COMPARISON OF KINETICS AND KINEMATICS IN SEOI-NAGE BETWEEN JUDO ATHLETES WITH DIFFERENT SKILL LEVELS

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The purpose of the present study was to compare the biomechanics parameters of seoi-nage between a skilled group and an unskilled group. The motion data of the seoi-nage were collected on three male elite judo athletes and sixteen male student judo athletes using a three-dimensional motion analysis technique. Groups based on skill level were compared. This study found that the anterior-posterior component of the centre of mass velocity of the tori and average anterior-posterior component of the hip velocity of the swing leg in the knee extension phase were significantly larger in the skilled group than those in the unskilled group. The information suggests that it may be more important for judo athletes to maintain the linear velocity towards an opponent than body position of the tori relative to the uke for better seoi-nage performance.

KEYWORDS: Nage-waza, seoi-nage, motion analysis.

INTRODUCTION: A well-designed training program is crucial to enhance judo performance. Because judo requires all-round physical abilities due to the characteristics as one of the martial arts, coaches have strived to develop a comprehensive program for maximizing the performance of their judo athletes. The coaches have also been asked to design time-efficient training programs based on the needs of individual judo athletes.

According to statistics from the Rio de Janeiro Olympics Games in 2016 and the world judo championships in Astana, Republic of Kazakhstan, in 2015, judo athletes were most likely to acquire points with seoi-nage techniques in the matches. Previous reports in the last 30 years of high-ranked international tournaments indicated that many judo athletes around the world used seoi-nage techniques during competitions (Nakamura, Tanabe, Nanjo, Narazaki & Shigeoka, 2002), suggesting that seoi-nage would be the most widely used and effective techniques for point acquisition in high-level judo athletes.

In order to improve the seoi-nage skill, we need a thorough understanding of kinematic and kinetic characteristics of seoi-nage. Ishii et al (2015) reported that there were apparently large differences in the joint torques of knee and hip extension of the swing leg between the elite and student judo athletes. It was speculated that the kinematic characteristics of the elite judo athletes potentially contribute to produce greater angular momentum in seoi-nage, allowing the elite athletes to perform successful seoi-nage by transferring the angular momentum to the uke (opponent) effectively. However, the relationship between some kinematic characteristics and the angular momentum of the uke during throwing remains to be confirmed. Therefore, we aimed to compare kinematic and kinetic variables of the lower extremities in seoi-nage motion between skilled and unskilled judo athletes.

METHODS: The participants were three male elite judo athletes who were medallists in the 2010 World Judo Championships (age, 24.3 ± 2.1 years; 1.66 ± 0.05 m; 72.6 ± 6.9 kg) and sixteen male college judo athletes (19.7 ± 1.7 years; 1.66 ± 0.04 m; 69.1 ± 6.5 kg). The college athletes currently compete at the Japanese collegiate level, which requires advanced judo skills.

Three-dimensional coordinate data for 94 reflective markers on the participants' body were captured with 18 cameras of a VICON-MX system (VICON Motion Systems, Ltd., Oxford, UK) operating at 250 Hz for the tori (the person throwing an opponent) and the uke (the person being thrown by the tori) while they performed seoi-nage in pre-arranged sparring

drills. The participants wore judo gear designed to improve visibility of the markers (Ishii et al, 2015) and performed seoi-nage as close as possible to that in their usual sparring drills.
The participants rated their own performance on a scale of 1 to 5 (1 = poor, 2 = below average, 3 = average, 4 = good, 5 = excellent). They were asked to repeat seoi-nage until five trials rated 4 or 5 had been captured successfully. In addition, five experienced coaches rated the participants' performance using the same evaluation scale. The seoi-nage move rated highest by the coaches was chosen as the best trial for motion analysis.
The anterior-posterior (Y) axis is defined as the directional line from the tori to the uke in the starting position, the vertical (Z) axis as the vertical direction, and the medial-lateral (X) axis as the direction perpendicular to both the Y and Z axes. The range covered by motion capture cameras was 2.5 m in the X axis, 4 m in the Y axis and 3 m in the Z axis.
Three-dimensional coordinate data of the tori and uke were smoothed by a Butterworth digital filter at a cut-off frequency ranging from 4.8 to 9.3 Hz, as determined by the residual method (Winter, 2009). When a marker could not be tracked by obstruction (e.g. uke's body), the 3D marker trajectory data were virtually estimated by adjacent three markers.
We analysed the seoi-nage motion from the time when the pivot foot of the tori (right foot for a right-handed athlete) lifted off to the time when a part of the uke's body was in contact with the mat. The knee extension phase was defined from the instant of the tori's maximum knee flexion to the instant of the tori's maximum knee extension. Data were normalised by duration of the knee extension phase. In this study the focus was on the knee extension phase.

