Influence of fatigue on head angular acceleration in judo high-intensity exercise

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A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Abstract

Background and Study Aim: Head injuries have become a serious problem in judo. For people to safely enjoy judo and with peace of mind, it is important to clarify the causes of head injury and undertake safety measures. The cognitive purpose of this study is the effects of high-intensity exercise fatigue on the angular acceleration of the head in judo.

Material and Methods: We included 15 male members of a university judo club. For high-intensity exercise, *seoi-nage* was performed once every 2.5 seconds. An angular velocity sensor was used to calculate the angular acceleration of the subjects' heads (200 Hz).

Results: The maximum angular acceleration of the head immediately increased after high-intensity exercise ($p<0.01$). The forward flexion muscle strength of the neck increased ($p<0.05$) and the strength of posterior flexion did not change.

Conclusions: Although the neck muscle strength was not reduced by high-intensity exercise, the maximum angular acceleration of the head increased, it may be related to the slow response of the neck muscle strength that is associated with head injury. Future safety measures should take into account that it is not enough to strengthen the neck muscle alone. Taking appropriate rest during exercise and not performing throwing exercises after high-intensity exercise will reduce the risk of head injury.

Keywords: accident prevention • heart rate • muscle strength • osoto-gari

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Acute subdural hematoma – is a state in which a hematoma is formed by a rupture of a vein connecting the brain and the dura and is classified as severe as a head injury.

Osoto-gari – a foot technique throw. Break your opponent's balance to his rear or right rear corner to shift most of his weight onto his right heel and then reap his right leg with your right leg.

Backward breakfall – breakfall taken to protect the body when thrown to the rear.

Ouchi-gari – a foot technique throw. Break your opponent's to his left back corner, causing his stance to open wide and his weight to shift mostly onto his heel, then step in deeply with your right leg and use it to reap his left leg from the inside with a large motion to your right to throw him backward.

Tai-otoshi – a hand technique throw. Break your opponent's balance to his right front corner, open your body and tune to step in front of his right foot with your right foot, then use the action of both hands to pull him down and throw him over your foot.

Seoi-nage – a hand technique throw. Break your opponent's balance to his front or right front corner, then pivot to the left while allowing the elbow of your right arm to bend and come under his right armpit, then load him onto your back and throw him over your right shoulder.

Tatami – flooring materials used in judo.

Nagekomi – practice throwing using throwing techniques.

Throwing – throwing opponent.

Randori – practice sparring sessions in which both participants practice attacking and defending using freely applied throwing and pinning techniques.

Dans (dan) – a detailed system used to classify levels of proficiency in judo techniques and training.

Maximal oxygen uptake (VO_2max) – is the maximum amount of oxygen (mL) that can be taken per kg of body weight per minute.

INTRODUCTION

Judo was founded in Japan in 1882, by Jigoro Kano [1]. Today, more than 200 countries and regions have joined the International Judo Federation and it has become a major sport, with World Championship and Olympic judo competitions being held. In France, judo is highly regarded for its educational value and has approximately 600,000 active participants [2]. However, in Japan, the number of people taking part in judo has dropped dramatically, with only around 150,000 (as of 2019) individuals registered with the All Japan Judo Federation [3]. This decline is thought to be largely a response to fatal accidents that have occurred following head injuries received while performing judo. In particular, injury is a serious problem in junior high schools and high schools.

From 1983 to 2011, 118 fatal accidents occurred, with 103 (87.3%) occurring during judo club activities [4]. The most common cause of death was head injury (73 cases, 70.9%), such as acute subdural hematoma, with death attributed to the judo throw known as *osoto-gari* (Figure 1) in 18 cases (24.7%). In addition, an accident report by the Japan Judo Federation for the period 2003 to 2014 reported that acute subdural hematoma accounted for 42 cases (95.5%) of severe head injuries. In particular, accidents are reported to be more common in junior high school and high school beginners [5].

In response, the All Japan Judo Federation proposed several security measures, including *osoto-gari* step-by-step instructions, communicating the importance of backward breakfall and strengthening of neck muscles. However, these recommendations are based on empirical rules, and there is no scientific evidence to support them. In fact, accidents due to head injury have continued to happen even after the All Japan Judo Federation proposed these safety measures. To eliminate the occurrence of deaths due to head injury in judo, it is necessary to promote safety measures based on scientific evidence.

