MEASURING AND ANALYZING THE ANGULAR MOMENTUM PRODUCED IN THE APPLICATION OF THE JUDO THROWING TECHNIQUE OSOTO-GARI

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The purpose of this study was to analyze the angular momentum in the judo throwing technique osoto-gari. Ten male judo athletes participated in this study. The kinematic and kinetic data were collected using a three-dimensional motion capture system and two force plates. We analyzed the resultant angular momentum of a system that includes both the thrower and the faller. The counterclockwise angular momentum continuously increased during the throwing phase, indicating the torque was always acting toward the throwing direction. Our results demonstrated that the angular momentum was associated with the horizontal GRF during the early swing phase and it was associated with the Y-axis moment arm during the late throwing phase.

KEYWORDS: judo, osoto-gari, motion analysis, angular momentum.

INTRODUCTION: Judo, the word meaning 'gentle way' in Japanese, is a modern martial art and combat sport, which emphasis on using the proper techniques and mechanics to achieve maximum efficiency with minimal effort (Melo et al.,2012; Imamura and Johnson,2003). Especially in throwing technique, the thrower (person throwing) needs to grab opponent's judogi (judo uniform), breaking his/her balance by using a series of clever motions such as pushing or pulling with hand and then moving to a position that easy to throw, throw the opponent's body back on the tatami (judo mat) with considerable momentum for an *ippon* score (perfect throw) (Matsumoto,1975). There are many factors based on the laws of mechanics which notably related to throwing performance: the impulse, the momentum, the force, the concept of levers, moment of inertia, etc. (Matsumoto,1975; Ohtaki,1984).
Imamura et al. (2006) stated that the linear momentum of the faller's (person being thrown) center of mass (COM) is useful for analyzing all of the judo techniques. Ishii and Ae (2014) stated that to get an *ippon* score in judo Tachi-Waza, the angular momentum of the faller's body must be generated. They evaluated the thrower's effectiveness of throwing by using the momentum or the angular momentum of the faller's body. Accordingly, this knowledge about the momentum produced in judo was useful for judo athletes and coaches to understand the mechanism and essence of the judo throwing technique and improve their skills and abilities.
Imamura et al. (2007) stated that success in judo is determined by the actions of the opponent as well as oneself. Therefore, both the thrower and the faller must be considered. In this paper, we analyzed osoto-gari, a judo throwing technique in which thrower sweeps the leg to rotate the faller's body, by calculating the angular momentum of a system that includes both thrower and faller, and sought to elucidate the factors of changes in angular momentum from the perspective of mechanics. We hypothesized that the angular momentum of the system turn into throwing direction depends on the change of direction about the Y-axis moment arm.

METHODS: Ten male judo athletes (age: 21.1 ± 2.6 years, height: 173.7 ± 2.5 cm, mass: 80.2 ± 8.5 kg, judo experience: 12.9 ± 2.8 years) participated in the study. The judo athletes belonged to the university's judo team. Fouty-seven reflective markers placed on the thrower and the faller's body landmarks were captured using 8-cameras at 250Hz (Qualisys Track Manager, Qualisys, Sweden). The ground reaction forces (GRFs) were collected using two force plates at 1000Hz (FP4060-10-2000, Bertec, Columbus, U.S.A.).

Figure1: Measurement environment

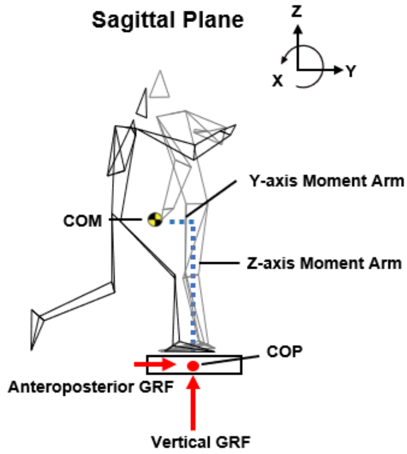

Figure 2: Illustration of the osoto-gari

The faller wore a specially designed judo gear and stood off one of the force plates with no conscious resistance. The thrower preformed osoto-gari throwing with a maximal effort at least eight times. The thrower was instructed to the pivot foot (left foot for a right-handed judoka) step onto the force plate (Figure 1). Before the actual measurement, the participants were allowed to practice osoto-gari to familiarize themselves with the measurement environment. Three-dimensional coordinate data and GRFs data were filtered using a 2nd-order low pass Butterworth filter with cutoff frequencies at 20 Hz and 50 Hz.

