

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 Katsuhiko KOYAMA⁵

¹Department of Health and Sports Sciences, Premedical Sciences, Dokkyo Medical University School of Medicine, Shimotsuga, Tochigi, Japan;

²Department of Legal Medicine, Shiga University of Medical Science, Otsu, Shiga, Japan;

³Department of Mechanical and Precision System, Teikyo University, Utsunomiya, Tochigi, Japan;

⁴Department of Neurosurgery, Dokkyo Medical University School of Medicine, Shimotsuga, Tochigi, Japan;

⁵Graduate 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 \pm 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 (α_x : 7.4 ± 0.2 , α_y : 8.5 ± 2.1 , α_z : 7.2 ± 0.8 G) or rotational (α_x : 576.7 ± 132.7 , α_y : 401.0 ± 101.6 , α_z : 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

Introduction

Judo is practiced in many countries around the world. The skill level of judoka has markedly increased along with the rate and severity of injuries since judo was first included at the Olympic Games.¹ In contrast, studies have suggested the number of severe

head injuries in judo decreases as the skill level of judoka expands.² However, serious head injuries, especially acute subdural hematoma (ASDH), have occasionally occurred in judo.^{3,4}

In Japan, many judokas younger than 20 years old, especially those in the first year of junior high school or high school, have suffered serious head injuries.^{3,4} Additionally, most head injuries have involved novices (i.e., judokas who have trained in judo for <36 months).³ These injuries were attributed to the deficient skills of novices in a break-fall technique called ukemi. The importance of ukemi was pointed out in a text-book written by the founder of judo, Jigoro Kano⁵:

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“Before practicing throwing techniques or engaging in randori, it is imperative to master ukemi”. Likewise, judo specialists⁶⁾ and researchers^{4,7–13)} 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.^{3,4)} In previous studies,^{9,10,14,15)} we biomechanically examined the head acceleration of an anthropomorphic test device (ATD), namely the POLAR dummy,¹⁶⁾ 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.^{9,10,14)} 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.¹⁷⁾ The present study examined Osoto-gari because ASDH in judo is far most commonly caused by this throwing technique.^{3,4)}

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

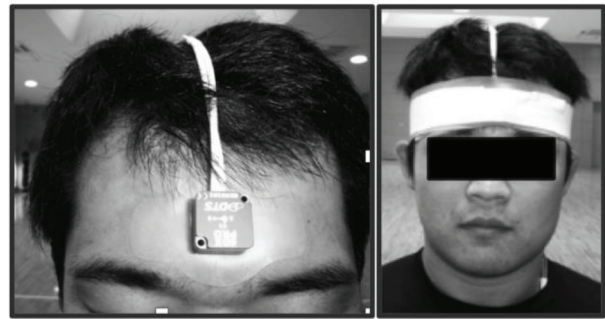


Fig. 2 Images of a six-DOF sensor location/situation on uke’s forehead. The sensor is 19 mm in width, 19 mm in length, and 14.5 mm in height. DOF: degree-of-freedom.



Fig. 1 Serial images (from a to d) of Osoto-gari technique. The thrower (tori: dressed in white) throws the faller (uke: dressed in black) whose ukemi technique is excellent. Both participants are judo experts.

angular rate with CFC60 filtering by differentiating the filtered data. The rotational acceleration values of the head were obtained 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 plane rotation). The 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 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 \pm 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,

