Biomechanics of the judo backward breakfall: comparison between experienced and novice judokas

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B Data Collection
C Statistical Analysis
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Abstract

Background & Study Aim: Head injuries sustained during the sport of judo have gained significant public attention because of the incidence of severe cases among novice judokas in Japan. The judo backward breakfall skill may play an important role in decreasing the number of head injuries. Therefore, more effective ways to acquire appropriate judo backward breakfall skills are needed, and this requires a greater understanding of the breakfall movement. The aim of the study was to investigate the kinematics and muscle activation patterns during a judo backward breakfall in experienced and novice judokas.

Material & Methods: Eleven experienced judokas and 13 novice judo judokas volunteered for the study. Three-dimensional kinematic data were collected while participants performed five sets of backward breakfalls. We documented head-, neck-, trunk-, hip and knee-angle time profiles and electromyographic activities of the sternocleidmastoid, external oblique and rectus abdominis muscles during breakfalls.

Results: We found significant difference in the knee joint motion during the judo backward breakfall between the experienced and novice judokas. However, there were no significant differences in the activation patterns of any muscles between the experienced and novice judokas. In addition, the timing of hand impact appeared to coincide with the timing of peak head linear acceleration.

Conclusion: The knee joint movement and the hand impact skill may be important components of the judo backward breakfall motion

Kewwords: electromyography • head injuries • kinematics • martial arts

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Judo backward breakfall – a basic skill to take a fall safely when one was being thrown backward in judo It is also known as *ushiro ukemi*.

Mild traumatic brain injury – brain injuries caused by an external mechanical force such as a bump, blow, or jolt to the head, which possibly leads to permanent or temporary impairment of cognitive, physical, and psychosocial functions of brain.

Osoto-gari – a judo throw that is classified as a foot technique, or *ashi-waza*. Traditional osoto-gari is executed by breaking the opponent balance towards either side of the leg and reaping the leg at the lateral or back of thigh.

Intoroduction

Judo athletes, also known as judokas, may suffer injury to any part of the body during a match and practices [1,2]. In particular, head injuries have attracted significant public attention. Approximately one-third of highly skilled judokas self-reported at least one episode of mild traumatic brain injury (MTBI) during judo activity [3]. Even a mild injury can lead to more serious consequences. In fact, a recent study by Kamitani, et al. [4] reported 30 incidents of severe traumatic brain injuries between 2003 and 2010 in Japanese judokas. This report had a significant influence on Japanese coaches and sports medicine practitioners. Studies also share a common finding that the number of the head injuries is much greater in novice judokas than in experienced judokas. Therefore, judo coaches and sports medicine practitioners need to develop better strategies for the prevention of head injuries, particularly in novice judokas. Importantly, the Ministry of Education, Culture, Sports, Science, and Technology in Japan has made it mandatory to teach Japanese martial arts (including judo) at junior high schools since 2012. Therefore, measures to prevent head injuries in judokas should be urgently developed to provide safer physical education programs in Japan.

Head impacts when judokas are thrown are reported to be directly responsible for head injuries [3,4]. Approximately 50% MTBIs occurred when judokas, both experienced and novice, were thrown backward by techniques such as *osoto-gari* [4] (Figure 1). Judokas are trained to use *ushiro ukemi* or the backward breakfall technique to avoid direct head impact on the floor. Therefore, it is reasonable to hypothesise that the skill level of the judo breakfall may help in identifying judokas at a high risk of head injury and that improvement of the skills required for a breakfall will decrease the number of head injuries sustained during judo.

According to instructional judo texts, a successful backward breakfall is achieved by curving the neck and trunk up to prevent the head from coming in direct contact with the floor and ensuring that the hands touch the floor to disperse the applied stress to the body [5]. Novice judokas may fail to perform important components of the breakfall skill, and this may increase the risk of head injury. Therefore, by identifying the biomechanical characteristics that distinguish experienced and novice judokas, coaches may advance the effective injury prevention plan. Most previous studies that have examined the biomechanical differences in the judo breakfall skill have not investigated the backward fall [6-10]. In other studies, only limited qualitative measures were undertaken [11,12].

