

# Rotational Acceleration during Head Impact Resulting from Different Judo Throwing Techniques

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## Abstract

Most severe head injuries in judo are reported as acute subdural hematoma. It is thus necessary to examine the rotational acceleration of the head to clarify the mechanism of head injuries. We determined the rotational acceleration of the head when the subject is thrown by judo techniques. One Japanese male judo expert threw an anthropomorphic test device using two throwing techniques, Osoto-gari and Ouchi-gari. Rotational and translational head accelerations were measured with and without an under-mat. For Osoto-gari, peak resultant rotational acceleration ranged from 4,284.2 rad/s<sup>2</sup> to 5,525.9 rad/s<sup>2</sup> and peak resultant translational acceleration ranged from 64.3 g to 87.2 g; for Ouchi-gari, the accelerations respectively ranged from 1,708.0 rad/s<sup>2</sup> to 2,104.1 rad/s<sup>2</sup> and from 120.2 g to 149.4 g. The resultant rotational acceleration did not decrease with installation of an under-mat for both Ouchi-gari and Osoto-gari. We found that head contact with the tatami could result in the peak values of translational and rotational accelerations, respectively. In general, because kinematics of the body strongly affects translational and rotational accelerations of the head, both accelerations should be measured to analyze the underlying mechanism of head injury. As a primary preventative measure, throwing techniques should be restricted to participants demonstrating ability in ukemi techniques to avoid head contact with the tatami.

Key words: head injury, judo, prevention, head acceleration, biomechanics

## Introduction

Head injuries are common in sports. The United States Centers for Disease Control and Prevention estimated that there are as many as 300,000 sports-related mild traumatic brain injuries annually.<sup>1,2)</sup> Judo originated from Japan and has become an Olympic event, and is widely used in schools or public facilities for educational, training, and recreational purposes around the world. However, severe head or neck injuries can result from practicing judo because participants fall and are thrown. In Japan, according to the revised government guidelines for teaching published by the Ministry of Education, Culture, Sports, Science and Technology, junior high school students are required to practice budo (Japanese traditional martial arts including judo, kendo, sumo, and so

on) as a class in school. Judo has been introduced into more than 60% of junior high schools, and more students are suspected to suffer from head injuries in practicing judo.

Recently, we biomechanically examined the mechanisms of head injuries in judo.<sup>3)</sup> The study revealed that if the recipient (uke) could not avoid head contact by responding adequately to the attack, the head underwent high translational acceleration when it occipitally struck the judo mat (tatami). Therefore, to reduce the impact force to the head, the installation of an under-mat was proposed. However, in real-world activities, isolated translational acceleration seems unlikely. Rotational acceleration is suspected to play a major role in some head injury mechanisms and therefore receives considerable attention.<sup>4)</sup> Recently, in Japan, most severe head injuries in judo have been reported as acute subdural hematoma (ASDH).<sup>5)</sup> Because a rotational force applied to the head strongly contributes to the occurrence of ASDH, it

is necessary to examine the rotational acceleration of the head in clarifying the mechanisms of head injuries in judo.

In this study, building on the previous research, we determined the rotational acceleration of the head of the uke thrown by judo techniques. The effect of an under-mat was also examined and we considered comprehensive preventive measures with which to prevent severe head injuries.

## Materials and Methods

### I. Judo practice

One Japanese male judo expert (26 years old, height of 177 cm, mass of 90 kg, black belt with fifth dan) repeatedly threw an anthropomorphic test device (ATD). Prior to the test, informed consent was obtained. Moreover, the study protocol was approved by the Research Ethics Committee of the Dokkyo Medical University School of Medicine.

The ATD used was a POLAR dummy with a height of 175 cm, mass of 75 kg, and high biofidelity.<sup>6,7)</sup> Because most ASDHs occur when the subject is thrown by the Osoto-gari or Ouchi-gari techniques,<sup>5)</sup> these two throwing techniques were considered in the present study.

In Osoto-gari, the thrower (tori) breaks the recipient's (uke's) balance toward the uke's rear corner and then reaps the uke's leg; these forces produce a motion of the body of the uke in the rotational sagittal plane that throws the uke backward (Fig. 1). In Ouchi-gari, the tori pushes the uke straight back and then reaps the uke's leg from the inside with his/her leg so that the uke falls onto his/her back (Fig. 2).

