

Biomechanical Analysis of the Head Movements of a Person Thrown by the Judo Technique ‘Seoi-nage’

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Abstract

The present study examined the kinematics and biomechanical parameters of the head of a person thrown forward by the judo technique ‘Seoi-nage’. A judo expert threw an anthropomorphic test device (the POLAR dummy) five times. Kinematics data were obtained with a high-speed digital video camera. Linear and angular accelerations of the head were measured by accelerometers mounted at the center of gravity of the dummy’s head. When Seoi-nage was performed, the dummy fell forward accompanied by contacting the anterior parietal regions of the head to the tatami, and the linear and angular accelerations of most axes reached peak values when the head contacted the tatami. Peak resultant linear and angular accelerations were 20.3 ± 9.8 G and 1890.1 ± 1151.9 rad/s², respectively (means \pm standard deviation). Peak values in linear and angular acceleration did not significantly differ between the three directional axes. Absolute angular accelerations in all axes observed in Seoi-nage were high and the resultant value was approximately equal to the already reported in Ouchi-gari, one of the predominant techniques causing judo-related acute subdural hematoma. However, the remarkable increase of linear acceleration in the longitudinal direction and/or angular acceleration in the sagittal plane, as previously reported in techniques being thrown backward (i.e., Ouchi-gari and Osoto-gari), was not detected. The likely mechanism of acute subdural hematoma caused by Seoi-nage is that a large angular acceleration causes large strains and deformations of the brain surface and subsequent rupture of cortical vessels.

Key words: acute subdural hematoma, judo techniques, prevention, head acceleration

Introduction

Judo is one of the official athletic events in the Olympic Games and is very popular, with an estimated 20 million participants in over 200 countries.¹⁾ Judo is also widely adopted in schools and public facilities for education, recreation, or health benefits. As judo continues to grow in popularity worldwide, there is also a growing interest in the prevention of serious judo-related injuries, especially head and neck injuries.^{2,3)}

The estimated incidence of catastrophic head injuries is 2.44 per 100,000 judokas per year.³⁾ According to serious accident reports provided from the All Japan Judo Federation, 30 severe head injuries including 28 cases of acute subdural hematoma (ASDH) were reported from 2003 to 2010.^{3,4)} Therefore, the prevention of severe head injuries, especially ASDH, is of the highest priority for judokas.

Severe head injuries most commonly occur when judokas are thrown by the judo throwing technique Osoto-gari, followed by Seoi-nage and Ouchi-gari.^{3,4)} We previously biomechanically analyzed the mechanisms of the head injuries that occur when judokas are thrown by Osoto-gari and Ouchi-gari.^{5–7)} In Osoto-gari and Ouchi-gari, the recipients are thrown

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backward and greater linear and angular accelerations occur when the recipient's occiput contacts the judo mat (tatami). However, in Seoi-nage, the recipient is thrown forward and the mechanism of severe head injury differs from that caused by Osoto-gari or Ouchi-gari. Although Seoi-nage is the second-most common throwing technique that causes severe head injuries in judo, to our knowledge, no study has examined the mechanism of head injuries when the recipient is thrown forward, as occurs in Seoi-nage.

The purpose of the present study was to use an anthropomorphic test device (ATD) to examine the kinematics and biomechanical parameters of the head when a judoka is thrown forward by Seoi-nage. Additionally, we clarified the head injury mechanisms due to Seoi-nage compared with the other throwing techniques evaluated in our previous study,⁵⁻⁷⁾ and proposed effective measures for preventing such injuries.

Materials and Methods

Testing procedure for the Seoi-nage judo throwing technique

One Japanese male judo expert (age 33, height 166 cm, weight 82 kg, fifth-dan) threw an ATD by Seoi-nage five times (Fig. 1). Prior to the experiment, the subject provided written informed consent, and the study protocol was approved by the Research Ethics Committee of the Dokkyo Medical University School of Medicine.

In Seoi-nage, the thrower (tori) brakes the recipient's (uke's) balance forward or toward the right (left) front corner. The tori inserts their own right (left) arm under the uke's right (left) armpit, loads the uke onto the tori's back, and throws the tori over the right (left) shoulder (Fig. 1).⁸⁾ The uke is then thrown forward.