This study aimed to compare kinematics and electromyographic activities during the judo backward breakfall movement between experienced and novice judokas. The role of the hand impact in the backward breakfall motion is also discussed. Because it is critical to provide injury prevention instructions during training for the successful modification of an assigned movement, this study will help in advancing the teaching strategies for appropriate judo backward breakfall skills.

Materials and methods

Participants

The participants included in this study were experienced (n = 11; 11.1 ± 4.0 years of judo experience) or novice (n = 13; no prior judo experience) male judokas. In the experienced group, the mean age, height and weight was 19.9 ± 0.18 years, 1.64 ± 0.05 m and 70.1 ± 8.8 kg. In the novice group, the mean age, height and weight was 21.3 ± 0.9 years, 1.69 ± 0.07 cm and 68.1 ± 9.8 kg. The novice judoka group had no current engagement in judo activities or experience of competitive or recreational judo. However, over the past few years, they had had at least 10 sessions (90 min each) of judo classes in the university and were led by the same instructors. After informing all subjects of the risks of the experiment, written consent to participate in the study was obtained. The study protocol was approved by the Ethics committee of the author's institution.

Data correction

We obtained three-dimensional (3D) marker trajectory data for the breakfall motion at 60 Hz through a digital Butterworth filter at a 6-Hz cut-off frequency using an 8-camera Mac3D motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA). For this, we attached 31 reflective markers (diameter, 1.9 cm) on the following bony landmarks of the participants: top of the head, front of the head, rear of the head, left/right mastoid process, left/right acromion process, elbows, wrists, upper sternum, left/right 10th rib, xiphoid process, left/right anterior superior iliac spine (ASIS), greater trochanters, medial/lateral knees, medial/lateral ankles, toes and heels (Figure 2). In addition, two surface electrodes were attached on both sides of the sternocleidomastoid, external oblique and rectus abdominis muscles on areas of the skin prepared using a standard procedure (Figure 2).