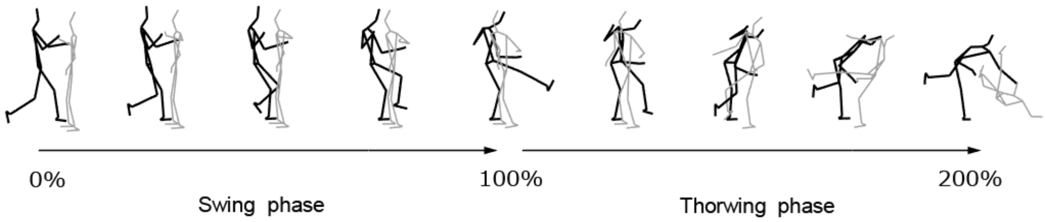

Figure 3: The phase of the osoto-gari

We divided the osoto-gari motion into two phases (Figure 3). The swing phase started when the thrower’s swing leg lifted off the floor, which was identified as the moment that the vertical position of the toe marker was higher than 0.4 m. The end of the swing phase was defined when the thrower’s swing toe marker was at the highest position on the vertical axis. The throwing phase was defined from the finish of the swing phase to the moment that the vertical GRF of the faller was less than 10N. The kinematic and kinetic data were normalized by 100% time of each movement phase.

In this paper, we focused on the sagittal plane (Figure 2) and calculated the following four parameters of which the results.
1: The center of masses (COM) of the thrower and faller were estimated using the 14-segment rigid body model for Japanese athletes (Ae, 1996).
2: The center of pressure (COP) and the forces of the thrower and faller were calculated using two force plates.
3: The moment arm was calculated by the displacement of the resultant COP to resultant COM. The moment arm = (resultant COP - resultant COM).
4: The resultant torque was calculated by the cross product of the moment arm and the resultant force.
5: The resultant angular momentum was calculated by the sum of the thrower and the faller’s segment angular momentum around the resultant COM.

RESULTS: Figure 4 illustrates the time series of the resultant angular momentum and the torque in the sagittal plane (X-axis) about the resultant COM. At the beginning of the swing phase, the clockwise angular momentum and torque, which was opposite to the throwing direction, were observed. Then they turned into counterclockwise (i.e., throwing direction) at the late swing phase.

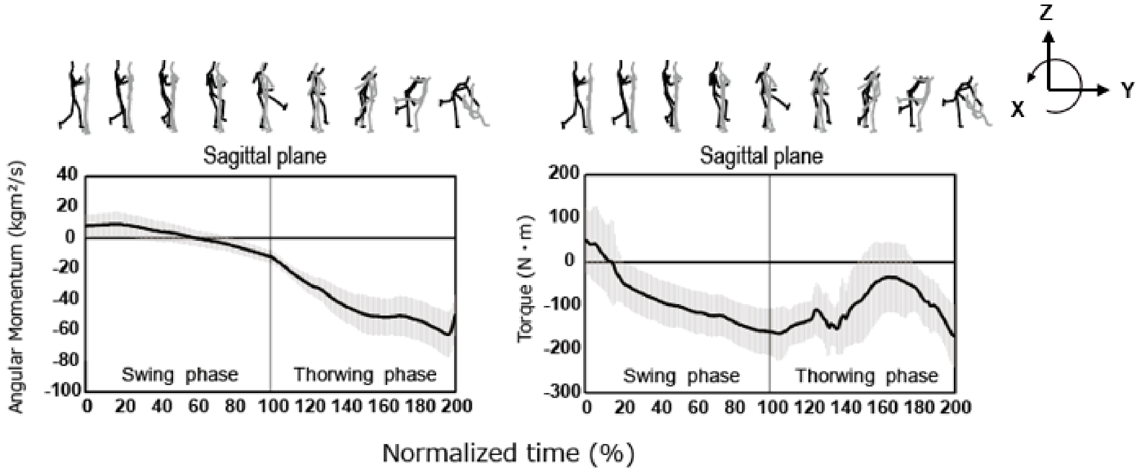

Figure 4: Resultant angular momentum and torque in the sagittal plane. The solid line indicates the inter-subject average and the gray area indicates the standard deviation.

Figure 5 illustrates the time series of the moment arms (Y-axis, Z-axis) and GRFs (anterior-posterior, Vertical) for osoto-gari. The Y-axis moment arm decreased from the positive to the negative, which was consistent with the resultant angular momentum. The Z-axis moment arm stayed constant during the swing phase and it shortened during the throwing phase. The anterior-posterior GRF stayed negative until the middle of the throwing phase, and it quickly turned into positive (i.e., forward for the thrower). The standard deviation of the anterior-posterior GRF showed that the forward force of some judo athletes appeared early. The vertical force changed in a range, with no obvious features.

DISCUSSION: Osoto-gari is a throwing technique in which thrower swept out his/her leg to rotate the faller's body. Therefore, the considerable resultant angular momentum in the sagittal plane must be generated to complete a successful throw. The angular momentum in the sagittal plane was the sum of the two torque terms: $-R_z * F_y + R_y * F_z$, where Ry and Rz were the moment arms in the anterior-posterior and the vertical axis, and Fy and Fz were the anterior-posterior and vertical GRFs.