An ATD is a mechanical model of the human body that is commonly used in vehicle crash testing. Simulations performed using an ATD enable the

attainment of the mechanical loading parameters at impact. Among several ATD models approved internationally in many official tests, a POLAR dummy was used in the present study.^{9,10)} The POLAR dummy (stature 175 cm, mass 75 kg) was designed to precisely simulate the kinematics of the human body during car-pedestrian collisions due to its high bio-fidelity. The high similarity between this dummy and the human body has been validated in several studies using post-mortem human subjects.¹⁰⁾ Because of the complex kinematics and high impact force of judo, the POLAR dummy is suitable to detect the physical parameters with sufficient reliability. With the accelerometers mounted at the gravity center of the ATD's head, the data were recorded using a high-speed data acquisition system, sampled at 20 kHz and filtered using a channel class 1000 filter. The kinematic data of the ATD were obtained using a high-speed digital video camera recording at 1000 frames per second.

On the day of the experiment, the tatami (SV230, Hayakawa Textile Industries Co., Ltd., Kashiwara, Osaka, Japan) was laid on a concrete surface. This style of tatami is allowed in official international judo tournaments. To simulate the buffer environment of the actual judo facility, a 60-mm-thick synthetic sponge consisting of urethane and polyethylene (AM2202, Senoh Corporation, Matsudo, Chiba, Japan) was placed under the tatami.

Head acceleration analysis

A tri-axial accelerometer was used to measure the linear acceleration values of the head in each direction: a_x (longitudinal), a_y (lateral), and a_z (vertical). The linear resultant acceleration (a_r) was then calculated as $a_r = (a_x^2 + a_y^2 + a_z^2)^{1/2}$. A three-degrees-of-freedom rotational accelerometer was used to measure the angular acceleration values of the head in the α_x direction along the anterior-posterior axis (coronal plane rotation), α_y direction along the medial-lateral axis (sagittal plane rotation), and α_z direction along the superior-inferior axis (horizontal

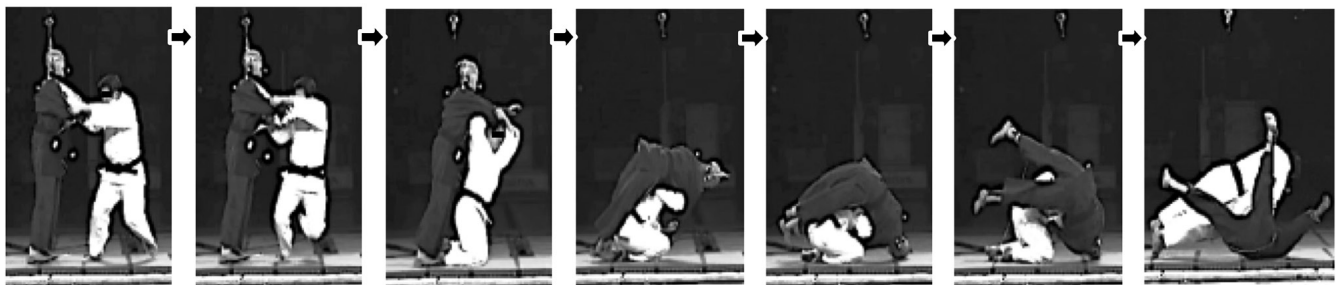


Fig. 1 Images showing the Seoi-nage technique. The white figure is the Judo expert, while the black figure is the anthropomorphic test device.

plane rotation). The angular resultant acceleration (α_r) was then calculated as $\alpha_r = (\alpha_x^2 + \alpha_y^2 + \alpha_z^2)^{1/2}$.

The peak absolute value for each acceleration measurement was examined for all experiments. According to the head acceleration diagram for each test, the peak acceleration was defined as the value at which the acceleration did not decrease for at least 3 ms.¹¹⁾

Statistical analysis

Data were expressed as mean \pm standard deviation (SD). Kruskal–Wallis tests were performed to compare the peak acceleration values in each direction caused by Seoi-nage, and to compare the peak resultant acceleration values caused by Seoi-nage versus other techniques. When a significant difference was observed between the acceleration values in the three directions using the Steel-Dwass test or between Seoi-nage and the other techniques values using the Steel's test, a multiple comparison test for non-parametric data was performed. *P* values of <0.05 were considered statistically significant.