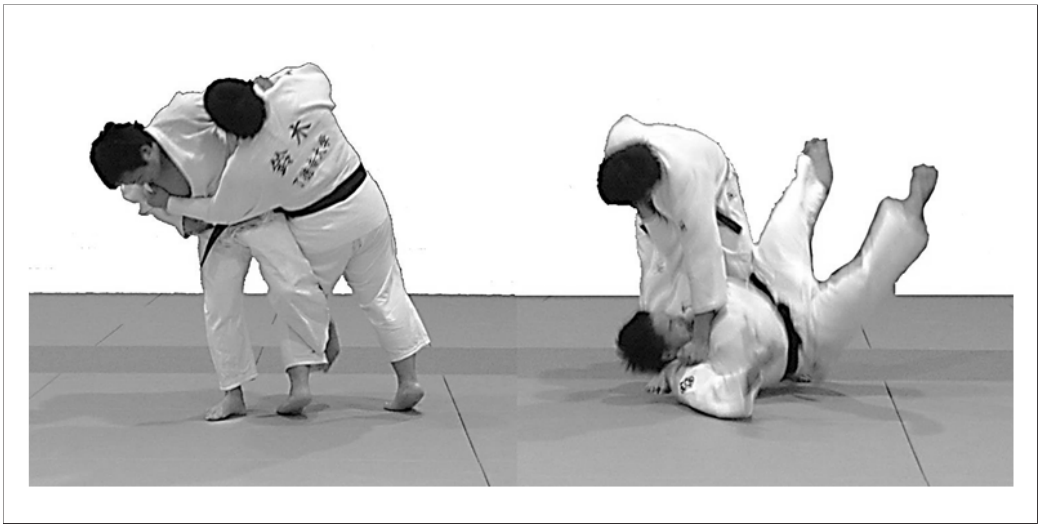

Figure 1. Backward breakfall for osoto-gari

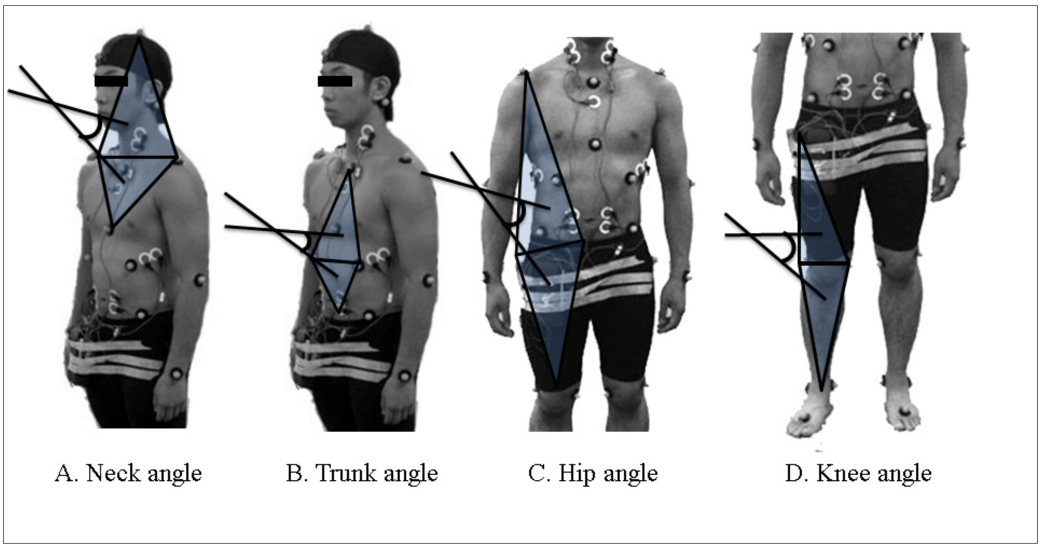

Figure 2. Marker electrode placments and the angle definition

All electromyography (EMG) data were collected at 1,000 Hz using an 8-channel Tele MyoG2 system (Noraxon U.S.A. Inc., Scottsdale, USA)

The protocol included five sets of backward breakfall motions (Figure 3). First, the participant adopted a half-squatting posture with both hands holding parallel bars as the starting position. Then, he executed the backward breakfall in his own time onto a urethane mat. We instructed the participants in both groups to perform the backward breakfall as they generally would in practice. The participants were also required to wear headgear for safety during the measurement.

Data reduction and analysis

We analysed the judo backward breakfall motion from the time the head started falling backward to when the head was at the lowest position in the vertical axis. The kinematic and EMG data were electrically synchronized and normalized (100%) to make group comparisons. We also identified the timing of the body made contact and the hands made an impact using force plate data.

The neck, trunk, hip and knee flexion angles during the judo backward breakfall movement were computed to determine the movements of each body

Figure 3. Judo backward breakfall task and the kinematic events for the study

segment. We used the modified method of Miyashita et al. [13], in which the angles are established by two corresponding triangles between the markers to define the body segments as illustrated in Figure 2. To calculate the neck angle, we formed one triangle using the two acromion process markers and the top of the head markers. The other triangle was formed using the two acromion process markers and the lower sternum marker. To calculate the trunk angle, we formed one triangle using the two rib markers and the upper sternum marker; the other triangle was formed using the two rib markers and the middle point of the ASIS markers. To calculate the hip flexion angle, we formed on triangle using the greater trochanter marker, the middle of the ASIS markers, and the shoulder marker; the other triangle was formed using the greater trochanter marker, the middle of the ASIS markers, and the middle of the knee markers. Finally, to calculate the knee flexion angle, we formed one triangle was formed using the trochanter marker, and the both knee markers; the other triangle was formed using the middle of the ankle markers and the both knee markers. We then calculated the normal unit vectors projecting from each corresponding triangle and the inner product of the two unit vectors. The cosine angle of the inner products was defined as each segment angle. The cardinal angles of the neck, trunk, hip and knee were set as 0º when the participant stood in an upright position. Each positive value represented neck flexion, trunk flexion, hip flexion or knee flexion in this study. Head linear acceleration in the sagittal plane was also calculated to reinforce the kinematic information of the judo backward breakfall motion.