On the test day, the tatami (SV230; Hayakawa Textile Industries Co., Ltd., Osaka) was laid on a concrete floor. The expert then threw the ATD eight times using the Osoto-gari ( $n = 4$ ) and Ouchi-gari ( $n = 4$ ) techniques. Following these throws, a synthetic sponge mat (under-mat) having a thickness of 60 mm and consisting of urethane foam rubber and a polyethylene sheet (AM2202; Senoh Corporation., Chiba) was laid under the tatami. According to the industrial standard, the deformation of the mat was determined to be from 10 to 20 mm when a static compressive load of 200 N was applied to it. The throwing protocol was then repeated.

### II. Measurement of biomechanical parameters

Translational acceleration was measured by a tri-axial accelerometer. From the accelerations obtained in each direction, the resultant acceleration was

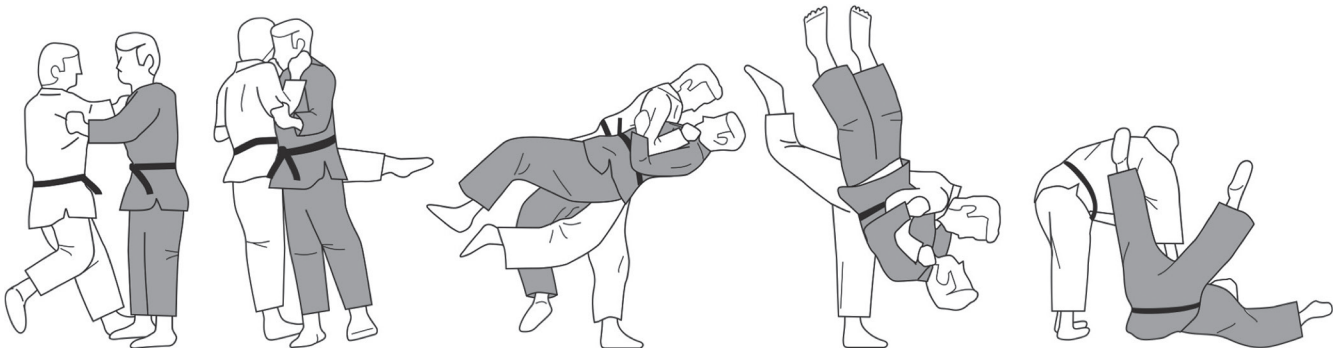


Fig. 1 Illustration of the Osoto-gari throw.



Fig. 2 Illustration of the Ouchi-gari throw.

calculated as described in our previous report.<sup>3)</sup> The resultant rotational acceleration was calculated from the measurements of three-degree-of-freedom rotational accelerometers. These accelerometers were mounted at the center of the gravity of the ATD head. The data were recorded using a high-speed data acquisition system, which could sample at 20 kHz, and filtered using a Channel Class 1,000 filter. The ATD kinematics data were obtained using a high-speed digital video camera recording at 1,000 frames per second.

### III. Statistical analysis

The accelerations obtained without the under-mat versus those obtained with the under-mat were compared in a Mann-Whitney test. Differences with a *p* value of < 0.05 were considered significant.

## Results

### I. ATD kinematics and acceleration

When Ouchi-gari or Osoto-gari was performed, the dummy fell backwards with the occipital area of the skull contacting the tatami. Representative time courses of the resultant translational and rotational accelerations presented in Figs. 3 and 4 and kinematics obtained by the video camera were found to correspond. Peak resultant translational and rotational accelerations were observed when the occipital area of the head came in contact with the tatami. According to the head acceleration diagrams for each test, the peak resultant acceleration was defined as the maximum value below which the acceleration did not fall for at least 3 ms.<sup>4)</sup> For Osoto-gari, the peak resultant rotational acceleration ranged from 4,284.2 to 5,525.9 rad/s<sup>2</sup> and the peak resultant translational acceleration from 64.3 g to 87.2 g. For Ouchi-gari,

the peak resultant rotational acceleration ranged from 1,708.0 to 2,104.1 rad/s<sup>2</sup> and the peak resultant translational acceleration from 120.2 g to 149.4 g.