Results

ATD kinematics and linear and angular head accelerations

When Seoi-nage was executed, the ATD fell forward accompanied by contacting the anterior parietal regions of the head to the tatami. Representative time courses of the linear and angular accelerations in each direction are presented in Fig. 2. The kinematics recorded on video revealed that both the linear and angular accelerations of most axes increased to reach the peak immediately after the contact of ATD's head against the tatami. As for the

linear acceleration, the anterior parietal convexity first contacted the tatami and the contact surface moved to the parietal region, and then the head received the whole-body mass of the thrown ATD in the vertical direction (a_z). Therefore, the linear acceleration of a_z peak was delayed from those along the other axes. For angular acceleration, the values increased sharply and reached peak values at the time of ATD head contact in all rotational axial directions.

Comparison of the acceleration in each axial direction during Seoi-nage

For linear acceleration, the peak a_x ranged from 5.2 to 18.6 G, peak a_y was 4.4 to 23.3 G, and peak a_z was 8.6 to 17.4 G. Linear accelerations in these three directions (11.1 ± 5.7 , 13.7 ± 9.7 , and 13.4 ± 4.7 G, respectively) did not significantly differ ($P = 0.89$; Fig. 3). For angular acceleration, the peak α_x ranged from 310.0 to 1740.2 rad/s², peak α_y was 542.5 to 2653.0 rad/s², and peak α_z was 306.0 to 1,428.7 rad/s². Angular accelerations in these three directions (900 ± 571 , 1525 ± 935 , and 716 ± 452 rad/s², respectively) did neither significantly differ ($P = 0.20$; Fig. 3).

Peak values of the resultant accelerations

For linear acceleration, the peak resultant values were 20.3 ± 9.8 G, ranging from 9.1 to 30.8 G (Table 1). For angular acceleration, the peak resultant values were $1,890.1 \pm 1151.9$ rad/s² ranging from 641.3 to 3195.4 rad/s² (Table 1).

Discussion

Among severe sports-related head injuries, ASDH is a leading cause of death and severe morbidity in

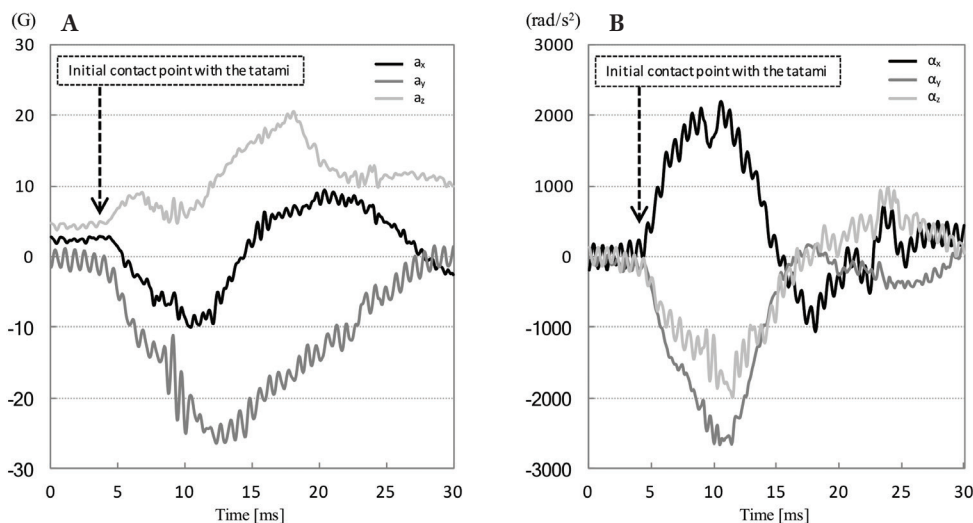


Fig. 2 Representative time courses for the linear (A) and angular (B) accelerations in each direction during Seoi-nage.