In addition, the EMG data were fully rectified, followed by band-pass filtering with cut-off frequencies of 10 Hz and 350 Hz. The EMG data of each muscle were then normalized to the peak EMG amplitude of each trial (% peak EMG amplitude). The normalized data were arbitrarily subdivided into 10% bins of each phase, and the EMG data were averaged in the subdivided phases so that we could visualize the muscle activation pattern. The averaged EMG data of both sides of the body were used for statistical analysis.

Statistical analysis

All statistical analyses were performed using Microsoft Office Excel 2010 (Redmond, Washington, U.S.) and a free statistical software R. For kinematic comparisons, we performed linear regression analysis for joint-angle curves of the neck, trunk, hip and knee in each group. We then tested the homogeneity of the regression slopes of each angle–time curve between the two groups. If homogeneity was rejected, it meant that the trends of two regression slopes were statistically not the same. When homogeneity was confirmed, we performed analysis of covariance (ANCOVA) to compare differences in the angle–time plots between the experienced and novice judokas. The effect size was also calculated by using a correlation ratio (η^2). We also compared the peak acceleration between the two groups using Student's t-test.

For the EMG comparison, after inverse sine transformation of the percentage of peak EMG amplitude data of each phase, we used repeated two-way analysis of variance (2-way ANOVA) for group comparisons. Statistical significance was set at 0.05.

Results

Body contact was observed in 54.5 ± 7.7% of the phase in the experienced judokas and 51.1 ± 6.6% of the phase in the novice judokas. Hand contact was observed in 78.8 ± 10.3% of the phase in the experienced judokas and 73.5 ± 4.7 % of the phase in the novice judokas.

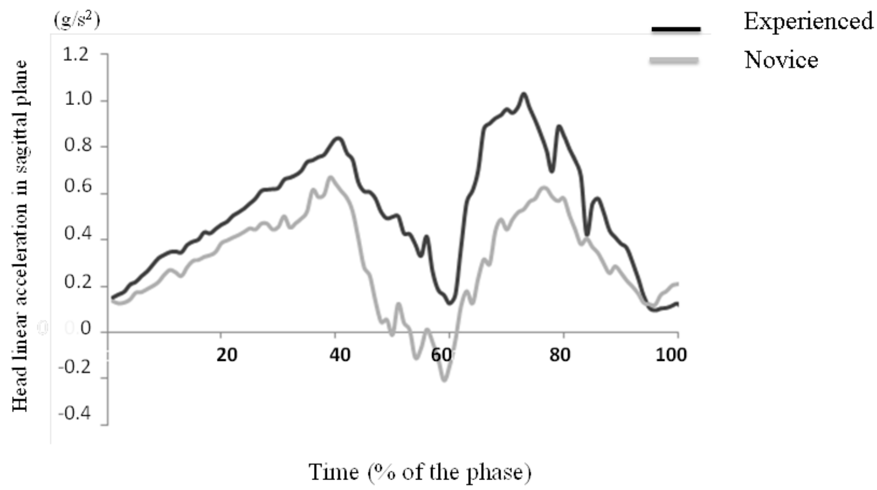

Figure 4. Angular acceleration curves for the head marker during the judo backward breakfall

The average head linear acceleration curves in the experienced and novice judokas are presented in Figure 4. The mean peak head linear acceleration in the sagittal plane was 2.11 ± 0.57 g/s^2 in the experienced judokas and 1.69 ± 0.48 g/s^2 in the novice judokas. There was no significant difference in the variable between the two groups ($p = 0.06$).