To date, there have been several studies on judo head injury. Hashimoto et al. [6] and Koshida et al. [7] conducted experiments with novice and experienced judo fighters who were thrown with *osoto-gari* and another throw, *ouchi-gari*, and both studies showed that *osoto-gari* resulted in a higher impact force than *ouchi-gari* on the head of the thrown person. Ishikawa et al. [8] reported that *osoto-gari* produced the highest maximum angular acceleration of the head of the thrown person compared with that produced by other throws, including *tai-otoshi*, *seoi-nage* and *ouchi-gari*. *Osoto-gari* was identified as more dangerous through studies in which a dummy doll was thrown in *osoto-gari* and *ouchi-gari* with or without a mat laid under the tatami [9-11]. Overall, there are many studies on the risk of *osoto-gari* but few studies on the prevention of head injury [12, 13].

In 2019, two elementary school children (9-11 years old) developed acute subdural hematoma while practising judo in Japan; one of the children subsequently died [14]. Following this accident, the All Japan Judo Federation has issued a notification to limit the practice time and matches for elementary school students [14]. In the latest safety measure, practice time is limited to 2 hours. However, whether limiting the practice time is sufficient remains questionable because there are many practice programmes that include.

The combination of practice programmes may also affect the outcomes. For example, it is believed that performing '*nagekomi*' immediately after practice for the purpose of strengthening cardiovascular fitness increases the risk of injury. This suggests that the risk of head injury is related to fatigue, but this has not been clarified.

Some researchers have measured changes in heart rate and blood lactate concentrations during judo matches [15-18]; however, no studies have focused on the association between fatigue and injuries in judo. In other sports, however, fatigue has been associated with poor performance and injuries [19, 20]. For example, American student footballers in a lower grade without muscle strength and skills are more likely to suffer concussions in the second half of games when their endurance is lost and their concentration is low [21]. Head trauma in boxing is not common among inexperienced athletes, and to a certain extent the data indicates that it generally occurs late in the game, suggesting that fatigue is related to sports trauma [22]. For this reason, in judo, the increased risk of injury to due to fatigue cannot be avoided. There has been a report that judo 'throwing' and 'randori' practice increased the maximum average heart rate to 183 ±14 beats/minute [16]. We believe that this closely relates fatigue resulting from high-intensity exercise to head injury. However, fatigue has not been identified as a factor of head injury, and the relationship between fatigue and head injury following *osoto-gari* has not been clarified at all.

Therefore, at the core of our research is the assumption that fatigue is a cause of head injury and clarifying the relationship between fatigue and head injury will prevent head injury and reduce fatal accidents and will strengthen safety measures in the future.

The cognitive purpose of this study is the effects of high-intensity exercise fatigue on the angular acceleration of the head in judo.

MATERIAL AND METHODS

Participants

Three coaches qualified to the level of an 'A' instructor (hereinafter referred to as instructor A) and certified by the Japan Judo Federation selected subjects with appropriate skills. Judo accidents can be affected by a participant's break fall skills and low strength of the neck in beginners. In order to consider safety measures for judo, it is desirable to conduct experiments with beginners. However, experiments for beginners are dangerous and difficult to implement. The subjects (people being thrown) were 15 male members of a university student judo club (mean age 19.4 ±1.1 years, mean height 168.1 ±4.3 cm, mean weight 77.5 ±8.0 kg, mean judo experience 11.1 ±2.6 years, mean dan 1.9 ±0.3 dans). The thrower was a male member of the university student judo club (age 18 years, height 173.0 cm, weight 74.0 kg, judo experience 9 years, first dan). The participants were given a written explanation of the purposes and methods of this study, and the experiment was conducted when the consent of the participants and their parents was obtained.

This study was conducted with the approval of the Ethics Committee of Osaka Kyoiku University (Accession Number 176).

Assessed trial techniques

In this study, *osoto-gari* was used as a trial (Figure 1). This is because, in Japan, the most common fatal accidents in judo clubs result from *osoto-gari* [4]. Daigo [23] described *osoto-gari* as follows: the thrower breaks the balance of the thrown person to the thrown person's rear or right rear corner, to shift most of the thrown person's weight onto the thrown person's right heel, and then the thrower uses their right leg to sweep out the thrown person's right leg.

