Biomechanical Factors to Shorten the Movement Time of Men Striking Motion in Kendo

Naoki Murase¹, Gen Horiuchi², Katsuhiro Sumi³, Kenji Horiyama⁴ and Sinji Sakurai⁴

¹Department of General Education, Salesian Polytechnic, 4-6-8 Oyamagaoka, Machida, Tokyo 194-0215, Japan
E-mail: naokimurase@yahoo.co.jp
²Graduate School of Health and Sport Science, Chukyo University, 101 Tokodachi, Kaizu-cho, Toyota, Aichi 470-0390, Japan
³School of International Liberal Studies, Chukyo University, 101-2 Yagotohonmachii, Shouwa-ku, Nagoya, Aichi 466-8666, Japan
⁴School of Health and Sport Science, Chukyo University, 101 Tokodachi, Kaizu-cho, Toyota, Aichi 470-0390, Japan

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The objectives of the present study were: to examine the relationship between kendo competition levels and men strike times in 20 university kendo club members; and to determine factors for shortening men strike times. LED lamps were attached to the men and the kote (the strike targets), and subjects struck in the direction of the lit LED lamp with maximal effort from a distance of 2.30 m. Phase times, movements, and ground reaction force on both feet were analyzed. The results were as follows.

1. Subjects of higher competition levels tended to demonstrate shorter men strike times. Reaction times, movement times, and shinai upswing phase time also tended to be shorter.

2. Factor for shortening men strike times in the upswing phase consisted of the following: lifting the right foot from the ground quickly, simultaneously pushing off the ground with great force with the left foot, quickly lifting the right thigh forward while moving the body forward, and to increase the range of upswing motion of the shinai with high velocity. In the downswing phase, the shinai should be swung at a higher velocity, and the left shoulder should be flexed more when striking.

Keywords: reaction time, movement time, kinematics, competition level

1. Introduction

Kendo is a sport developed from training in ancient Japanese swordsmanship. Kendoka (practitioners of kendo) wear armor and fight against opponents with a shinai (bamboo sword). In these fights, kendoka attempt to obtain yuko-datotsu (valid strikes) by striking one of four targets: the men (the top or sides of the head), the kote (the padded area of the right or left wrist protector), the do (the right or left side of the armor protecting the torso), and the tsuki (the area of the head protector in front of the throat) (Mitsuhashi, 1972).

In kendo, the men-uchi (men strike: strike to the center of the forehead) has tended to be treated with great importance. In kendo practice, men strike is the strike for which the most training is given. In training, men strike is typically the first area which beginners practice striking. In a study of techniques and valid strike during a series of matches, Edo et al., (1983), found that 378 of a total 801 strikes and 25 of a total 47 valid strikes were men strikes. Also, Tatsumi (1985) found that, in the All Japan University Kendo Championships and the All Japan Kendo Championships, the most frequently appearing technique among strike that valid strikes were the ippon-uchi-no-waza (attacking at one’s own timing when a clear target: men, kote, do, or tsuki, appears: 36.1%), while the most frequently struck target zone was the men (58.0%). Thus, men strikes (the most basic of all strike) are frequently played in kendo matches and account for a high proportion of valid strike.

Edo and Hoshikawa (1984) stated that, in order to get valid strikes, it is important for one’s own strike movements to be faster than the opponent’s defensive movements. Thus, while moving in attack and defense in response to the opponent, it is important for kendoka to shorten the length of time from the moment in which they sense an opportunity to attack to the moment they strike. In an examination of the relationships of men strike time to physique, muscle strength, and power, Osaki et al. (1987) found that practitioners with taller height,
higher body weight, stronger back muscles, and greater leg flexion tended to indicate shorter men strike times. In another study, Yokoyama et al. (1981) asked subjects to perform men strikes as simple reactions to LED lamps lighting up in order to examine the relationship between distribution of weight on both legs and men strike times in the chudan-no-kamae (basic middle-level posture). They found that subjects who distributed $\geq 50\%$ of their body weight on the front foot demonstrated shorter men strike times than subjects who placed $\geq 50\%$ of their body weight on the back foot. In a study of experienced and inexperienced kendoka, Wakita et al., (1989) examined the effects of the following five relative positions of the feet in chudan-no-kamae on men strike movement: the left foot 25 cm in front of the right foot; left and right feet level with each other; and the right foot 25, 50, and 75 cm in front of the left foot. Both the experienced and inexperienced groups demonstrated the shortest men strike times when the left foot was 25 cm in front of the right foot. However, we couldn’t find any previous studies which examined the characteristics of strike movements in order to shorten men strike times, and relationships between movements speed and kendo player competition level. As for fencing, in an examination of lunge reaction time, lunge movement time, and total response time in elite and novice fencer, Williams and Walmsley (2000) found that elite fencers showed significantly shorter response times and total response times, and characteristics of motion in order to shorten movement time. Therefore, while kendo is similar to fencing regarding to be a martial arts with a sword, elucidating the factors which shorten men strike times is significant in providing practitioners with the necessary information for improving kendo competition levels.