The mean angle curves of the neck, trunk, hip and knee flexion during the backward breakfall in both groups are shown in Figure 5. Regression formulae for the neck, trunk, hip and knee segment angle–time plots in the experienced group were $y = 0.8067x - 51.205$, $y = 0.1338x - 1.1107$, $y = -0.3629x + 117.15$ and $y = -0.889x + 122.05$, respectively, while those for the novice group were $y = 0.9526x - 56.38$, $y = 0.1531x - 0.3907$, $y = -0.3439x + 119.86$ and $y = -0.6091x + 108.41$, respectively. The homogeneities of the regression formula in the neck and the knee were denied between the experienced and novice judokas (neck: $F = 46.998$, $df_1 = 1$, $df_2 = 2420$, $p < 0.001$, $\eta^2 = 0.019$; knee, $F = 72.020$, $df_1 = 1$, $df_2 = 2420$, $p < 0.001$, $\eta^2 = 0.029$). In contrast, the homogeneities of the regression lines were confirmed in the hip and trunk slopes between the novice and experienced judokas (hip: $F = 1.29$, $df_1 = 1$, $df_2 = 2420$, $p = 0.256$; trunk: $F = 1.758$, $df_1 = 1$, $df_2 = 2420$, $p = 0.185$). The result of ANCOVA for hip and trunk data revealed significant differences in the adjusted mean values of the hip ($F = 51.684$, $df_1 = 1$, $df_2 = 2421$, $p < 0.001$, $\eta^2 = 0.014$) and the trunk ($F = 15.684$, $df_1 = 1$, $df_2 = 2421$, $p < 0.001$, $\eta^2 = 0.006$) between the two groups.

The mean % peak EMG data for the sternocleidomastoid, external oblique and rectus abdominis muscles in the each phase are presented in Figure 6. The results of 2-way ANOVA demonstrated a significant interaction effect only in the neck EMG activation pattern ($F = 3.282$, $df = 9$, $p < 0.001$). However, a significant simple main effect was not found in any phases of neck movement between the experienced and novice judokas. Finally, there were no significant differences in the EMG activation patterns of the external oblique ($F = 0.436$, $df = 1$, $p > 0.05$) and rectus abdominis muscles ($F = 0.868$, $df = 1$, $p > 0.05$) between the experienced and novice judokas.

Discussion

Prevention of head injuries sustained during judo has gained significant public attention because of the increasing number of recent head injuries that have been reported [3]. Direct head trauma caused by backward throws in judo appears to be the major incident responsible for head injuries in males in their first year of school. Therefore, it is crucial for coaches to provide effective teaching strategies to prevent such injuries in novice judokas. The objective of

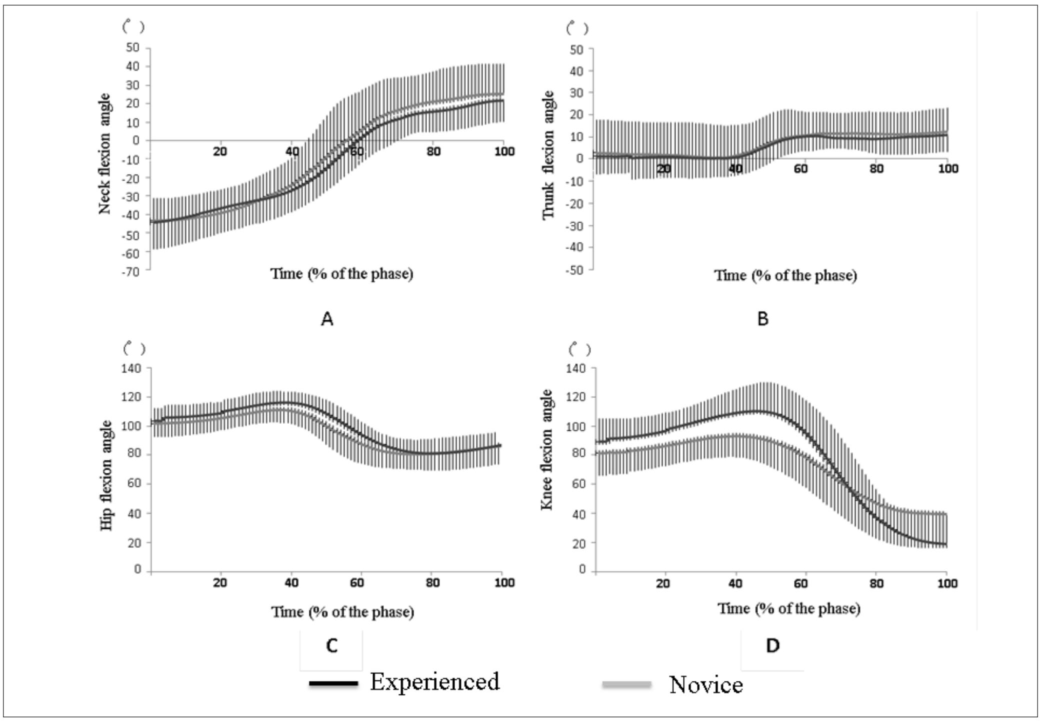

Figure 5. Mean (standard deviation) neck (A), trunk (B), hip (C), and knee (D) angle-time curves during the judo backward breakfall

