Armonk, NY, USA), the Shapiro-Wilk test was employed to assess the normal distribution of the variables. Following the confirmation of normality, Welch's t-test was employed to compare the peak values of each item between the two groups. The significance level was established at $p < 0.05$. The effect size was Cohen'd as proposed by Cohen (1988). Pearson product-moment correlation coefficient (r) was used to determine relationships between the peak angular momentum of the uke's trunk, both the peak angular velocities of the tori's arms and legs. Correlation coefficient r values as 0.1, 0.3, 0.5, 0.7, and 0.9 were used as the thresholds for small, moderate, large, very large, and extremely large correlations.

RESULTS: Table 1 presents a comparison of the peak angular velocities of the tori's arms and legs, COM (front-back) velocity, and the peak angular momentum of the uke's trunk between both groups during the preparation phase. While there was no significant difference in the peak angular velocity of the tori's arms, the high skilled group exhibited a significantly greater peak angular velocity of the tori's leg compared to the low skilled group (p=0.04). Additionally, the tori's peak COM (front-back) velocity was significantly higher in the high skilled group than in the low skilled group (p=0.01). Furthermore, the peak angular momentum of the uke's trunk was significantly greater in the high skilled group compared to the low skilled group (p=0.04) (Table 1). A very larger positive correlation was observed between the peak angular momentum of the uke's trunk and the peak angular velocity of the tori's arms (r=0.813, p<0.001), as well as between the peak angular momentum of the uke's trunk and the peak angular velocity of the tori's legs (r=0.804, p<0.001). Statistically significant correlations were observed in each of the correlations (Figure 4).

DISCUSSION: During the preparation phase of uchimata, tori advances towards uke, and the pivot foot of the second step contacts the ground in the opposite direction to the movement. Subsequently, tori's hips and upper limbs undergo a twisting motion, resulting in a unique 180-degree change in tori's movement direction by the end of the preparation phase (Figure3). Consequently, tori must effectively transfer the forward momentum from the lower limbs to the upper limbs after the pivot foot makes contact. In this study, the high skilled group exhibited significantly greater angular velocity of the tori's leg, COM (front-back) velocity, and the uke's trunk angular momentum. Moreover, a very larger positive correlations were found between the peak angular velocity of the tori's arms(the only one connected to uke) and the peak angular momentum of the uke's trunk, as well as between the peak angular velocity of the tori's legs and the peak angular momentum of the uke's trunk. These results suggest that the high skilled group with a high level of tori may be capable of moving their arms and legs faster, facilitating the forward movement of uke. This result supported the hypothesis. Regarding the correlation between the angular velocity of the tori's arms and angular momentum of the uke's trunk, Imamura et al. (2007) found that in harai-goshi, a hip-throwing technique similar to uchimata in that it is executed with single-leg support, that skilled judokas first pulled the upper body

Table 1: Comparison of the peaks of high skilled and low skilled group.

	High skilled	Low skilled	*p*-value	Effect size
Peak angular velocity of the tori (rad/s)				
ω Arm	2.09±1.10	1.17±0.36	0.90	0.88
ω Leg	2.42±0.67	1.79±0.19	0.04*	0.52
Peak velocity of centre of mass of the tori (m/s)				
COM (front-back)	0.82±0.24	0.52±0.08	0.01*	0.19
Peak angular momentum of the uke (kg·m^2/s)				
H Trunk	2.22±0.98	1.24±0.26	0.04*	0.83

Mean ± standard deviation. *p <0.05 (n=7/group)

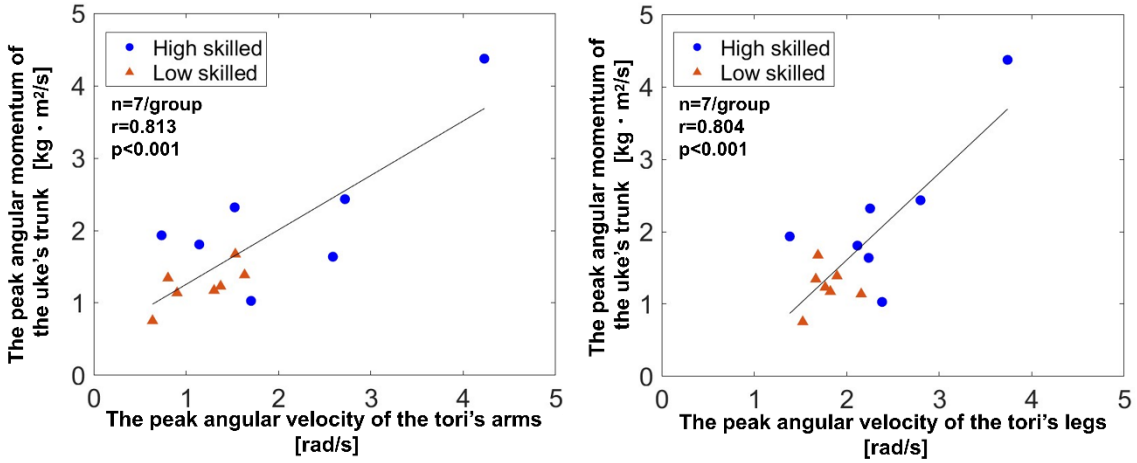

Figure 4: The relationship between the peak angular velocity of the tori's arms and the peak angular momentum of uke's trunk, in addition to the relationship between the peak angular velocity of the tori's legs and the peak angular momentum of the uke's trunk.

forward with the arm rather than directly implementing the throw. The results of this study supported previous research. The COM (front-back) results also highlight the importance of rapid forward movement for high skilled judokas. In a practical judo match, the thrower must initiate the attempt before the opponent can react. Uchimata is a rotational throwing technique like seoi-nage (shoulder throw). In actual combat situations, it is crucial for the thrower to seamlessly transition into a throw before the opponent can react, as any delay may allow the opponent to evade or launch a counterattack (Ishii et al., 2018). Additionally, tori swiftly advances and forcefully contacts uke with their hips during the hip twist, potentially aiding in pulling uke forward and executing an effective throw. Overall, these results suggest that during the preparation phase, movements involving the lower limbs are crucial for transitioning to the subsequent throwing phase.

CONCLUSION: This study's results indicated that during the preparation phase, the peak angular velocity of the tori's legs, COM (front-back) velocity, and the peak angular momentum of the uke's trunk were significantly greater in the high skilled group compared to the low skilled group. Additionally, a significant very larger positive correlation was observed between the peak angular momentum of the uke's trunk, both the peak angular velocities of the tori's arms and legs. These findings suggest that judo practitioners aiming for effective uchimata should prioritize swift forward movement towards their opponent rather than focusing solely on rapid arm and leg twisting.

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