Thus, the purposes of this study were: 1) to investigate the relationships between men strike time and competition level, and 2) to clarify the characteristics of strike movement concerning the factors which shorten men strike times.

2. Methods

2.1. Subjects

The subjects were 20 male students belonging to the Chukyo University Kendo Club (mean age: 19.5 ± 1.1 years, height: 1.73 ± 0.03 m, weight: 68.2 ± 6.1 kg, experience: 13.2 ± 1.7 years; dan (grade): 4-2). The subjects were ranked according to the results of intra-squad round-robin matches held two months prior to the experiment described below (Table 1).

The purpose and significance of the study, details of the data collection process, and the safety of the experimental set-up were explained to the subjects prior to the experiment and informed consent was obtained from all subjects.

2.2. Experiment practice swings

Before performing practice swings for the experiment, subjects engaged in warm-up exercises and practice strikes with the shinai they would use in the trials. Subjects practiced actual strikes against the men and the kote.

In order to detect movement characteristics, reflective markers were affixed to 36 anatomical points on the subjects’ bodies (the top of the skull, upper sternal border, seventh cervical vertebra, xiphoid process, and the left and right tragi, acromion, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), medial epicondyle, lateral malleolus, medial malleolus, calcaneus, and second metatarsophalangeal joint) and two points on the shinai (kensaki: tip of the shinai, and the tsubamoto: where the handguard meets the blade). Subjects then assumed their stances against the strike targets while standing on two force platforms. In accordance with previous studies (Nakabachi et al., 1987; Wakita et al., 1989), the subjects stood with the toes of left feet (the back foot) at a distance of 2.3 m from the men (the strike target). This distance is nearly identical to the maai when standing face-to-face with an opponent in an actual match. The height of the men was adjusted to match the height of the individual subject. The height of the kote was adjusted to match the height of the individual subject’s right hand when on guard. LED lamps (PH-1133, DKH) were attached to the men and the kote (the strike targets). Subjects were asked to make a strike movement in the direction of the lit LED lamp (either on the men or the kote) (Fig. 1, Top). The order in which the LED lamps lit up was randomized. Subjects were instructed to make their strike movements as quickly as possible after the LED lamp lit up. Assessment
Table 1  Subjects’ rankings, ages, physical characteristics, years of experience, dan, and men strike times.

| Subjects No. (Ranking) | Ages (years) | Height (m) | Weight (kg) | Yrs. Exp. | Dan | Men strike time (s) |
|------------------------|--------------|-----------|-------------|-----------|-----|---------------------|
| 1                      | 21           | 1.72      | 69.2        | 16        | 4   | 1.039               |
| 2                      | 20           | 1.70      | 59.5        | 14        | 3   | 1.020               |
| 3                      | 20           | 1.72      | 68.2        | 14        | 3   | 0.952               |
| 4                      | 21           | 1.73      | 62.0        | 13        | 3   | 0.937               |
| 5                      | 19           | 1.69      | 72.2        | 14        | 3   | 0.821               |
| 6                      | 20           | 1.75      | 69.3        | 12        | 3   | 0.901               |
| 7                      | 19           | 1.71      | 79.1        | 14        | 3   | 0.801               |
| 8                      | 20           | 1.69      | 58.0        | 15        | 3   | 1.104               |
| 9                      | 19           | 1.77      | 66.3        | 14        | 3   | 1.064               |
| 10                     | 18           | 1.75      | 67.2        | 14        | 3   | 1.000               |
| 11                     | 18           | 1.67      | 58.9        | 11        | 3   | 1.172               |
| 12                     | 20           | 1.75      | 65.9        | 14        | 3   | 1.044               |
| 13                     | 21           | 1.74      | 68.2        | 12        | 3   | 1.033               |
| 14                     | 19           | 1.73      | 66.3        | 10        | 3   | 1.049               |
| 15                     | 21           | 1.81      | 67.9        | 13        | 3   | 1.013               |
| 16                     | 19           | 1.75      | 69.3        | 15        | 3   | 1.159               |
| 17                     | 20           | 1.78      | 84.5        | 16        | 3   | 1.110               |
| 18                     | 18           | 1.72      | 69.2        | 12        | 3   | 1.139               |
| 19                     | 20           | 1.73      | 70.0        | 11        | 2   | 1.153               |
| 20                     | 18           | 1.72      | 72.2        | 11        | 3   | 1.110               |