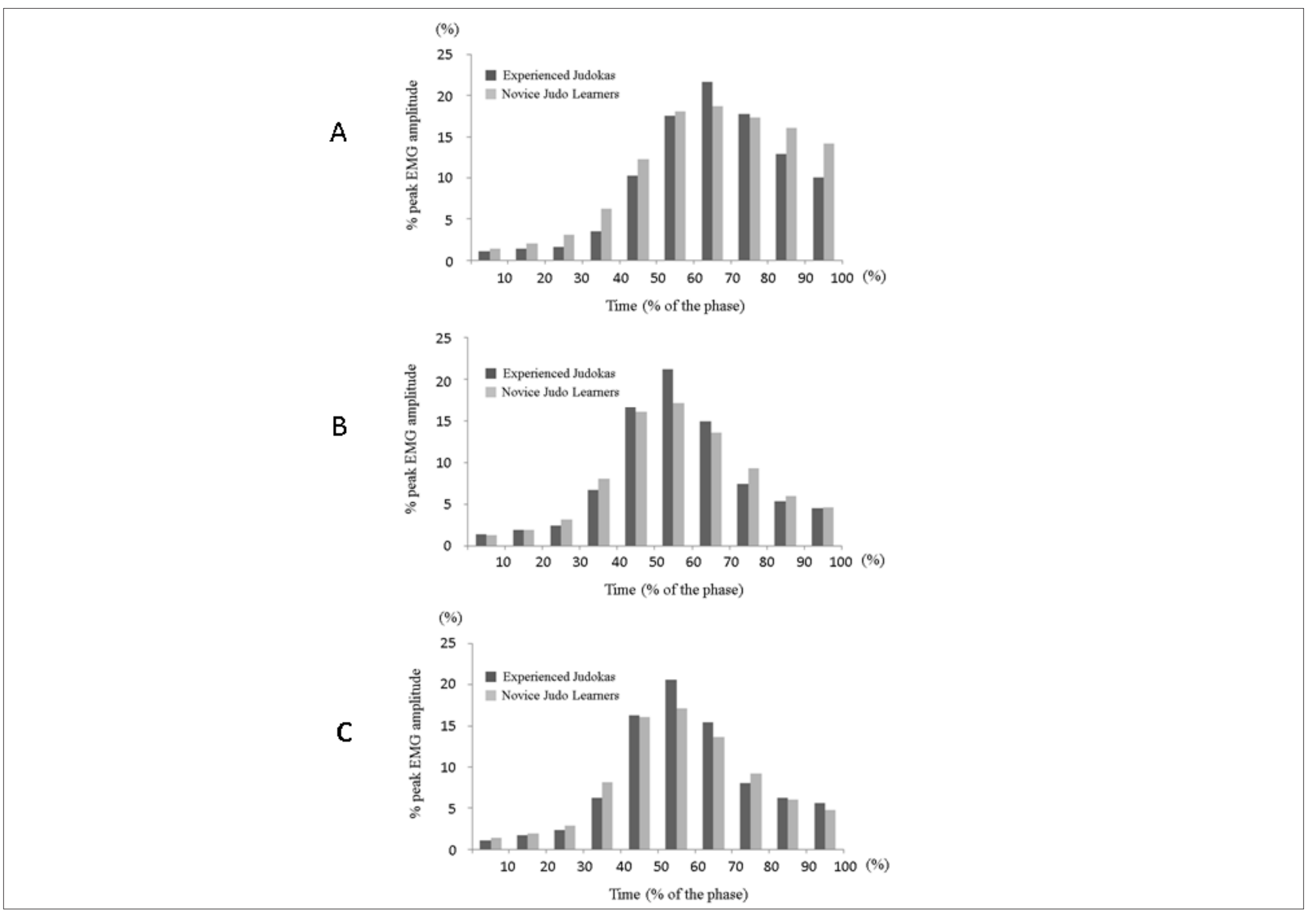

Figure 6. Muscle activation patterns of sternocleidomastoid (A), external oblique (B), and rectus abdomnis (C) muscles during backward breakfall

our study was to identify the biomechanical components that distinguish the skill level of the breakfall between experienced and novice judokas by comparing the kinematics and EMG activities during a judo breakfall motion.

