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ORIGINAL

Relationship between Ground Reaction Force and Attack Time According to the Position of Hand Segments during Counter Attack in Kendo

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Objective: The purpose of this study was to analyze the relationship between ground reaction force (GRF) and attack time according to the position of hand segments during counter attack in Kendo.

Method: The participants consisted of 10 kendo athletes (mean age: 21.50±1.95 yr, mean height: 175.58±5.02 cm, mean body weight: 70.96±9.47 kg) who performed standard head strikes (A) and counter attack with a preferred hand position of +10 cm (B), 0 cm (C), and -10 cm (D). One force-plate (AMTI-OR-7., USA) was used to collect GRF data at a sample rate of 1,000 Hz. The variables analyzed were the attack time, medial-lateral GRF, anterior-posterior GRF (AP GRF), peak vertical force (PVF), and loading rate.

Results: The total attack time was shorter in types A and C than in types C and D. The AP GRF, PVF, and loading rate had significantly higher forces in types C and D than in types A and C. The attack time (bilateral and unilateral leg support and total) was positively correlated with the GRF variables (vertical GRF and loading rate) during the counter attack in Kendo ($r = 0.779$ [R^2=0.607], $p < 0.001$).

Conclusion: The positions of the hand segments can be changed by various conditions of the opponent in Kendo competitions; however, the position preferred by an individual can promote the successful ratio of the counter attack.

Keywords: Kendo, Hand positions, Attack time, Counter attack, GRF

INTRODUCTION

The variability of sports performance is important not only in team matches (Gregson, Drust, Atkinson, & Salvo, 2010; James, Mellalieu, & Jones, 2005) but also in individual matches (Montelpare, McPherson, & Puumala, 2013; O'Donoghue, 2005). Sports performance factors are not as stable as physical measurements or physical examination results (Ogle & O'Donoghue, 2015). Although diverse factors can affect the variability, the biggest factor is the outstanding opponent (McGarry & Franks, 1994).

Several sports such as Taekwondo, Judo, Hapkido, and Wushu require stable defenses and swift attacks under different conditions set by the opponent. Among these sports, it is difficult to predict the outcomes of a Kendo match because the outcomes are instantly decided by a valid hit with bamboo swords.

Kendo literally means "the way of the sword" (Ogle & O'Donoghue, 2015). Kendo requires the alignment of the synchronization of the spirit, sword, and body. In a Kendo match, the fighter scores by striking or thrusting first (Min, Bae, & Lee, 2001). To win, the fighter needs to use diverse attack techniques and high precision (Min et al., 2001). Broadly, two types of attacks, namely attacking movements and counter-attacks, lead to scoring.

Standard attacks refer to simultaneous charging towards the opponent and striking with the sword. The technical characteristics have been defined by Park (2005), who stated that the angle of the left elbow is maintained during the backswing motion in a head attack. Furthermore, the balance between the pushing strength of the right arm and the pulling strength of the left arm leads to a successful strike. Lim (2000) stated that the optimal distance between the striker and the opponent for men and kote attacks were 247 cm and 193 cm, respectively, while the strike times were 1.10 sec and 0.64 sec, respectively. To attack effectively, the tip of the sword should not waver and not deviate from the midline of the opponent's body (Min et al., 2001). During the attack motion, the strength is considered to originate from the left leg, although the right leg moves forward towards the opponent (Broderick, Chart, & Ko, 2004). The stride length of the attacker, distance between the attacker and the opponent, and attack time are known to be important factors that determine the results of the attack (Min et al., 2001).

Another method of scoring, counter-attack, takes advantage of the instance when the opponent attacks to land a hit (Ogle & O'Donoghue,

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2015). This technique requires a simultaneous collaboration of both defense and offense. Furthermore, factors, such as the opponent's posture change and attack location, should be considered. Although the frequency of return techniques is high in Kendo matches, quantitative data on related techniques are limited, since the attacking conditions of the attackers and the postures of the defenders vary highly.

