Ukemi Technique Prevents the Elevation of Head Acceleration of a Person Thrown by the Judo Technique ‘Osoto-gari’

Haruo MURAYAMA,1 Masahito HITOSUGI,2 Yasuki MOTOZAWA,3 Masahiro OGINO,4 and Katsuhiro Koyama5

1 Department of Health and Sports Sciences, Premedical Sciences, Dokkyo Medical University School of Medicine, Shimotsuga, Tochigi, Japan;
2 Department of Legal Medicine, Shiga University of Medical Science, Otsu, Shiga, Japan;
3 Department of Mechanical and Precision System, Teikyo University, Utsunomiya, Tochigi, Japan;
4 Department of Neurosurgery, Dokkyo Medical University School of Medicine, Shimotsuga, Tochigi, Japan;
5 Graduate School Department of Interdisciplinary Research, University of Yamanashi, Kofu, Yamanashi, Japan

Abstract

Biomechanical analysis was performed to evaluate the effectiveness of mastering ukemi in preventing severe head injury in judo. One judo expert (tori) threw another judo expert (uke) with a skilled break-fall (ukemi) four times. We obtained kinematic data of uke with a digital video camera. Both translational and rotational accelerations were measured with a six-degree-of-freedom sensor affixed to uke’s forehead. When Osoto-gari was performed, uke fell backward and his arm made contact with the tatami; the translational and rotational accelerations rose to peak values. The peak resultant translational and rotational accelerations were respectively 10.3 ± 1.6 G and 679.4 ± 173.6 rad/s² (mean ± standard deviation). Furthermore, when comparing the values obtained for the judo experts with those obtained using an anthropomorphic test device (ATD: the POLAR dummy) that did not perform ukemi, both the peak resultant translational (P = 0.021) and rotational (P = 0.021) accelerations of uke were significantly lower than those for the ATD, whose head struck the tatami. Additionally, there was no significant difference among the three axis directions for either translational (aₓ: 7.4 ± 0.2, aᵧ: 8.5 ± 2.1, aₐ: 7.2 ± 0.8 G) or rotational (αₓ: 576.7 ± 132.7, αᵧ: 401.0 ± 101.6, αₐ: 487.8 ± 66.6 rad/s²) acceleration. We confirmed that performing correct ukemi prevented the elevation of head acceleration by avoiding head contact with the tatami when a judoka is thrown by Osoto-gari. Judoka should therefore undertake intensive practice after they have acquired ukemi skills.

Key words: head injury, head hitting, head acceleration, biomechanics, ukemi

Received February 18, 2020; Accepted March 30, 2020

Copyright © 2020 by The Japan Neurosurgical Society This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives International License.
“Before practicing throwing techniques or engaging in randori, it is imperative to master ukemi”. Likewise, judo specialists and researchers have suggested that it is essential to learn ukemi appropriately to prevent head injury in judo. Indeed, ukemi has been developed to prevent the head striking the judo mat (tatami) and minimize the damaging effect of a fall. Notwithstanding the highlighting of the importance of mastering ukemi in preventing severe head injury, the impact-reducing effect of ukemi on the head of the thrown person has not been clearly quantified.

Osoto-gari has been reported to be the most common throwing technique causing severe head injuries, followed by ouchi-gari and seoi-nage, in judo. In previous studies, we biomechanically examined the head acceleration of an anthropomorphic test device (ATD), namely the POLAR dummy, which is a pedestrian dummy used in vehicle crash testing) when the head strikes the tatami after being thrown by the three techniques listed above. The results are for falls without ukemi and they are compared with those for a judo expert falling with good ukemi ability in the present paper. We thus evaluate the effectiveness of mastering ukemi biomechanically in preventing severe head injury in judo.

Materials and Methods

Experiment on the judo throwing technique

A male judo expert as a thrower (tori: age, 29 years; height, 177 cm; weight, 90 kg; fifth-dan) repeatedly and accurately threw another male judo expert as a faller (uke: age, 32 years; height, 172 cm; weight, 90 kg; fifth-dan) (Fig. 1). The same tori who executed the throw of the ATD in our previous study participated in the present study. The participants gave written informed consent prior to perform the experiment, and the study protocol was approved by the Research Ethics Committee of the Dokkyo Medical University School of Medicine.