The results of the present study showed that the clockwise angular momentum (i.e., opposite to the throwing direction) was observed at the beginning of the swing phase. This was due to the thrower's sweeping leg and pulling arm. The throwing angular momentum to the system was provided by the angular torque generated by the anterior-posterior GRF and vertical moment arm. Imamura and Johnson (2003) indicated that two competitors' chest to chest contact is a very important action for osoto-gari. In the present result, the timing of the Y-axis moment arm turning into negative coincides with the timing when the resultant angular momentum turned to counterclockwise. From the kinetic perspective, the chest-to-chest contact may be interpreted as reducing the Y-axis moment arm. Also, this result supports our hypothesis, which stated that the change of the angular momentum in the sagittal plane depends greatly on the Y-axis moment arm.

From the middle of the throwing phase, the counterclockwise angular momentum quickly increased (i.e., to the throwing direction), this was helpful for getting *ippon* score. However, it may not be appearing under a real competitive condition, because the faller's defense could reduce the generation of the angular momentum. At the late throwing phase, the sign of the anterior-posterior GRF turned into positive. This change might be associated with the contact between the thrower's sweeping leg and the faller's leg. The positive horizontal GRF and the vertical moment arm generated the counterclockwise torque (i.e., opposite to the throwing direction) to the system. To continue the system rotating toward the throwing direction, the counterclockwise angular torque must be generated by the other term. Given that the vertical GRF was always positive, it was essential to the Y-axis moment arm being negative. In other words, the location of the resultant COM must exceed the location of the resultant COP.

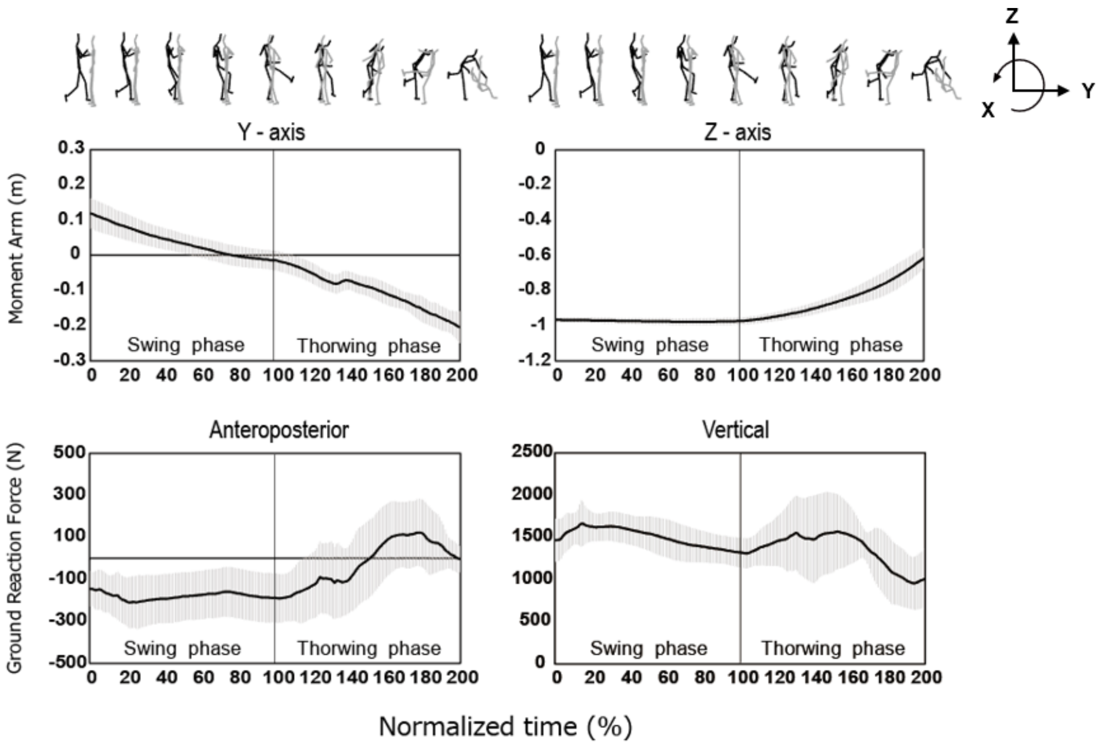

Figure 5: Changes in Y-axis, Z-axis moment arm and anteroposterior, vertical GRF. The solid lines indicate the inter-subject average and the gray areas indicate the standard deviation.

CONCLUSION: In this study, we investigated the changes in the resultant angular momentum for osoto-gari in which both of the thrower and the faller were included in a system. The counterclockwise angular momentum continuously increased during throwing phases, meaning the counterclockwise torque was needed throughout the throwing. It was demonstrated that the counterclockwise torque was associated with the horizontal GRF during the early swing phase and it was associated with the and the Y-axis moment arm during the late throwing phase.

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