In Kendo, most fighters hold the swords, using both hands, and stand with the right foot in front of the left foot as a base stance (Koshida & Matsuda, 2013). The winners in kendo competitions showed a higher consistency of shorter attack time, and martial arts-trained practitioners exhibited faster speed of the hand segments during striking (Neto, Magini, & Saba, 2007). Victorious fighters show high consistency and short attack times. During the strike, the hand segments have the fastest speed (Neto, Magini, & Saba, 2007). Prominent strengths in Kendo are produced by the left lower and upper limbs. Therefore, the location of the hand segments is very important for precision, excellence, and strong attacks (Ogle & O'Donoghue, 2015). The location of the hand segments could affect the defensive and offensive techniques.

The attack success rate should be improved by aligning the synchronization of the spirit, sword, and body under different conditions set by the opponent. Most studies have been confined to analyzing standard attacks, such as head, wrist, and waist strikes, using kinematic data. Further, statistical analysis on the timing variability between the tip of the sword and the forward foot is limited. Improper attack postures can lead to injuries. Although Kendo is known to be a relatively injuryless sport, there is a high possibility of back pain (L3/4 and L4/5) after attacks due to the stress on the joints of the lower limb (Kishi & Morikita, 2009; Kishi, Morikita, Takasaki, Yamaguchi, & Suzuki, 2009). Schultzel, Schultzel, Wentz, & Bernhardt (2016) studied 307 Kendo fighters and reported that the most common location of injury is the sole and the ankle accounting for 65.1% of the injuries. Further studies should be conducted taking into account left/right and anterior/posterior (AP) shear forces that are parallel between the foot and the ground surface during attacks, maximum vertical ground reaction force (VGRF), load factors, etc. In other words, since the outcome of Kendo matches can be determined by instantaneous attacks or strikes under different conditions set by the opponent, it is important to avoid injuries and improve the quality of the techniques (Ogle & O'Donoghue, 2015).

Therefore, the goal of this study was to analyze the counter attack according to the location of the attacker's hand segments to determine the changes in factors such as time alignment and ground reaction force (GRF). Furthermore, a correlation analysis between the factors was conducted to obtain quantitative data.

METHODS

1. Subject

Ten male Kendo fighters were selected as the subjects of this study (mean age: 21.50±1.95 yr, mean height: 175.58±5.02 cm, mean weight: 70.96±9.47 kg). All participants had no episodes of musculoskeletal problems in their lower limbs within the last year and are proficient in counter-attacks. Prior to the study, the purpose and the content of the study were explained to the volunteering subjects, and their written consents were obtained.

2. Experimental procedure

Before the experiment, sufficient warm-up and attack practice times were provided to the participants. The distance between the front right foot and the strike zone was set to 1 m 70 cm at the preparatory stance. The strike zones were indicated using dummies at the same height as each participant's face. After the strike, the landing location of the striker was determined, and a GRF detector (AMTI-OR-7., USA) was installed. To calculate the time variables, two cameras (HDR-HC7/HDV 1080i, SONY) were used to film the motion. The filming speed was set to 60 frames/sec, and the exposure time was set to 1/500 sec.

For the experiment, a standard head attack (A) was performed followed by a counter-attack. To express the location of the hand segments during the counter-attack, the grip of the bamboo sword was removed (Figure 1). The location of the hand segments was defined as the height of the hand segments of the right hand during the preparatory stance of each subject ±10 cm vertically (preferred location, +10 cm [B], 0 [C], and -10 cm [D]). The GRFs produced by the landing