In Osoto-gari, the thrower (tori) breaks the faller’s (uke’s) balance to the rear or right/left rear corner, then reaps up uke’s right/left leg, which carries uke’s weight, to throw uke backward. The present study examined Osoto-gari because ASDH in judo is far most commonly caused by this throwing technique.

On the day of the experiment, tori threw uke four times using Osoto-gari correctly. Uke implemented ukemi adequately without hitting his head against the tatami in all trials.

Biomechanical measurement

A six-degree-of-freedom (DOF) sensor array comprising three accelerometers and three angular rate sensors (DTS 6DX PRO, Diversified Technology Systems, Inc., Seal Beach, CA, USA) was mounted on the center of uke’s forehead and fixed with self-adhesive tape (Fig. 2). All data were recorded at a sampling rate of 10 kHz. We measured translational accelerations of the head with CFC180 filtering. The translational acceleration of the head was obtained in each direction; i.e., \(a_x\) (longitudinal), \(a_y\) (lateral), and \(a_z\) (vertical). The translational resultant acceleration \((a_r)\) was then calculated as \(a_r = (a_x^2 + a_y^2 + a_z^2)^{1/2}\). We calculated the rotational acceleration from the
angular rate with CFC60 filtering by differentiating the filtered data. The rotational acceleration values of the head were obtained in the $\alpha_x$ direction along the anterior–posterior axis (coronal plane rotation), $\alpha_y$ direction along the medial–lateral axis (sagittal plane rotation), and $\alpha_z$ direction along the superior–inferior axis (horizontal plane rotation). The rotational resultant acceleration ($\alpha_r$) was then calculated as $\alpha_r = (\alpha_x^2 + \alpha_y^2 + \alpha_z^2)^{1/2}$. The peak absolute value was taken for each acceleration measurement. According to the head acceleration diagram for each test, the peak acceleration is defined as the value at which the acceleration did not decrease for at least 3 ms.\(^{18}\)

Kinematic data of uke’s whole-body movements were recorded during all trials using a digital video camera (HDR-PJ590, Sony Corporation, Tokyo, Japan) at a sampling rate of 60 Hz.

**Statistical analysis**

Results are presented as mean ± standard deviation. Kruskal–Wallis tests were conducted to compare the peak acceleration values in each direction for the judo expert using ukemi. A multiple comparison test for non-parametric data was performed when a significant difference was observed among the acceleration values in the three directions in a Steel–Dwass test. \(P\)-values <0.05 were considered statistically significant.

The peak resultant accelerations obtained for the judo expert versus those obtained for the ATD in our previous study were compared in a Mann–Whitney test. Differences with a \(P\)-value <0.05 were considered significant.

**Results**

**Kinematics of the expert during ukemi**

When Osoto-gari was performed accurately by tori with a proficient throwing technique, uke was thrown backward onto the tatami with the contacting arm, shoulder, buttocks, and back striking the tatami in order, without the head striking the tatami. Representative time courses of the three-axis resultant translational and rotational accelerations are shown in Fig. 3. Although uke’s head swayed around the neck under the effect of the body contacting the tatami, it avoided colliding with the tatami through the proficient execution of ukemi, and thereby neither the translational nor rotational head acceleration increased noticeably (Fig. 3). Along with the kinematic data, both accelerations increased from when the arm struck the tatami and reached a maximum value when the head placed the lowest position from the tatami surfaces.

**Accelerations obtained in each of the three directions**

In the case of translational acceleration, the peak $a_x$ ranged from 7.2 to 7.6 G, the peak $a_y$ ranged from 6.7 to 10.7 G, and the peak $a_z$ ranged from 6.4 to 8.2 G. The translational accelerations in the three directions (7.4 ± 0.2, 8.5 ± 2.1, and 7.2 ± 0.8 G,}

![Fig. 3](image_url) Representative time courses of the resultant translational and rotational accelerations during Osoto-gari.
respectively) did not significantly differ \((P = 0.87,\) Table 1). For the rotational acceleration, the peak \(\alpha_x\) ranged from 449.1 to 721.4 rad/s\(^2\), the peak \(\alpha_y\) ranged from 306.8 to 515.4 rad/s\(^2\), and the peak \(\alpha_z\) ranged from 403.0 to 565.8 rad/s\(^2\). The rotational accelerations in the three directions \((576.7 \pm 132.7, 401.0 \pm 101.6, \text{ and } 487.8 \pm 66.6 \text{ rad/s}^2, \text{ respectively})\) did not significantly differ \((P = 0.55,\) Table 1).