We found significant differences in the patterns of knee movement between the experienced and novice judokas during the judo backward breakfall. On the basis of the qualitative observation of the angle–time curve, both the experienced and novice groups started extending their knees immediately after the body contact till the end of the motion. However, compared with novice judokas, the experienced judokas demonstrated a greater range of knee extension movement, and their motion was greater in the extended position when the hand contacted the mat and at the end of the motion. This supports the findings of Shigeoka and Miura [11], who, on the basis of the qualitative observation of a single subject, reported that a novice judoka tended to flex the knee more than experienced judokas. We speculate that greater knee extension during the motion observed in the experienced judokas may help them to better control the velocity of backward falls. This may be achieved by increasing the distance from the rotation axis to the centre of mass of the shank and foot segments. This could help judokas to decrease the risk of direct head impact on the floor, although further analyses are required to elucidate the roles of knee kinematics in the backward fall.

We also demonstrated that the neck movement pattern was significantly different between the experienced and novice groups. However the interpretation of the result warrants careful consideration because of the small effect size. In both groups, the neck flexion angle increased until approximately 70% of the phase. After reaching approximately 20°, the neck flexion angle remained stable or slightly flexed in the last phase of the motion, and it seems that the statistical difference in neck movement was minimal between the two groups. We also showed significant differences in the angle–time plots of the trunk and hip segments between the two groups. However, similar to that with neck movements, the difference may have little meaning because of the small effect sizes. The result suggests that novice judokas may have retained the neck and trunk movement even if they were not involved in any judo activity at the time of the study.

There were no significant differences in the EMG activation patterns of any muscles during the judo backward breakfall between the experienced and novice judokas. Our result indicates that the trunk muscles appear to be activated to stabilise the body in response to body contact. The sternocleidomastoid muscle may have also been activated more in the late phase of the motion for neck stabilisation in both groups. The index of % peak EMG amplitude can identify only the timing of muscle activity. In order to improve our knowledge about muscle activity during a judo breakfall, we also need to investigate the influence of muscle strength and relative EMG amplitude to the maximum muscle contraction on the kinematics of judo backward breakfalls.

Notably, our results suggest that hand contact may be associated with deceleration of the head during judo backward breakfalls. We therefore believe that appropriate skill of hand contact needs to be acquired to decrease the risk of head injury in judo. Theoretically, the hand contact would decrease the momentum of the backward fall and dissipate the applied stress to the body. Therefore, the timing of hand contact may determine, in part, the skill level of the backward breakfall. A previous study by Yabune et al. [12] stated that the timing of the hand manoeuvre may distinguish between novice and experienced judokas. However, in our study, we were not able to distinguish the skill level by the timing of hand contact. The breakfall motion was a basic movement initiated by each participant's own will. In contrast, Yabune et al. [12] analysed the breakfall motion when the participants were thrown by other judokas; this may explain the differences between their findings and ours.

It is important to note that the acceleration applied to the head during the current breakfall task would most likely be much lower than that applied while being thrown during judo practice or a match. In the future, we need to further investigate the biomechanics of the judo backward breakfall and head acceleration control after an actual judo throw.

Conclusion

We found significant differences in knee movement patterns between novice and experienced judokas. In addition, neck movement patterns and trunk and hip angle–time plots were also significantly different; however, there were only small effect sizes. There were no significant differences in any phases of EMG activation patterns between the two groups. Finally, because the timing of hand impact appeared to coincide with the timing of peak head linear acceleration, the hand impact skill may be an important component of the judo backward breakfall motion.

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Competing interests

The authors declare that they have no competing interests.

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