Measurement method

Heart rate measurements

Heart rates immediately before and after high-intensity exercise were measured using a heart rate monitor (M400, POLAR Corp., Finland). Physiological exercise strength can be measured in terms of maximal oxygen uptake (VO_2max). However, it is difficult to determine exercise intensity based on maximum oxygen uptake in a judo hall. Therefore, heart rate was adopted as an indicator to gain a simple measure of the exercise intensity.

Measurement of neck muscle strength (forward and backward flexion)

Neck muscle strength (forward and backward flexion) was measured using a manual weight gauge (Movi MT100, SAKAImed Corp., JPN). The head is anchored by the neck muscles, and the sternocleidomastoid muscles are critical for the safe performance of a 'backward breakfall' [13]. *Osoto-gari* is a technique that risks hitting the occipital region with tatami. Subjects were immobilised with their shoulders supine; they were asked to lie with their backs on the bed and both their shoulders were fixed at the end of the bed according to the methods described by Okada et al. [24] and Fujita et al. [13]. Next, a manual weight gauge was applied to the subject's eyebrows and occipital region and neck flexion (forward and backward) was performed.

Head angular acceleration measurement and axis definition

In this study, the motion plane of the body was defined as the X-axis in the left–right direction of the sagittal plane, the Y-axis (Figure 2, arrow) in the sagittal plane of the frontal plane, and the shaft in the vertical direction of the horizontal plane. Head injuries can be caused by angular accelerations in the sagittal plane (around the X-axis) [5, 25, 26]. Therefore, the angular acceleration was obtained by numerical differentiation of the value of the angular velocity around the X-axis obtained from the three-axis angular velocity sensor (MVP-RF8-GC, MicroStone Corp., hereinafter referred to as the sensor). The frontal direction and occipital direction were designated as '–' and '+', respectively. The sensor was placed on the top of headgear (d3o, made by LAB) and fixed in place with tape.

Sagittal plane – the plane that cuts the body symmetrically and the plane parallel to it is known as the sagittal plane.

Frontal plane – the plane that cuts the body back and forth, perpendicular to the sagittal plane.

Horizontal plane – a plane parallel to the floor and perpendicular to the sagittal and frontal planes.

Angular acceleration – is the time rate of change in angular velocity.

Angular velocity – is a physical quantity that expresses the speed of rotational movement around a point by the angle that advances in unit time and is the rate of change in angle over time.

Calibration – is the work of adjusting the relationship between the reading (output) of a measuring instrument and the value to be input or measured.

Ipponseoi-nage – a hand technique throw. Float your opponent's balance to his front, then while pivoting to the left, grip his right inner sleeve and slip your right arm up from under his chest under his right armpit to grab the top of his right sleeve or shoulder, pull him onto your back and throw him over your right shoulder.

Throwing technique – techniques in which the opponent is thrown.

H-reflex – is the reflex response of the muscle after electrical stimulation of the nerve.

Motor neuron responses – motor neurons are the nerve cells that control skeletal muscle.

Putamen – controls functions such as motor control and motivation.

Tori – the person who applies a technique in ***judo*** training. The receiver of the technique is referred to as ***uke*** [34].

Figure 1. Performing the "*osoto-gari*" throw in judo.

Experimental procedure

The experiment was divided into three phases: pre-exercise, exercise implementation and post-exercise (Table 1).

We used a heart rate metre to measure the heart rate of each subject prior to exercise. Next, we measured the neck muscle strength (forward and backward flexion) at rest, three times, using a manual weight gauge. The subject wore headgear with the sensor attached. Calibration was performed after setting the sampling frequency of the sensor to 5 ms. Each subject was thrown five times by the thrower, using *osoto-gari*, to measure the angular velocity of the subject's head.