Mean ± SD  19.5 ± 1.1  1.73 ± 0.03  68.1 ± 6.1  13.2 ± 1.7  1.031 ± 0.105

of whether the strike would valid strikes was carried out by assessors with previous experience as referees. Under the above conditions, subjects continued until they had landed five convincing valid strikes strike against both the men and the kote. The shinais conformed to conditions for those permitted in official matches (length: ≤120 cm, weight: ≥510 g, diameter: ≥26 mm).

2.3. Definitions of coordinates

A right-handed global coordinate system was established in which the direction of forward movement in relation to the strike targets was defined as the Y-axis, the lateral direction was defined as the X-axis, and the vertical direction was defined as the Z-axis (Fig. 1, top)

2.4. Data collection

Images of strike movements were captured with a three-dimensional optical motion capture system (Vicon MX, Oxford Metrics Group) with 10 cameras (MX13, Oxford Metrics Group). A sampling frequency of 250 Hz was used. Ground reaction force was simultaneously measured (1000 Hz) with two force plates (9281B, Kistler) and two eight-channel charge amplifiers (9865B, Kistler) synchronized with the three-dimensional optical motion capture system.

2.5. Data processing

2.5.1. Range of analysis

The range of strike movement analysis in the present study was the time from the moment in which the LED lamp lit up to the moment at which the target was struck. The strike instance was defined as one frame (1/250 s) before the angular velocity of the shinai suggested a negative value.

2.5.2. Smoothing

The three-dimensional coordinates obtained from each part of the body were smoothed with a Butterworth low-pass filter. Cutoff frequencies (14.6-27.1 Hz) were determined according to the method described by Yu et al. (1999). Taking into consideration the rapid decrease in the velocity of the shinai as a result of the impact from the strike instance, the coordinates of the kensaki and the tsubamoto were not smoothed.
2.6. Calculated items

2.6.1. Bodily center of gravity position and velocity

Fourteen part of the body (head, trunk, and left and right upper arms, forearms, hands, thighs, lower legs, and feet) were made into a rigid link segment model, which was then used to calculate the location of the body’s center of gravity. (Ae et al., 1996).

2.6.2. Joint angles and angular velocities during movement (Fig. 1, bottom)

Joint angles during movement were defined as follows:
\( \theta_1 \): Upper body anterior tilt angle: the angle on the Y/Z plane formed by: the line segment drawn from the midpoint of the two center of ASIS and PSIS towards the Z axis; and the line segment connecting the midpoint of the two acromia and the midpoint of the two center of ASIS and PSIS.
\( \theta_2 \) and \( \theta_3 \): Left and right shoulder joint angles: the angles on the Y/Z plane formed by: the line segment connecting the acromion and the greater trochanter on the respective right and left sides; and the line segment connecting the acromion and the midpoint of the elbow joint.
\( \theta_4 \) and \( \theta_5 \): Left and right elbow joint angles: the angles formed by: the line segment connecting the acromion and the midpoint of the elbow joint; and the line segment connecting the midpoint of the elbow joint and the midpoint of the wrist joint.
\( \theta_6 \) and \( \theta_7 \): Left and right wrist joint angles: the angle formed by the shinai and the line segment connecting the midpoint of the wrist joint and the midpoint of the elbow joint.
\( \theta_8 \) and \( \theta_9 \): Left and right hip joint angles: the angles on the Y/Z plane formed by: the line segment connecting the greater trochanter and the midpoint of the knee joint; and the Y-axis.
\( \theta_{10} \) and \( \theta_{11} \): Left and right knee joint angles: the angles formed by: the line segment connecting the greater trochanter and the midpoint of the knee joint; and the line segment connecting the midpoint of the knee joint and the midpoint of the ankle.
\( \theta_{12} \) and \( \theta_{13} \): Left and right ankle angle: the angles formed by: the line segment connecting the midpoint of the knee joint and the midpoint of the ankle joint and the midpoint of the ankle and the second metatarsophalangeal joint.