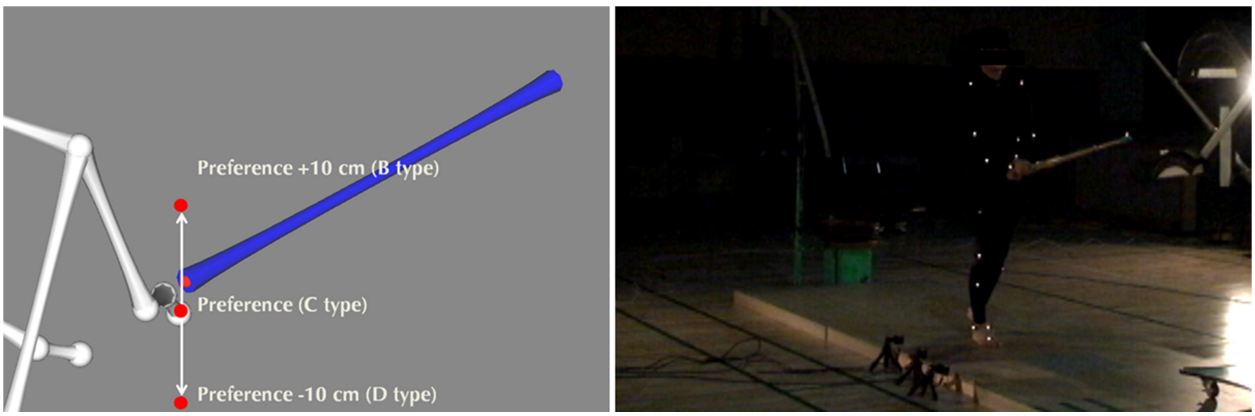

Figure 1. Positions of the hand segment during a counter attack

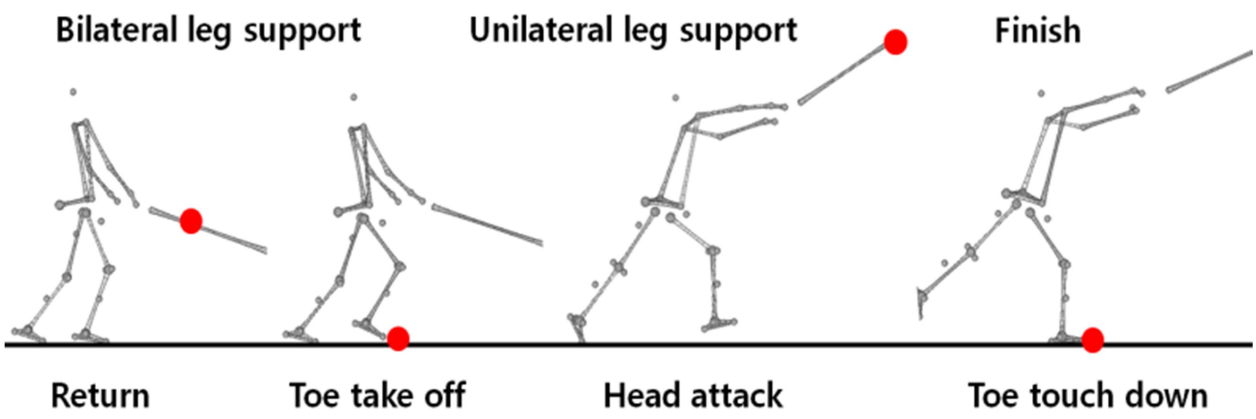

Figure 2. Events and phases during head strike

Table 1. Attack times according to wrist positions (unit: sec)

Section	Types				*F*	*P*	Post-hoc
	Standard (A)	+10 cm (B)	Preference (C)	-10 cm (D)			
BLS	0.10±0.01	0.18±0.08	0.16±0.06	0.18±0.06	5.258	.005**	A>B, C, D
ULS	0.30±0.05	0.25±0.05	0.25±0.06	0.27±0.05	3.605	.026*	B, C>A, D
F	0.02±0.01	0.03±0.01	0.03±0.01	0.03±0.01	.300	.825	–
Total	0.42±0.04	0.46±0.11	0.45±0.10	0.50±0.07	1.477	.243	–

Note: $^{**}p < 0.01$, $^{*}p < 0.05$; BLS: bilateral leg support, ULS: unilateral leg support, F: finish, Total: BLS-F

of the right foot during the attack were collected at a sampling rate of 1,000 Hz, and the motion was determined as completed once the entire sole of the right foot came in contact with the GRF measurer. The counter-attack was defined as the instantaneous reaction and the head attack when the opponent strikes between the leather tie and the handle with match-equivalent attack strength.