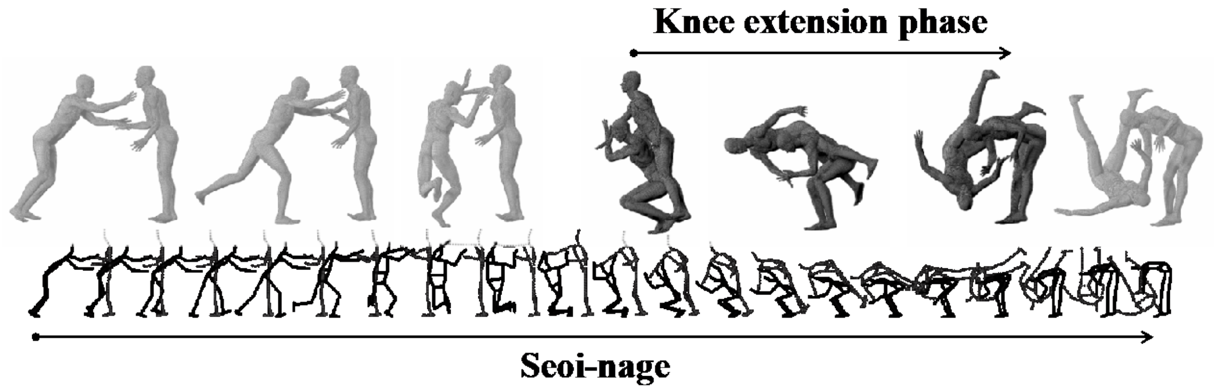

Figure 1: The knee extension phase of seoi-nage.

The centres of mass (COM) of the tori and uke were estimated after body segment parameters for the Japanese athletes (Ae et al., 1996). The angular momentum of the tori and the uke about their centres of mass were calculated. We normalized the angular momentum of the whole body by the square of body height and the body mass of the participant based on Hinrichs's (1987) method. Therefore, the unit of angular momentum was indicated by (s^{-1}) as normalized angular momentum. The correlation coefficient between the angular momentum of the tori at the maximum knee flexion and the change amounts of the angular momentum of the uke in the knee extension phase were calculated. Based on the magnitude of the change amounts of angular momentum of the uke in the knee extension phase, we selected the top and bottom six participants; comparing the skilled and unskilled groups, respectively.
To compare the kinetics and kinematics for both groups, the knee joint angle of the swing leg was calculated using a joint coordinate system described by Suzuki et al. (2014).
The Mann-Whitney U test from non-parametric statistics was conducted to test differences between the two groups in the calculated biomechanical variables, described below. Effect size was calculated using r proposed by Cohen (1988). The effect size was assessed as trivial (<0.1), small (0.1-0.3), medium (0.3-0.5), large (0.5+) (Cohen, 1988). MATLAB and its statistics toolbox (The MathWorks Inc., R2017b, Version 8.6, Massachusetts, USA) were used for all calculations, and the level of significance was set at 5%.

The kinetic and kinematic variables compared between the groups included the difference in the COM height of the whole body between the tori and uke, the knee joint angle of the swing leg and the COM velocity in the anterior-posterior direction of the tori at the peak knee flexion time, the peak knee joint angular velocity and the joint torque of the swing leg, the average velocity of the hip joint of the swing leg in anterior-posterior direction and the vertical direction in the knee extension phase.

RESULTS: We found a positive correlation between the normalized angular momentum of the tori at 0% mark of the knee extension phase and the change of the normalized angular momentum of the uke at 100% mark of the knee extension phase (r = 0.425, P = 0.07) (Figure 2).