### Peak resultant accelerations and comparison with ATD results

The peak resultant translational accelerations were \(10.3 \pm 1.6\) G, ranging from 8.9 to 12.3 G (Fig. 4).

#### Table 1  Peak absolute value of translational and rotational accelerations for each direction in Osoto-gari; expert and ATD investigated in a previous study

| Translational acceleration (G) | Expert  | ATD      |
|-------------------------------|---------|----------|
| \(a_x\)                      | 7.4 ± 0.2 | 41.0 ± 5.2 * |
| \(a_y\)                      | 8.5 ± 2.1 | 19.2 ± 6.3 * |
| \(a_z\)                      | 7.2 ± 0.8 | 18.7 ± 1.4 |

| Rotational acceleration (rad/s\(^2\)) | Expert  | ATD      |
|-------------------------------------|---------|----------|
| \(\alpha_x\)                     | 576.7 ± 132.7 | 1760.3 ± 553.9 * |
| \(\alpha_y\)                     | 401.0 ± 101.6 | 3315.2 ± 335.7 |
| \(\alpha_z\)                     | 487.8 ± 66.6 | 2224.5 ± 207.3 |

\(^*P<0.05,\) Steel–Dwass test. ATD data obtained from Hitosugi et al.\(^9\). ATD: anthropomorphic test device.

The peak resultant rotational acceleration values were \(679.4 \pm 173.6\) rad/s\(^2\), ranging from 538.8 to 896.9 rad/s\(^2\) (Fig. 4).

When comparing the data of the judo expert with those of the ATD in our previous report,\(^10\) both the peak translational \((P = 0.021)\) and rotational \((P = 0.021)\) accelerations of the judo expert were significantly lower than those of the ATD (Fig. 4).

### Discussion

In judo, head injury is less common than other injuries (e.g., injuries to the knee, shoulder, and fingers),\(^19\) having an occurrence of 2.44 cases per 100,000 judoka per year, but still tends to be more serious.\(^3\) Approximately 70% of severe head injuries have occurred when a judoka is thrown by Osoto-gari while approximately 60% of ASDH in judo has been caused by occipital head striking of the tatami.\(^3\) These situations might readily occur if the judoka cannot perform ukemi accurately. Although the cause of severe head injuries is considered to be an insufficient ability to perform ukemi\(^3,4,9–12,20\) to the best of our knowledge, no detailed studies have confirmed the preventive effects of ukemi for serious head injuries biomechanically.

In the present study, both peak resultant translational and rotational accelerations of the judo expert were small owing to the avoidance of head contact through the skilled execution of ukemi. In our previous study with the ATD not performing ukemi (Fig. 4), there was occipital head impact with the tatami immediately after the ATD was thrown.

Fig. 4  Comparison of the peak resultant translational (A) and rotational (B) accelerations between the case of the judo expert and the case of an anthropomorphic test device (ATD) during Osoto-gari \((\ast P<0.05,\) Mann–Whitney test). ATD values were obtained from Murayama et al.\(^10\).
by Osoto-gari. Subsequently, there was a significant difference between values for the judo expert and ATD. The present study therefore clarified that ukemi effectively prevents high head acceleration due to contact with the tatami. Furthermore, previous reports suggested head injury thresholds; i.e., a 75% risk of mild traumatic brain injury corresponds to a translational acceleration of 98 G\(^2\)\(^{21}\) while there is a limit for concussion of rotational acceleration of 4500 rad/s\(^2\)\(^{22}\). The values obtained in the present study were much lower than these values.

We also found that there were no significant differences among the three axis directions for both translational and rotational accelerations (Table 1). Avoiding the striking of the head on the tatami through the skilled execution of ukemi, therefore, resulted in no high acceleration in any axis direction following Osoto-gari. These results differ from those of the ATD experiments that showed higher translational acceleration in the longitudinal direction and/or higher rotational acceleration in the sagittal plane direction with the head hitting the tatami, which might lead to higher strains on the bridging veins\(^{22-29}\) (Table 1).