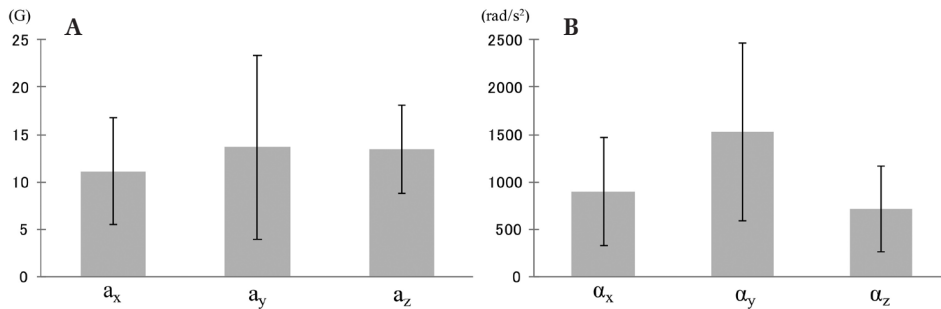


Fig. 3 Peak absolute values of the linear (A) and angular (B) accelerations in each direction during Seoi-nage. * $P < 0.05$, Steel-Dwass test.

Table 1 Peak values of the resultant linear and angular accelerations in Seoi-nage versus other judo techniques investigated in a previous study

	Linear acceleration [G]	Angular acceleration [rad/s ²]
Seoi-nage	20.3 ± 9.8	1890.1 ± 1151.9
Osoto-gari	46.5 ± 3.8	4572.6 ± 357.4
Ouchi-gari	87.9 ± 3.8	2176.0 ± 826.6

* $P < 0.05$, Steel's test. Values for other judo techniques obtained from Murayama et al.⁶⁾

general and particularly in judo, boxing, American football, and snowboarding.¹²⁾ Data from the Japan Sports Council on sports injuries that occurred in Japanese elementary, junior high, and senior high schools from 1998 to 2011 showed that judo was the leading cause of catastrophic head injuries.¹²⁾ To establish effective measures to prevent severe head injuries, we first have to investigate the detailed mechanism of severe head injuries, especially for ASDH.

Regarding the kinematics of the judoka thrown by Seoi-nage, as the ATD moved forward, the anterior parietal head contacted the tatami, and then the body rotated. After the initial contact of the head, as the body continued to move, a large linear acceleration in the vertical direction was maintained than the other directions. In contrast, there was a large angular acceleration in each direction when the head contacted the tatami. No significant differences were noted in linear and angular accelerations between three directions. This phenomenon differs from the head injuries sustained by judokas thrown by Osoto-gari or Ouchi-gari, in which the occipital head of the thrown judoka contacts the tatami and subsequently causes greater linear acceleration in the longitudinal direction and greater angular acceleration in the sagittal plane.⁵⁾

Acute subdural hematoma often occurs due to falls, motor vehicle collisions, and assault, as a result of the head directly impacting a rigid surface.¹³⁾ At the moment of impact, the head undergoes both linear and angular acceleration, and the large angular acceleration plays an important role in the occurrence of ASDH. Therefore, the peak resultant angular

acceleration value shown in the present study is the primary cause of ASDH in judokas thrown by Seoi-nage. Judo-related ASDH predominantly occurs when the judoka is thrown by Osoto-gari, followed by Seoi-nage and Ouchi-gari. The mechanism of ASDH caused by Osoto-gari and Ouchi-gari in which the occipital head of the recipient contacts the tatami is suggested to be due to rupture of the bridging veins. To be concrete, greater angular acceleration in the sagittal plane during the impact of the occipital head causes the elongation and rupture of bridging veins that travel from the surface of the brain to the dural sinuses.^{12,14-21)} However, Seoi-nage produced large angular acceleration in all directions in the present study, which may lead to strains and deformations of the brain surface including temporal and parietal lobes. Subsequent rupture of the cortical vessels possibly with cerebral contusion, as well as the rupture of bridging veins, is the major etiology of ASDH. Previous investigation on ASDH in relation to the origin of the hemorrhage emphasized that ASDHs bled from the cortical vessels shared many characteristics with those from the bridging veins.²²⁾ The present findings suggest that injury of the cortical vessels mainly contribute to the formation of ASDH at the time of head impact in Seoi-nage.