The joint angles calculated as described above were differential time to calculate the angular velocities of the respective joint.

2.6.3. Shinai angle and angular velocity

The angle of the shinai defined as the angle formed on the Y/Z plane by the tip of the shinai and the line segment drawn from the tsubamoto of the shinai; and the Y-axis (Fig. 1, bottom). The angular velocity of the shinai was calculated by differential the angle of the shinai over time.

2.6.4. Men strike time and phase times

The following showed landmarks which became the points of each phase times.
Light-On: as the moment the LED lamp lit up.
CG-Start: as the moment when the resultant velocity of the body’s center of gravity reached \( \geq 0.05 \)
m/s.
Shinai-Min: as the moment when the shinai angle reached its minimum value.
RF-Off: as the moment when the vertical ground reaction force acting on the right foot (the front foot) reached a value of 0.
TS: as the moment in which the target was struck.

*Men* Strike Time and Phase Times were defined as follows:
Reaction time: as the length of time from the Light-On to the CG-Start.
Movement time: as the length of time from CG-Start to the TS.
*Men* strike time: as the length of time from Light-On to the TS (reaction time + movement time).
Shinai upswing phase time: as the length of time from CG-Start to the Shinai-Min.
Shinai downswing phase time: as the length of time from Shinai-Min to the TS.
Right foot lift time: as the length of time from CG-Start to the RF-Off.

2.7. Statistical processing

To calculate each subject’s individual value, the longest and shortest *men* strike times among five valid practice swings were excluded, and the times of the remaining three swings were averaged. Pearson product-moment correlation coefficients were calculated in order to examine the relationship between *men* strike time and other calculated items. The level of statistical significance was set at 5%.

3. Results

3.1. Relationships between rankings in intra-squad round-robin matches and phase times

*Figure 2* shows the relationship between rankings in intra-squad round-robin matches (hereinafter abbreviated as “rankings”) and phase times. Rankings demonstrated significant correlation with *men* strike time ($r = 0.620$, $p < 0.01$), reaction time ($r = 0.651$, $p \leq 0.01$), movement time ($r = 0.552$, $p < 0.05$), and shinai upswing phase time ($r = 0.577$, $p \leq 0.01$). No significant correlation was observed between ranking and shinai downswing phase time ($r = -0.154$, n.s.).

3.2. Relationships of *Men* strike time to calculated items in each phase

3.2.1. Shinai upswing phase

*Figure 3* (Upswing Phase) shows the relationships between *men* strike time and calculation outcomes in the shinai upswing phase. *Men* strike time demonstrated significant correlations with right foot lift time ($r = 0.759$, $p \leq 0.001$), mean resultant velocity for the bodily center of gravity ($r = -0.748$, $p < 0.001$), minimum shinai angle ($r = 0.498$, $p < 0.05$),...
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Figure 3 Relationships of strike time to calculated items in the upswing phase (top and middle rows), and in the downswing phase (bottom rows).

and peak upswing angular velocity (r = 0.613, p < 0.01). No significant correlation was observed between men strike time and left-right leg weight distribution when the LED lamp lit up (r = −0.308, n.s.).

3.2.2. Shinai downswing phase

Figure 3 (Downswing Phase) shows the relationships between men strike time and the calculated items in the shinai downswing phase. Men strike time demonstrated significant correlations with peak downswing angular velocity (r = −0.678, p < 0.001), movement distance of the bodily center of gravity from the moment the LED lamp lit up to the moment the target was struck (r = 0.742, p < 0.001), and left shoulder angle at the moment the target was struck (r = −0.501, p < 0.05).

3.3. Other significant correlations among calculated items

Figure 4 shows significant correlations between other pairs of calculated items. A significant correlation was observed between peak vertical ground reaction force and mean resultant velocity of the bodily center of gravity (r = 0.482, p < 0.05). A significant correlation was also observed between minimum shinai angle and peak downswing angular velocity (r = −0.806, p < 0.001).