Next, we performed repetitive throwing practice, a high-intensity exercise. This is a general exercise that requires various muscle activities due to repeated muscle exertion and rest. The skills performed during this high-intensity exercise were *seoi-nage* and *ipponseoi-nage*. High-intensity exercise used the metronome function

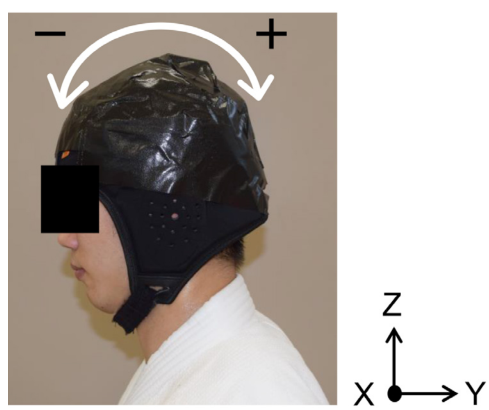

Figure 2. Sensors affixed to the top of the head.

Table 1. Experiment flow chart.

	Order	Content
Pre-exercise	1	Heart rate measurement (once)
	2	Measurement of neck muscle strength (forward and backward flexion) (three times)
	3	Headgear set calibration
	4	Measurement of head angular velocity of a participant (uke) thrown by osoto-gari (five times)
Exercise	5	Repetitive throwing practice at a tempo of once every 2.5 seconds (throwing exercise ends when a delay occurs five times)
Post-exercise	6	Heart rate measurement (once)
	7	Headgear set calibration
	8	Measurement of head angular velocity of a participant (uke) thrown by osoto-gari (five times)
	9	Measurement of neck muscle strength (forward and backward flexion) (three times)

of a digitiser (TOP60, Molten corp., JPN), and the subjects repeatedly threw a laboratory assistant at a rate of once every 2.5 seconds. The subjects were instructed to throw using maximal effort, and the practice was terminated when the number of delays reached five.

We measured the heart rate of the subjects once the high-intensity exercise had been completed. The subjects were calibrated by wearing the headgear with a sensor attached. The thrower (tori) then threw each subject (uke) five times, using *osoto-gari*, to measure the angular velocity of the subject's head.

When performing *osoto-gari*, we instructed the thrower (tori) to 'throw as usual' and each subject (uke) to 'receive it as usual'. We checked both the thrower (tori) and the subject (uke) at the time of *osoto-gari* throwing technique to see if the subject's head contacted the thrower's legs. When the head of the subject contacted the legs, we repeated the experiments until five successful trials were performed, to obtain accurate data. Three instructors confirmed the actions of the thrower and the subject. At that time, if it was judged that there was a problem by even one of them, the experiment was repeated. Finally, we measured the neck muscle strength (forward and backward flexion) three times.

Statistical analysis

The maximum angular acceleration of the head, neck muscle strength (forward and backward flexion) and maximum heart rate immediately before and after high-intensity exercise were compared. We used the mean of five measurements for head maximum angular acceleration and three measurements for neck muscle strength. Statistical processing was performed using the Wilcoxon signed-rank test (for non-parametric variables). The significance level was set at less than 5%. Moreover, the effect size was calculated using Cohen's d [27]. The effect sizes were assessed using Cohen's r as trivial (<0.1), small (0.1-0.3), medium (0.3-0.5) and large (>0.5). Statistical analysis was performed using IBM SPSS Statistics ver.20.0 (IBM Corp., USA).

RESULTS

As a result of comparing the maximal angular accelerations of the head in the sagittal plane occurring when thrown with *osoto-gari* immediately before and after high-intensity exercise, the maximal angular accelerations were significantly increased immediately after high-intensity exercise compared with those just before high-intensity exercise (Figure 3A $p<0.01$, $r = 0.32$). Heart rate measurements showed a significant increase immediately after high-intensity exercise compared with measurements made just before high-intensity exercise (Figure 3B $p<0.01$, $r = 0.88$). The forward flexion of neck muscle strength was significantly higher immediately after high-intensity exercise than immediately before high-intensity exercise (Figure 3C $p< 0.05$, $r = 0.51$). The backward flexion of neck muscle strength was not significantly different before and after high-intensity exercise (Figure 3D).