### II. Comparison of accelerations

The average peak values of the resultant translational and rotational accelerations when using the under-mat for each throwing technique are summarized in Table 1. With or without an under-mat, average peak values (mean ± standard deviation) of the resultant translational acceleration were tend to higher for Ouchi-gari than for Osoto-gari; however, average peak values of the resultant rotational acceleration were adversely higher for Osoto-gari.

When the under-mat was installed, the peak values of resultant translational acceleration were significantly less for both Ouchi-gari (*p* = 0.021) and Osoto-gari (*p* = 0.021) as shown in our previous report.<sup>3)</sup> However, the resultant rotational acceleration did not decrease with the installation of the under-mat for Ouchi-gari. Additionally, the mean peak resultant rotational acceleration did not decrease significantly for Osoto-gari (*p* = 0.29).

## Discussion

Annually, emergency departments in the United States treat an estimated 135,000 sports- and recreation-related traumatic brain injuries among individuals aged 5–18 years.<sup>8)</sup> Among youth practicing martial arts, if exposure time is taken into account, cerebral concussion in judo occurs in 2.38/1,000 athlete-exposures for boys and 2.92/1,000 athlete-exposures for girls.<sup>9)</sup> Because head injuries to young judo participants sometimes lead to life-threatening, long-term disability or cognitive impairment, it is necessary to understand the detailed head injury

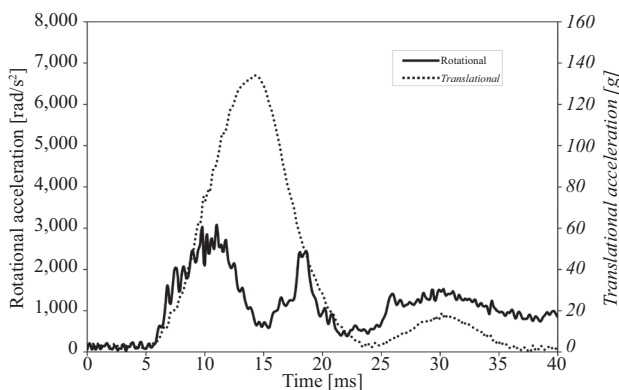


Fig. 3 Representative time course of the peak resultant rotational and translational accelerations of Ouchi-gari (without an under-mat).

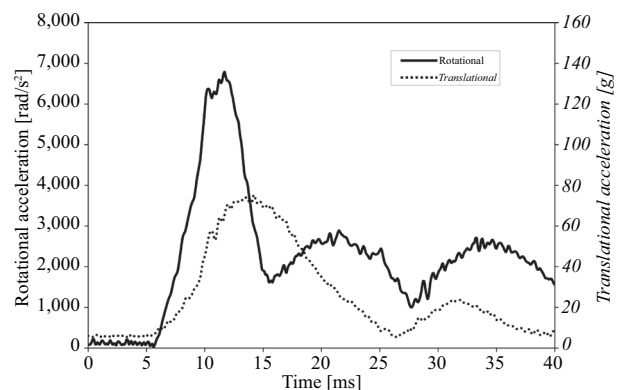


Fig. 4 Representative time course of the peak resultant rotational and translational accelerations of Osoto-gari (without an under-mat).

**Table 1 Comparison of peak resultant rotational and translational accelerations with and without an under-mat in Ouchi-gari and Osoto-gari**

	Peak resultant rotational acceleration (rad/s <sup>2</sup> )	Peak resultant translational acceleration (g)
Ouchi-gari (without an under-mat)	1,960.0 ± 280.1	130.0 ± 13.2
Ouchi-gari (with an under-mat)	2,176.0 ± 826.6	87.9 ± 3.8
Osoto-gari (without an under-mat)	5,081.3 ± 691.8	74.4 ± 9.8
Osoto-gari (with an under-mat)	4,572.6 ± 357.4	46.5 ± 3.8

\*Statistically significant,  $p < 0.05$ . Statistical analysis: Mann-Whitney's U-test. n.s.: not significant.

mechanism in judo to establish an injury prevention strategy.