The mean resultant angular acceleration detected in the present study is similar to that detected previously in Ouchi-gari (Table 1). This trend is well accorded with the fact that among the patients with ASDH due to being thrown in judo, the prevalence of injury due to Seoi-nage (15%) is similar to that due to Ouchi-gari (10%).³⁾ Previous studies have revealed the angular acceleration thresholds for the rupture of bridging

veins. The criteria derived from whole-body cadaver tests were a rotational acceleration of greater than 4500 rad/s² and/or a change in angular velocity of greater than 50 rad/s in sagittal plane rotation.²³⁾ According to other cadaver tests, rupture of the bridging veins occurs with a pulse duration of longer than 10 ms and a peak angular acceleration of about 5000 rad/s² at the time of head impact.¹⁶⁾ The angular acceleration values obtained in the present study were slightly lower than these previously reported values; this is the reason why the mechanism of ASDH in the present study is more likely to be rupture of the cortical vessels than rupture of the bridging veins. In future, the angular acceleration values of patients with ASDH should be examined in real-world accidents, as has been done in the study of US football players.¹⁴⁾ As the current study replicates the disruption of the cortical vessels in Seoi-nage, similar injuries may occur in other throwing techniques or in various situations in judo. Therefore, it is important to reproduce the scene of judo throwing and investigate the mechanism of injuries using the ATD.

From the viewpoint of injury prevention, the most important measure is avoidance of direct head contact with the tatami. As shown in current and our previous⁵⁻⁷⁾ study results, the head acceleration sharply increases when the head hits the tatami. In other words, the impact on the head is essential for veins' disruption. If the thrown persons flex their neck and bend their upper body as they rotate in the sagittal plane, their back lands on the tatami and head contact may be avoided. However, if the thrower is not standing but kneeling on the tatami, the thrown persons cannot completely rotate their body and their head may directly contact the tatami. Therefore, Seoi-nage should not be performed when the thrower is kneeling. There is a special rule in Japan for judokas <16 years of age, which prohibits Seoi-nage when the thrower has both knees touching the tatami. Furthermore, Seoi-nage should not be performed to inexperienced judokas. Approximately half of the students who sustained catastrophic head injuries during judo were novice judokas without fully developed physical power and break fall skills (Ukemi).¹²⁾ Thus, Seoi-nage should only be performed to experienced judokas who can perform the Ukemi protection technique in which the head is flexed and one arm is extended horizontally to prevent them from incurring head and neck injuries when they land on their back.

The present study had some limitations. First, the influence of neck movement was not considered. As the contact point of the head and applied acceleration depend on the degree of neck flexion, neck factors may vary kinematics when a judoka is thrown by Seoi-nage. However, the aim of this study was to

mimic the head injury that occurs when the recipient is thrown forward, and to compare the results to those that occur when thrown backward. Therefore, the neck factors were not considered in the present study similar to our previous studies.⁵⁻⁷⁾ The influence of neck flexion or concomitant neck injuries should be investigated biomechanically in future studies. Second, there were only a small number of experimental samples, although our thrower was an expert judoka who had received high-level technical certification (fifth-dan). Because the data had sufficient repeatability with small variability, the small number of experiments was unlikely to influence our findings.

In conclusion, we clarified the kinematics of the head of a person who was thrown forward onto the tatami by Seoi-nage. The large rotational acceleration values in three directions are the likely cause of ASDH at the time of head contact. The mechanism of head injury by Seoi-nage differed from those of other techniques in which the judoka is thrown backward. The most important measure for preventing severe head injuries was avoiding direct head impact to the tatami. We propose that Seoi-nage should not be performed when the thrower is in a low posture with kneeling on the tatami and should not be performed to inexperienced judokas.

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Conflicts of Interest Disclosure

All authors declare that they have no conflicts of interest. Masahiro Ogino is a member of the Japan Neurosurgical Society (JNS) and has registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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