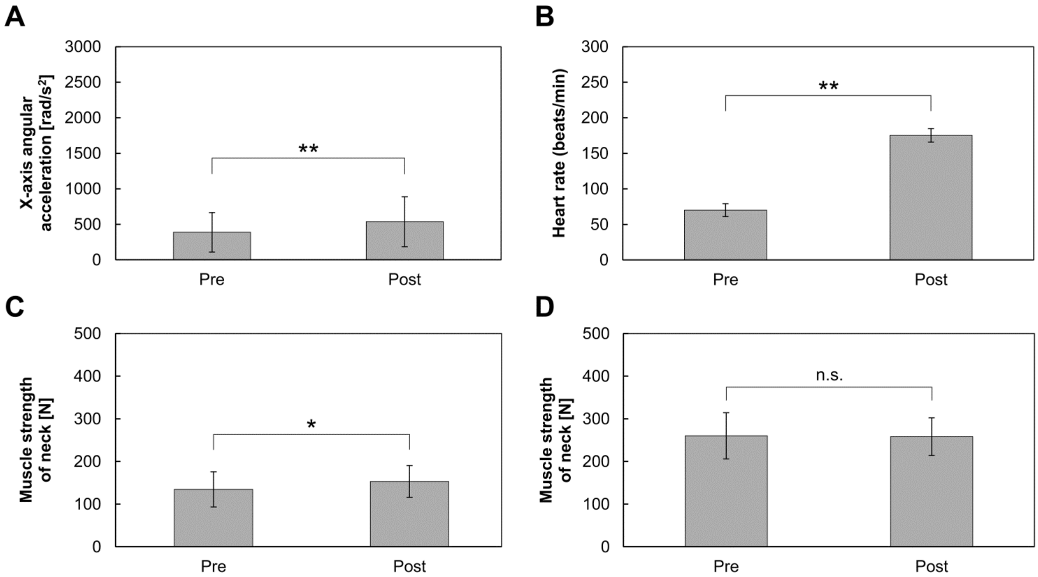

Figure 3. Results of (A) head angular acceleration, (B) heart rate, (C) neck strength (forward flexion), (D) neck strength (backward flexion) before and after throwing. * $p<0.05$, ** $p<0.01$ (Statistical analysis was performed using the Wilcoxon signed-rank test).

DISCUSSION

In this study, the maximal angular acceleration of a subject's head increased when thrown with *osoto-gari* immediately after high-intensity exercise. This revealed that an *osoto-gari* throw immediately after high-intensity exercise increased the risk of head injury. Therefore, fatigue can be considered a causal factor for head injury in this situation.

Rampinini et al. [28] examined the effect of exhaustion on players' technical performance in soccer. They pointed out that players with a greater than 8.9% reduction in running distance in the first and second half of a game exhibited reduced physical performance and technical scores (ball involvement, pathway success). Apriantono et al. [19] analysed instep kick movements before and after inducing knee-extensor and flexor muscle fatigue and reported that, after fatigue, the coordination of movement was decreased and the original movement was suppressed.

An increase in heart rate during physical activity may have a negative effect on the accuracy of break falls in judo. Higashiyama et al. [29] investigated the relationship between heart rate and competitive performance in trap and skeet shooting. As the result, Individuals who scored highly showed lower heart rates than individuals who scored poorly. Following an examination of the heart rates and hit rates of athletes who attended Kyudo national sports festival in Japan, it was noted that the lower the heart rate, the better the outcome and the stronger the concentration force [30]. These results suggest that a lower heart rate is related to higher performance.

From the above studies, it is considered that the fatigue caused by the high-intensity exercise in this study resulted in decreased judgement and performance of break falls, and the angular acceleration of the head increased. Therefore, immediately following high-intensity judo exercises, we suggest that it would be helpful to take sufficient rest to prevent head injury. However, we did not examine resting time in this study, so it will be necessary to clarify this in the future.

In judo, the thrower (tori) and the thrown (uke) person repeatedly defend and attack; therefore, they are vulnerable to fatigue. The heart rate of competitors immediately after a judo match has been reported to increase to 182.4 beats/min [17]. In this study, high-intensity exercise increased the heart rate of participants from 70 ±9 beats/min to 175 ±9 beats/min. The maximum heart rate was 201 beats/min, expressed by the general formula (220 − age). When calculated by the Carbone method (Karvonen method; exercise intensity (%) = (heart rate during exercise − heart rate at rest)/(heart rate at maximum − heart rate at rest) × 100), the exercise intensity was

80.2%. The exercise time was 280 ± 80 seconds, so this can be considered high-intensity exercise. Neck muscle strength is expected to decrease after high-intensity exercise. In the case of junior high school students and high school beginners who frequently suffer deaths due to head injury and the elementary school students who died in 2019, weak neck muscle strength may be the cause of head injury.