In research on head injuries, translational acceleration has been used to quantify the external force. The Wayne State Tolerance Curve was developed from a series of tests on animals and human cadavers and relates translational acceleration and the duration of acceleration to injury tolerance.<sup>10)</sup> From that work, metric factors of head injury such as the head injury criterion, which we measured in our previous study,<sup>3)</sup> were proposed. However, these widely used injury metrics only account for translational acceleration. The rapid forceful movement generates a rotational force that may be sufficient to cause injury.<sup>11)</sup> Because rotational acceleration is associated with diffuse axonal injury, concussion, and ASDH, which are common severe head injuries in judo, it is crucial to measure the rotational acceleration in addition to the translational acceleration. Therefore, building on our previous research, we developed a biomechanical approach for investigating judo-associated head injuries.

In the present study, the peak resultant rotational acceleration for Osoto-gari was found to be greater than that for Ouchi-gari, with or without an under-mat. This trend is the opposite of that for the translational acceleration. The discrepancy is due to the difference in the uke's kinematics. In Ouchi-gari, after the leg was reaped, the uke moved straight back and fell, and the occipital area of the uke's head came into contact with the tatami (Fig. 2). In Osoto-gari, when the uke's leg was reaped, his/her body rotated immediately in a standing position and the occipital area of the head came into contact with the tatami with less translational motion (Fig. 1). Therefore, Osoto-gari resulted in higher rotational acceleration and lower translational acceleration. In general, because kinematics of the

body strongly affects translational and rotational accelerations, both accelerations should be measured while analyzing the underlying mechanism of head injury. Evaluating the risk of throwing techniques by comparing only the translational acceleration or rotational acceleration is obviously inadequate.

The present study also found that rotational acceleration was not significantly reduced by inserting an under-mat. This trend is different from that for translational acceleration shown in our previous study.<sup>3)</sup> Although the direct impact force was reduced by the shock-absorbing effect of the under-mat, rapid movement of the brain did not remarkably decrease. Therefore, even if the under-mat is used, more than 4,500 rad/s<sup>2</sup> of rotational acceleration may result from Osoto-gari. In previous reports, rotational acceleration of 6,383 rad/s<sup>2</sup> was proposed as a threshold of concussion for football players,<sup>12)</sup> and a limit of 4,500 rad/s<sup>2</sup> for concussion was suggested by Ommaya.<sup>13)</sup> Therefore, our result confirmed that contact of the uke's head with the tatami can possibly result in severe head injuries including ASDH.

The most important finding of the present study was that an under-mat was not effective in terms of decreasing rotational acceleration. Similar results were obtained in an analysis carried out by Kumar et al. who showed that rotational acceleration was not effectively reduced by the subject wearing a helmet.<sup>14)</sup> The present study also clarified the limitation of a shock absorber. Therefore, avoiding head contact is essential to prevent head injury. In judo, a technique to minimize contact of the head with the tatami and thus prevent injury to the head, neck, and elsewhere is for the uke to have his/her neck flexed forward and an arm horizontally extended when landing on his/her back. This learned technique is part of the ukemi skills and is performed when the uke falls or

is thrown. However, the young beginner or inexperienced person can experience severe head injury if he/she does not perform this technique adequately. Therefore, as a primary measure of injury prevention, participants and especially youths have to master ukemi. Furthermore, as severe head injuries can result if the head of the uke comes into contact with the tatami, throwing techniques have to be restricted to participants demonstrating sufficient ukemi ability.

Finally, we should address the limit of our research. Our experiments do not measure the shearing forces on the bridging veins causing ASDH. However, the shape and structure of individual heads varies from each other, which may largely affect on the incidence of intracranial injuries. Furthermore, because the dummy model employed in our study does not reflect these differences among individuals, our results may not be directly applied for the actual head injuries in judo. Nevertheless, the result provides us informative suggestion that other device, technique, and/or caution will be needed to reduce the rotational acceleration. Advanced researches simulating the actual head injuries will be needed in the future study.

This is the first report to measure both the translational and rotational acceleration of the head in judo. The study considered the two major throwing techniques responsible for head injuries. However, biomechanical parameters for other throwing techniques need to be analyzed in establishing further safety measures in judo.

### Acknowledgments

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### Conflicts of Interest Disclosure

There are no conflicts of interest for all authors. Masahiro Ogino who is member of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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