3.4. Relationships between lift time and Men strike time

Figure 5 shows change in vertical ground reaction force acting on both feet from the moment the LED lamp lit up until the right foot was lifted from the
ground in three subjects with the shortest men strike times (No. 7, 5, and 6) and three subjects with the longest men strike times (No. 19, 16, and 11) (representative example). The three subjects with short men strike showed that the time when the ground reaction force on the right foot reaches 0 was shorter than the three subjects with long men strike times. Also, the three subjects with long men strike times shifted their weight between their feet until lifting the right foot from the ground.

4. Discussion

4.1. Relationships between rankings and phase times

Subjects with higher ranking tended to suggested shorter reaction times, movement times, and shinai upswing phase times. The results of the present study suggest that the shortening of men strike time is a factor in improving kendo competition level. Tabuchi and Ando (1966) investigated reaction times, and movement times in two types of tasks: a simple reaction task in which subjects struck a tar-
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strike movements, the kensaki moves before the right foot; whereas in battle strikes, the right foot moves before the kensaki. These reports indicate that, when performing combat strikes, the right foot must be lifted at first in order to move the body forward. In addition, taking a long time to lift the right foot will inevitably prolong men strike time. Therefore, in order to confirm the characteristics of these factors in the present study, we compared right foot lift times in three subjects with shorter men strike times versus foot lift times in three subjects with longer men strike times. The three subjects with shorter men strike times showed that the time when the ground reaction force on the right foot reaches 0 was shorter than the three subjects with longer men strike times. We consequently found that the subjects with longer men strikes times shifted their weight from the left foot to the right foot and back to the left foot, which tended to prolong the time they took to lift the right foot.

In the results of the present study, no significant correlation was observed between right foot weight distribution at the moment the LED lamp lit up and men strike time. Also, while nine subjects placed ≥50% of their weight on the right foot, eleven subjects placed ≥50% of their weight on the left foot. The results of the present study differ from the results reported by Yokoyama et al. (1981), in which subjects performed men strikes as simple response to LED lamps lighting up. Kendo training and matches involve striking various targets, moving forward and occasionally retreating backward in response to the opponent’s movement, and constantly evading and countering the opponent’s attacks. If weight distribution between the feet does not decisively affect men strike time, weight should be equally distributed between the feet to enable flexible reaction to any situation. Practitioners also perform skillful footwork and change in weight distribution in responding to attacks of the opponent and preparing counterattacks. Based on the above, the effects of differences in assessment conditions are inferred to be responsible for the differences between the results of the present study and those reported by Yokoyama et al. (1981). Shortening the time required to lift the right foot is thought to be more important than weight distribution ratio in stances.

In strike movements, the body is moved forward by pushing off the ground with the left foot. The

4.2. Relationships of Men strike time to calculated items in each phase

4.2.1. Shinai upswing phase

A significant correlation was also observed between men strike time and right foot lift time. This result shows that quickness in lifting the right foot from the ground is related to the shortening of men strike time. Yokoyama et al. (2001) reported that men strike movement involves the initial movement of the right leg forward in order to plant it before swinging the shinai upward. In a study of the characteristics of two types of movement in basic strikes and battle strikes in men strike movements, Kanzaki and Ito (2005) presented the following: in basic

get which was designated in advance; and a three-choice reaction task in which subjects struck the men, kote, or do. Subjects were divided into four groups based on level of kendo experience: no experience, beginners (four months of experience), moderate experience (3-5 years), and All-Japan Kendo Champions. The results showed that reaction times and movement times in both tasks got shorter as experience increased. In a similar study regarding fencing, Williams and Walmsley (2000) examined the relationships of the body's movements and reaction times with lunge reaction time, movement time, and total response times. As a result of their study, elite fencers were shorter time than novice fencers. The subjects in the present study were similar to each other in terms of relative experience and competition level. However the results of this study supported the results of previous studies whose subjects were varied greatly in terms of experience. Specifically, subjects of higher competition levels tended to indicate shorter men strike times, reaction times, and movement times. Ranking data, which was used as an indicator of competition level in the present study, was compiled in the course of 50 intra-squad round-robin matches per club member over the span of two to three weeks. Therefore, unlike a tournament-style format, there is little randomness in the final rankings, which are thus considered highly reliable reflections of competition level. Based on the above, in kendo, a sport in which victory or defeat is decided in a single moment, the