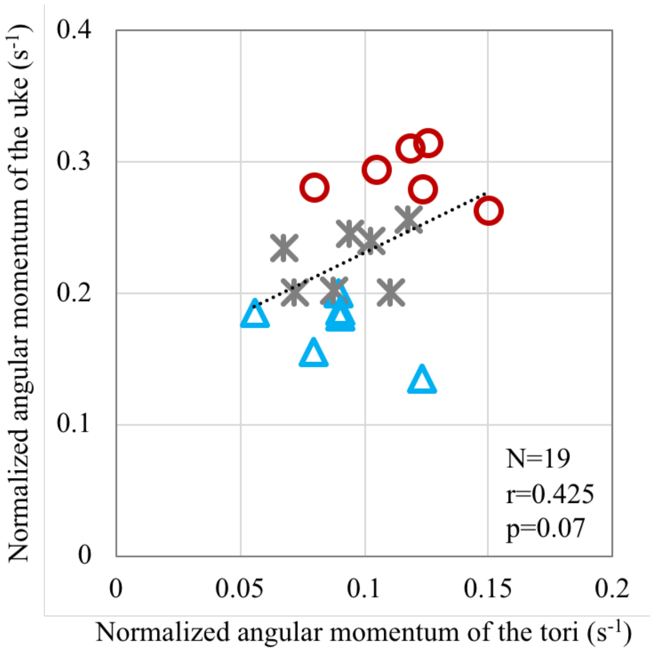

Figure 2: Relationship between normalized angular momentum of the tori at the start of the knee extension phase and the change amounts of normalized angular momentum of the uke in the knee extension phase. The circles indicate the normalized angular momentum of the skilled group, and the triangles indicates the unskilled group, and the asterisks indicate the other participants.

Table 1: Differences in the kinematic and kinetic variables between both groups.

	Median			
	skilled	unskilled	*P*	ES
0% mark				
Distance of the COM between the tori and uke (m)	0.32 (0.13)	0.28 (0.04)	0.378	S (0.25)
Knee joint angle of swing leg of the tori (°)	-99.5 (39.7)	-87.1 (9.8)	0.230	M (0.35)
A-P component of the COM velocity of the tori (m/s)	1.14 (0.61)	0.59 (0.07)	0.045*	L (0.58)
0-100% mark obtained only swing leg motion				
Peak angular velocity of the knee (rad/s)	8.11 (1.26)	6.23 (2.88)	0.173	M (0.39)
Average A-P component of the hip velocity (m/s)	0.69 (0.20)	0.34 (0.24)	0.020*	L (0.67)
Average vertical component of the hip velocity (m/s)	0.76 (0.44)	0.55 (0.33)	0.298	M (0.30)
Peak extension torque of the knee (Nm/kg)	2.07 (1.10)	2.01 (1.53)	0.936	T (0.02)

Notes: Median (quartile deviation); *, significant;
ES, Effect size: T, trivial (<0.1); S, small (0.1-0.3); M, medium (0.3-0.5); L, large (0.5+).

Table 1 shows the differences in the kinematic and kinetic variables between both groups. Although there was no significant difference in the distance of centres of mass between the tori and uke and the knee joint angle of the swing leg at the 0% mark between the two groups, A-P component of the mean centre of mass velocity of the tori was significantly larger in the skilled group than in the unskilled group ($p = 0.045$, ES = 0.58). There were no significant group differences in peak angular velocity and peak extension torque of the knee of the swing leg, average vertical component of the hip velocity of the swing leg in the knee extension phase. The average A-P component of the hip velocity of the swing leg in the knee extension phase was significantly larger in the skilled group compared with the unskilled group ($p = 0.020$, ES = 0.67).

DISCUSSION: Understanding the biomechanics of judo techniques is crucial in judo coaching. However, there is little detailed information on biomechanics of seoi-nage. Therefore, we compared the kinematics of the seoi-nage motions performed by judo athletes with different skill levels. The information will provide us important knowledge on developing an effective and time-efficient program for seoi-nage coaching.

The present study demonstrated a positive correlation between the angular momentum of the tori and that of the uke. In addition, this study also found that the anterior-posterior component of the COM velocity of the tori and average anterior-posterior component of the hip velocity of the swing leg in the knee extension phase were significantly larger in the skilled group than those in the unskilled group.

Most elite judo athletes and coaches with excellent skills of seoi-nage are likely to believe that lowering the whole-body COM by the deep knee flexion in the preparatory phase that precedes the quick knee extension motion during the execution plays an important role in successful seoi-nage performance. However, the present study indicates that knee flexion angle, COM height difference between the uke and tori, knee extension velocity, and the magnitude of knee extension torque are not so important contributing factors for developing angular momentum of the uke. The present study suggests that judo athletes need to maintain the hip and COM velocities of the tori (i.e. A-P direction) during the preparatory phase, even at the instant of the maximum knee flexion, to effectively transfer the angular momentum to the uke from the tori.

CONCLUSION: This study found that the anterior-posterior component of the COM velocity of the tori and average anterior-posterior component of the hip velocity of the swing leg in the knee extension phase were significantly larger in the skilled group than in the unskilled group. The results indicated that judo athletes need to maintain linear velocity towards an opponent through the whole motion phase for effective seoi-nage performance rather than lowering their body position.

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