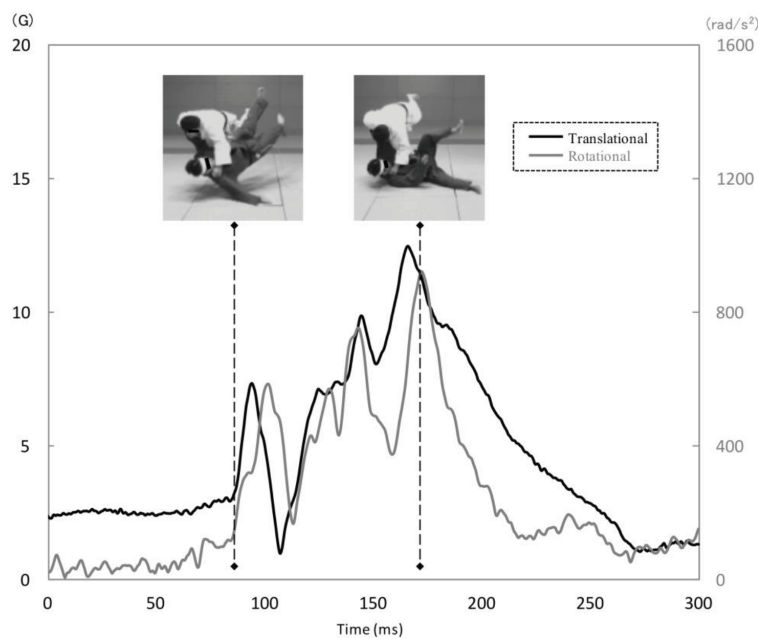


Fig. 3 Representative time courses of the resultant translational and rotational accelerations during Osoto-gari.

respectively) did not significantly differ ($P = 0.87$, Table 1). For the rotational acceleration, the peak α_x ranged from 449.1 to 721.4 rad/s², the peak α_y ranged from 306.8 to 515.4 rad/s², and the peak α_z ranged from 403.0 to 565.8 rad/s². The rotational accelerations in the three directions (576.7 ± 132.7 , 401.0 ± 101.6 , and 487.8 ± 66.6 rad/s², 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 ± 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
α_x	7.4 ± 0.2	$41.0 \pm 5.2^*$
α_y	8.5 ± 2.1	$19.2 \pm 6.3^*$
α_z	7.2 ± 0.8	18.7 ± 1.4
Rotational acceleration (rad/s ²)	Expert	ATD
α_x	576.7 ± 132.7	$1760.3 \pm 553.9^*$
α_y	401.0 ± 101.6	3315.2 ± 335.7
α_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 ± 173.6 rad/s², ranging from 538.8 to 896.9 rad/s² (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

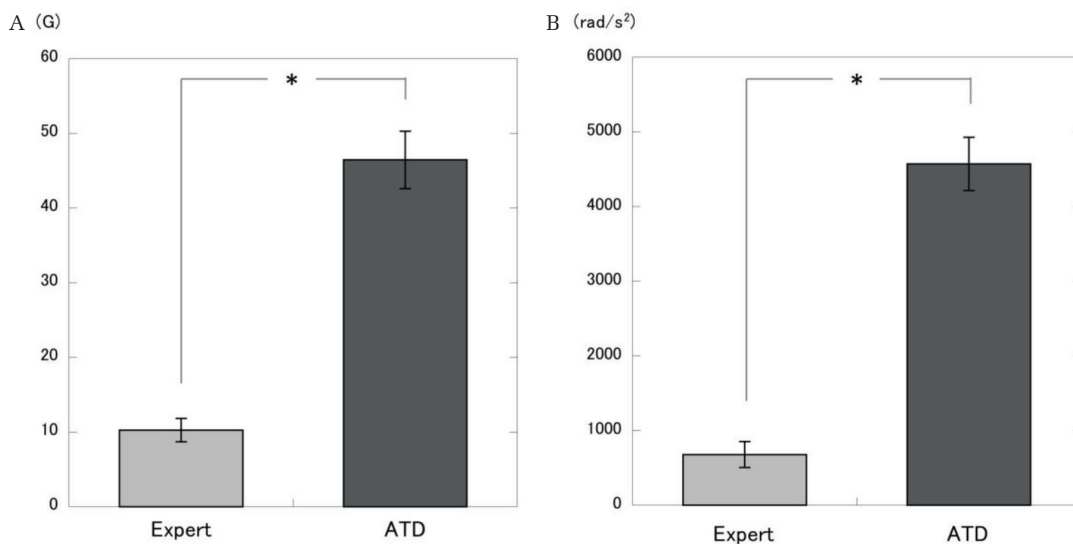


Fig. 4 Comparison of the peak resultant translational (A) and rotational (B) accelerations between the case of the judo expert and the case of an anthropomorphic test device (ATD) during Osoto-gari (* $P < 0.05$, Mann–Whitney test). ATD values were obtained from Murayama et al.¹⁰.

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 $98 G^{21)}$ 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.

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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.

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