3. Event

The time between the ready stance and the moment the right hand (front foot) comes in contact with the ground surface after striking the dummy was divided into a total of four events and three phases (Figure 2).

- Event

Event 1: Time between the ready stance and the moment the sword comes in contact with the opponent

Event 2: The moment the right foot detaches from the ground to charge-in and attack

Event 3: The moment the tip of the sword touches the dummy

Event 4: The moment the front sole of the right foot comes in contact with the ground surface after the attack

- Phase

Phase 1: Support on both feet

Phase 2: Support on one foot

Phase 3: Attack termination

4. Data processing

To analyze the attack time and counter-attack time, the Kwon 3D XP ver 4.0 (Visol., Korea, 2007) program was used. The filming speed was 60 frames/sec. Therefore, each frame was multiplied by 0.016667 sec to calculate the time. The calculated values (standard attack, counter-attack ×3) were analyzed using the multivariate analysis of variance. If a significant difference was observed, the post-hoc test: Duncan was used. The significance level for all statistics was set to a=.05.

RESULTS

1. Attack time

In the counter-attacks, the duration of each phase is shown in (Table 1). In the bilateral leg support (BLS), type A had the shortest attack time by a significant margin. In the unilateral leg support (ULS), types B and C had shorter attack times than types A and D by a significant margin. In the Finish and Total, no significant differences were observed between the counter-attack types.

Table 2. GRF variables according to wrist positions

Section	Types				*F*	*P*	Post-hoc
	Standard (A)	+10 cm (B)	Preference (C)	-10 cm (D)			
ML GRF (N/BW)	0.09±0.26	-0.13±0.22	0.02±0.35	-0.12±0.31	1.885	.156	–
AP GRF (N/BW)	-0.01±0.34	-0.36±0.14	-0.19±0.24	0.29±0.21	17.598	.001***	D>A>C>B
VGRF (N/BW)	2.86±0.80	4.55±0.83	3.30±1.07	4.38±0.74	12.525	.001***	B, C, D>A
Loading rate (N/BW·sec^{-1})	34.17±19.13	65.61±17.76	44.58±22.31	61.41±10.13	7.716	.001***	B, C, D>A

Note: ***p < 0.001; GRF: ground reaction force, ML: Medial/lateral, AP: anterior/posterior, VGRF: vertical ground reaction force