Regarding the kinematics of the judo expert thrown by Osoto-gari, although the head swayed around the neck without contact with the tatami, neither translational nor rotational acceleration noticeably increased (Fig. 3). To avoid the head striking the tatami, the judoka is required to maintain neck flexion while being thrown backward. It is therefore important to strengthen the neck muscle in mastering ukemi. The avoidance of the head striking the tatami through ukemi in the present results might partly depend on the strength of the neck muscle. However, scientific evidence for this dependence has not yet been obtained.\(^7\) Further research may clarify the effect of training the neck muscle in terms of preventing head contact with the tatami.

In Japan, concerned about the occurrence of serious head injuries, the All Japan Judo Federation first published the textbook entitled Judo Safety Instructions in 2006. The third edition of the book, published in 2011, specifically described the prevention and response to serious head and neck injuries.\(^2\) As described in the textbook, it is indispensable to teach ukemi correctly worldwide.

Our study has limitations. First, the six-DOF sensor was placed at the center of uke’s forehead. In the previous study using the ATD, the sensor was placed at the center of gravity within the head of the POLAR dummy.\(^{16}\) However, it is not feasible to position a sensor inside the head of a living human. The distance between the center of the forehead and center of gravity of the head was small, and we consider that this limitation did not seriously affect our findings. In future work, we will aim to clarify differences in values obtained between the forehead and the head’s center of gravity. Second, although the skilled execution of ukemi was shown to be an effective preventive measure, it has been pointed out that increasing the neck muscle strength along with acquiring ukemi skill is important in preventing head injury in judo.\(^7\) However, the current study did not examine the relationship between the neck strength and the skilled execution of ukemi. In future work, the strength of neck muscles and the quality of ukemi will be clarified. Finally, we repeated a few experimental trials. Our designated judo experts were highly skilled (being fifth-dan) and the throw was repeated with high reproducibility. Results deviated only slightly and we thus consider the results to be highly reliable.

In conclusion, the most important measure in preventing severe head injury is avoiding the head striking the tatami through the skilled execution of ukemi. Thus, novice judoka should not undertake intensive practice (e.g., randori\(^{30}\) which is the practice of actual offence and defense involving free movements with an opponent) until they have acquired skills in ukemi.

Acknowledgments

The authors gratefully acknowledged Honda R&D (Tochigi, Japan) for their support for the experiment. This study was supported by a Grant-Aid for Scientific Research (C) from the Ministry of Education, Culture, Sports, Science, and Technology, Japan (16K01730).

Conflicts of Interest Disclosure

No authors have conflicts of interest. Masahiro Ogino, who is a member of the Japan Neurosurgical Society (JNS), has registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