On the other hand, the subjects in this study were college students close to adulthood, and they were experts in judo training. Therefore, it is unlikely that weakness of the neck muscles played a role. As mentioned above, it is expected that neck muscle strength will decrease after high-intensity exercise. However, in the study subjects, the neck muscle forward flexion strength increased and the backward flexion neck muscle strength did not change. It was surprising to find that the maximum angular acceleration of the head increased even though the neck muscle strength did not decrease. This suggests that head injury is not due to a decrease in neck muscle strength from fatigue, but it is very likely that fatigue does play some role in increasing the maximum angular acceleration of the head. In addition, this new finding indicates that the safety measures of strengthening the neck muscle recommended by the All Japan Judo Federation and previous studies are not enough [13, 24, 31]. We believe that the slow response of the neck muscle strength is associated with head injury. This is because sustained muscle fatigue causes a decrease in H-reflex, motor neuron responses and muscle responses [32]. In addition, the activity of the putamen, which is involved in the supplementary motor area and motivation, decreases during maximal voluntary muscle contractions before and after fatigue [33]. However, we did not measure neck muscle activity. In the future, we need to investigate the timing of neck muscle contractions during *osoto-gari*, using an electromyograph.

CONCLUSIONS

In this study, fatigue was implicated as a cause of head injury in judo. The maximum angular acceleration of the head immediately increased after high-intensity exercise, and this happened although the neck muscle strength was not reduced by high-intensity exercise, it may be related to the slow response of the neck muscle strength is associated with head injury. Future safety measures should take into account that strengthening the neck muscles alone is not sufficient. Not practising throwing immediately after high-intensity exercise and taking appropriate rest during exercise will help prevent head injuries in judo.

HIGHLIGHTS

In judo, the maximum angular acceleration of the head increased, although the muscle strength of the neck did not decrease after high-intensity exercise, that is, the risk of head injury increased.

REFERENCES

1. Kodokan. Kano Jigoro. Osaka: Nunoi shobo; 1977 [in Japanese]
2. Hamada H, Cadot Y. Study on judo coaching qualification systems in France. Res J Budo 2015; 48: 89-112 [in Japanese]
3. All Japan Judo Federation. All Japan Judo Federation registered population [accessed 2019 Dec 24]. Available from: URL:https://www.judo.or.jp/wp-content/uploads/2019/04/tourokujinkou-suii2019.pdf [in Japanese]
4. Uchida R. Accidents in Judo. Tokyo: Kawade shobo shinsha; 2013 [in Japanese]
5. All Japan Judo Federation. Safety Instruction for Judo: How to Prevent an Accident in Judo [accessed 2019 Dec 24]. Available from: URL:http://www.judo.or.jp/wp-content/uploads/2013/08/print-shidou.pdf [in Japanese]
6. Hashimoto T, Ishii T, Okada N et al. Impulsive force on the head during performance of typical ukemi techniques following different judo throws. J Sports Sci 2015; 33: 1356-1365
7. Koshida S, Ishii T, Matsuda T et al. Biomechanics of judo backward breakfall for different throwing techniques in novice judokas. Eur J Sport Sci 2017; 17: 417-424
8. Ishikawa Y, Anata K, Hayashi H et al. Effects of different throwing techniques in judo on rotational acceleration of uke's head. Int J Sport Health Sci 2018; 16: 173-179
9. Murayama H, Hitosugi M, Motozawa Y et al. Simple strategy to prevent severe head trauma in Judo -Biomechanical Analysis-. Neurol Med Chir (Tokyo) 2013; 53(9): 580-584
10. Hitosugi M, Murayama H, Motozawa Y et al. Biomechanical analysis of acute subdural hematoma resulting from judo. Biomed Res 2014; 35: 339-344
11. Murayama H, Hitosugi M, Motozawa Y et al. Rotational acceleration during head impact resulting from different judo throwing techniques. Neurol Med Chir (Tokyo) 2014; 54(5): 374-378
12. Sannohe N, Iida T. Methods of *Ushiro-Ukemi* in judo: with Safety of Head and Arms. Akita: Akita University; 2008: 71-78 [in Japanese]
13. Fujita E, Hamada H, Nakamura I et al. Association between activity levels of neck flexor muscles and head acceleration during ushiro-ukemi. Res J Budo 2013; 46: 21-29 [in Japanese]
14. All Japan Judo Federation. To eradicate serious judo accidents in elementary school students (notice) [accessed 2019 Dec 24]. Available from: URL:https://www.judo.or.jp/wp-content/uploads/2019/11/4531ef9bb4c8dc404796d3f9d948f0-1.pdf [in Japanese]