response to the opponent's movement, and con-
present study established a distance from the stance position to the target of 2.3 m. This distance, which is nearly identical to the maai in actual matches, cannot be covered simply by extending the arms. Therefore, both upward and downward swings of the shinai require forward movement of the body. The significant correlation observed between men strike time and mean resultant velocity for the bodily center of gravity suggest that quick forward movement of the body is important for shorten men strike time. In addition, this research observes the significant correlation between the mean resultant velocity for the bodily center of gravity and the peak vertical ground reaction force acting on the left foot. In consequence, it is important to push off hard the ground with the left foot at the same time as lifting the right foot in order to quickly move the body forward.

Subjects with shorter men strike times tended to demonstrate larger shinai upswings and larger upswing angular velocities (Fig. 3, Upswing Phase). In order to shorten men strike time, it is necessary to swing the shinai upward with high velocity. On the contrary, a large upswing of the shinai angle can confer an advantage: in this examination of the relationship between minimum shinai angle and shinai downswing velocity, subjects with larger upswings tended to demonstrate higher downswing velocity (Fig. 4).

4.2.2. Shinai downswing phase

Subject with shorter men strike times tended to demonstrate larger shinai downswing angular velocity (Fig. 3, Downswing Phase). Increasing the shinai downswing angular velocity becomes a significant factor in order to shorten men strike time.

Men strike times demonstrated significant correlations with the movement distance of the bodily center of gravity from the moment the LED lamp lit up until the moment in which the target was struck. Also, men strike times demonstrated significant correlations with the left shoulder joint angle at the moment in which the target was struck. The subjects with shorter men strike time are characterized as to take a striking posture away from the target. The present research result suggests that there is a need to develop more shoulders extension as one of the reasons to successfully achieve this. However, future studies will be required to delve more deeply into the striking posture.

Lastly, the limitation of this study is the point that the joint angles were calculated in the Y/Z plane. The shoulder joint was greatly flexed in kendo men strike motion. Therefore, there is a possibility that the shoulder joint whose degree of freedom is 3 includes the motion other than simple flexion/extension. This may be as well the other joints whose degree of freedom is 2 or 3. This point is should be mentioned. Also as all the subjects in the present study were members of the same kendo club, they were relatively similar in terms of age and competition level. Whereas actual matches involve confronting an opponent while moving constantly, the practice swings in the present study involved the use of LED lamps as a signal to execute strikes from a static state in a two-choice format; therefore, the practice swing environment differed somewhat from an actual match situation. In the future, it would be necessary to conduct studies with subjects of a wider range of age groups and competition levels, as well as studies which more closely approximate the environment of an actual match.

5. Conclusions

The present study examined the characteristics of strike movement as a primary factor to shorten men strike time. Results showed a relation between competition level and movement time, as well that there are factors to shorten this time as follow in the explanation below.

1. Subjects of higher competition levels tended to indicate shorter men strike times. Reaction times, movement times, and shinai upswing phase time also tended to be shorter.

2. Factor for shortening men strike times in the upswing phase consisted of the following: lifting the right foot from the ground quickly, simultaneously pushing off the ground with great force with the left foot, and to increase the range of upswing motion of the shinai with high velocity. In the downswing phase, the shinai should be swung at a higher velocity, and the left shoulder should be flexed more when striking.

The above motions will lead to a shortening of movement time of men striking motion in kendo, and consequently an improvement in competition level.
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Name: Naoki Murase

Affiliation: Lecturer, Department of General Education, Salesian Polytechnic

Address: 4-6-8 Oyamagaoka, Machida, Tokyo 194-0215, Japan

Brief Biographical History:
2012-2014 Master’s Program in Graduate School of Health and Sport Sciences, Chukyo University
2014-2015 Doctoral Program in Graduate School of Health and Sport Sciences, Chukyo University
2015-2017 Assistant Professor, Department of General Education, Salesian Polytechnic
2017- Lecturer, Department of General Education, Salesian Polytechnic

Membership in Learned Societies:
• Japan Society of Physical Education, Health and Sport Sciences
• Japanese Academy of Budo