References

1) Pierantozzi E, Muroni R: Judo high level competitions injuries. Medit J Musc Surv 17: 26–29, 2009
2) All Japan Judo Federation: The safety instruction of judo, 4th edition. Tokyo, All Japan Judo Federation, 2015 (in Japanese)
3) Kamitani T, Nimura Y, Nagahiro S, Miyazaki S, Tomatsu T: Catastrophic head and neck injuries in judo players in Japan from 2003 to 2010. Am J Sports Med 41: 1915–1921, 2013
4) Nagahiro S, Mizobuchi Y, Hondo H, et al.: Severe head injuries during judo practice. No Shinkei Geka 39: 1139–1147, 2011 (in Japanese)
5) Kano J: Kodokan judo. Tokyo, Kodansha International, 1994
6) Inokuma I, Sato N: Best judo. Tokyo, Kodansha international, 1986
7) Kamitani T, Malliaropoulos NG, Omiya M, Otake Y, Inoue K, Onidani N: On the way to the Tokyo Summer Olympic Games (2020). Prevention of severe head and neck injuries in judo: it’s time for action. Br J Sports Med 51: 1581–1582, 2017
8) Hashimoto T, Ishii T, Okada N, Itoh M: Impulsive force on the head during performance of typical ukemi techniques following different judo throws. J Sports Sci 33: 1356–1365, 2015
9) Hitosugi M, Murayama H, Motozawa Y, Ishii K, Ogino M, Koyama K: Biomechanical analysis of acute subdural hematoma resulting from judo. Biomed Res 35: 339–344, 2014
10) Murayama H, Hitosugi M, Motozawa Y, Ogino M, Koyama K: Rotational acceleration during head impact resulting from different judo throwing techniques. Neurol Med Chir (Tokyo) 54: 374–378, 2014
11) Nishimura K, Fujii K, Maeyama R, Saiki I, Sakata S, Kitamura K: Acute subdural hematoma in judo practitioners—report of four cases. Neurol Med Chir (Tokyo) 28: 991–993, 1988
12) Hirakawa K, hashizume K, Fuchinoue T, Nakamura N: Patterns of cranioencephalic injuries caused by sports. No Shinkei Gaisho 3: 579–586, 1971 (Japanese)
13) Norton ML, Cutler P: Injuries related to the study and practice of judo. J Sports Med Phys Fitness 5: 149–151, 1965
14) Murayama H, Hitosugi M, Motozawa Y, Ogino M, Koyama K: Simple strategy to prevent severe head trauma in Judo. Neurol Med Chir (Tokyo) 53: 580–584, 2013
15) Murayama H, Hitosugi M, Motozawa Y, Ogino M, Koyama K: Biomechanical analysis of the head movements of a person thrown by the judo technique ‘Seoi-nage’. Neurol Med Chir (Tokyo) 60: 101–106, 2020
16) Akiyama A, Okamoto M, Rangarajan N: Development and application of the new pedestrian dummy. ESV Papers 463: 1–12, 2001
17) Daigo T: Kodokan judo throwing techniques. Tokyo, Kodansha International, 2005
18) Schmitt K, Niederer P, Muser M, Walz F: Trauma biomechanics: an introduction to injury biomechanics, 5th edition. Heidelberg, Springer, 2019
19) Poccio E, Ruedl G, Stankovic N, et al.: Injuries in judo: a systematic literature review including suggestions for prevention. Br J Sports Med 47: 1139–1143, 2013
20) Koshiba S, Ishii T, Matsuda T, Hashimoto T: Kinetematics of judo breakfast for osoto-gari: Considerations for head injury prevention. J Sports Sci 35: 1059–1065, 2017
21) King AI, Yang KH, Zhang L, Hardy W, Viano DC: Is head injury caused by linear or angular acceleration? Proceedings of the IRCOBI Conference (Vol. 12). Lisbon, 2003, 1–12
22) Ommaya AK, Goldsmith W, Thibault L: Biomechanics and neuropathology of adult and paediatric head injury. Br J Neurosurg 16: 220–242, 2002
23) Forbes JA, Zuckerman S, Abla AA, Mocco J, Bode K, Eads T: Biomechanics of subdural hemorrhage in American football: review of the literature in response to rise in incidence. Childs Nerv Syst 30: 197–203, 2014
24) Nagahiro S, Mizobuchi Y: Current topics in sports-related head injuries: a review. Neurol Med Chir (Tokyo) 54: 878–886, 2014
25) Depreitere B, Van Lierde C, Sloten JV, et al.: Mechanics of acute subdural hematomas resulting from bridging vein rupture. J Neurosurg 104: 950–956, 2006
26) Kleiven S: Influence of impact direction on the human head in prediction of subdural hematoma. J Neurotrauma 20: 365–379, 2003
27) Huang HM, Lee MC, Chiu WT, Chen CT, Lee SY: Three-dimensional finite element analysis of subdural hematoma. J Trauma 47: 538–544, 1999
28) Gennarelli TA, Thibault LE: Biomechanics of acute subdural hematoma. J Trauma 22: 680–686, 1982
29) Ommaya AK, Gennarelli TA: Cerebral concussion and traumatic unconsciousness. Correlation of experimental and clinical observations of blunt head injuries. Brain 97: 633–654, 1974
30) Matsumoto D: An introduction to Kodokan judo: history and philosophy. Tokyo, Hon-No-Tomosha, 1996

Address reprint requests to: Haruo Murayama, PhD, Department of Health and Sports Sciences, Premedicaal Sciences, Dokkyo Medical University School of Medicine, 880 Kita-kobayashi, Mibu, Tochigi 321-0293, Japan.
e-mail: hmurayam@dokkyomed.ac.jp