15. Ikai M, Kaneko M. Heart rate variability during judo practice-By telemetry (wireless telemetry). Bull Assoc Sci Stud Judo. Kodokan Rep 1969; 3: 63-68 [in Japanese]
16. Matsumoto Y, Asami T, Sasaki T. Physiological study of judo instruction in developing children. Judo 1972; 43: 51-59
17. Degoutte F, Jouanel P, Filaire E. Energy demands during a judo match and recovery. Br J Sports Med 2003; 37: 245-249
18. Julio UF, Panissa VLG, Esteves JV et al. Energy-system contributions to simulated Judo matches. Int J Sports Physiol Perform 2017; 12(5): 676-683
19. Apriantono T, Nunome H, Ikegami Y et al. The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. J Sports Sci 2006; 24(9): 951-960
20. Akutsu T, Kiryu T, Ushiyama Y et al. Evaluation of functional activities during skiing exercise by knee joint angles and surface EMG signals. T Soc Instrum Control Eng 2008; 44(11): 905-910 [in Japanese]
21. Ogino M, Abe H, Kanto University American Football Federation Safety Committee. Head and neck trauma due to American football-from the record of Kanto University American Football Federation. Neurotraumatology 1998; 21: 101-105 [in Japanese]
22. Tani S, Ohhashi G, Ohtuki , et al. Analysis of acute subdural hematoma in professional boxing bouts: Statistics from the last 23 years. J Jpn Soc Clin Sports Med 2002; 10: 310-314 [in Japanese]
23. Daigo T. Throwing Techniques: ashi-waza. Tokyo: Hon no tomo sha; 1999 [in Japanese]
24. Okada S, Inokuma M, Matsui I et al. The characteristics of the strength of neck flexor and extensor muscles in Judo players. Res J Budo 1991; 23(3): 35-40 [in Japanese]
25. Ommaya AK, Gennarelli TA. Cerebral concussion and traumatic uncon-sciousness: Correlation of experimental and clinical observations on blunt head injuries. Brain 1974; 97(1): 633-654
26. Gennarelli TA, Thibault LE. Biomechanics of acute subdural hematoma. J Trauma 1982; 22(8): 680-686
27. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale: Lawrence Erlbaum; 1988
28. Rampinini E, Impellizzeri FM, Castagna C et al. Technical performance during soccer matches of the Italian serie A league: effect of fatigue and competitive level. J Sci Med Sport 2009; 12: 227-233
29. Higashiyama A, Hayashi K, Honda M. Examination of clay shooting competition improvement from the viewpoint of heart rate. Shiga Prefectural Society of Physical Education. Sci Committee Sports 2001; 19: 76-85 [in Japanese]
30. Higashiyama A, Usami Y, Morita H et al. Relationship between Kyudo hit rate and heart rate. Shiga Prefectural Society of Physical Education. Science Committee of Sports 1999; 17: 49-58 [in Japanese]
31. Iteya M. Research on backward breakfall. Sci Res Judo 2012; 17: 16-17 [in Japanese]
32. Nozaki D. Brain and fatigue. In: Miyashita M, editor. Fatigue and physical exercise. Tokyo: Kyorin Shoin; 2018: 8-11 [in Japanese]
33. Van Duinen H, Renken R, Maurits N et al. Effects of motor fatigue on human brain activity, an fMRI study. Neuroimage 2007; 35(4): 1438-1449
34. Budō: The Martial Ways of Japan. Tokyo: Nippon Budokan Foundation; 2009

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