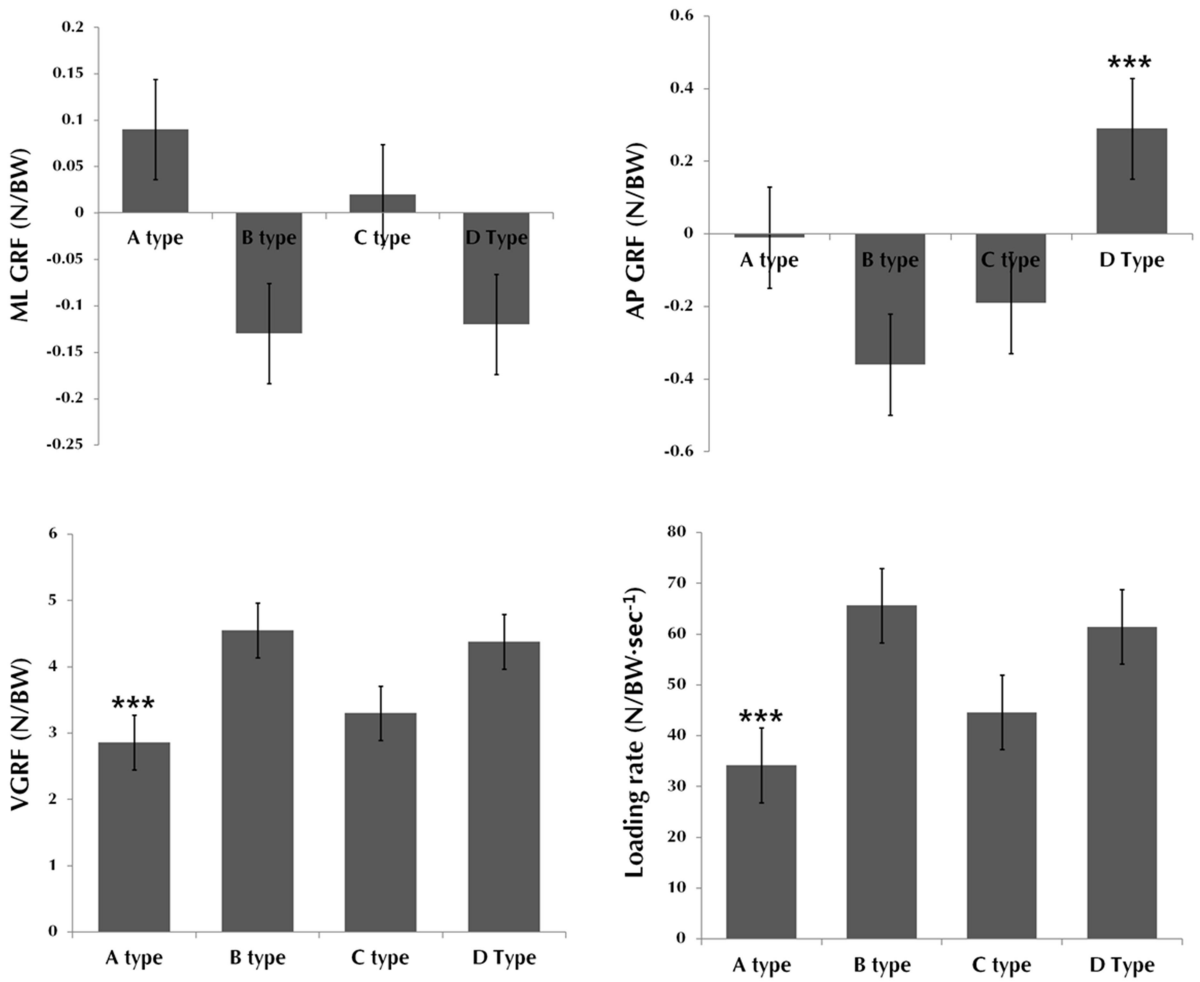

Figure 3. GRF variables. GRF: ground reaction force, AP: anterior/posterior, VGRF: vertical ground reaction force

2. GRF variables

Changes in the GRF variables of the front foot after the head attacks are shown in (Table 2) and (Figure 3). No significant differences in the ML GRF were observed in the different hand segment positions. Types A and C had the lowest average AP GRF values by a significant margin. Type A had the lowest VGRF and loading rate changes by a significant margin.

Using the standard Kendo attack (type A) as a reference, each variable in the counter-attacks (types B, C, and D) was standardized (%), and a correlation analysis was conducted. The results are shown in (Table 3) and (Figure 4).

In terms of the attack time, the BLS and Total showed a very high static correlation at r = .801 (R^2=0.642, p < 0.001) as well as the ULS and Total at r = 0.779 (R^2=0.607, p < 0.001). The GRF variables VGRF and load rate showed a similar static correlation at r = 0.821 (R^2=0.673, p < 0.001).

Table 3. Correlation between the attack time and GRF variables during Kendo (unit: *r*)

Section	Attack time			GRF variables			
	ULS	F	Total	ML GRF	AP GRF	VGRF	Loading rate
BLS	.293	-.235	.801***	.027	-.008	.207	.197
ULS		-.322	.779***	.133	.055	.212	.235
F			-.235	.190	.050	-.027	-.138
Total				.175	.067	.204	.222
ML GRF					-.071	.129	-.018
AP GRF						-.253	-.211
VGRF							.821***

Note: ***p < 0.001; BLS: bilateral leg support, ULS: unilateral leg support, F: finish, Total: BLS-F, GRF: ground reaction force, AP: anterior/posterior, VGRF: vertical ground reaction force

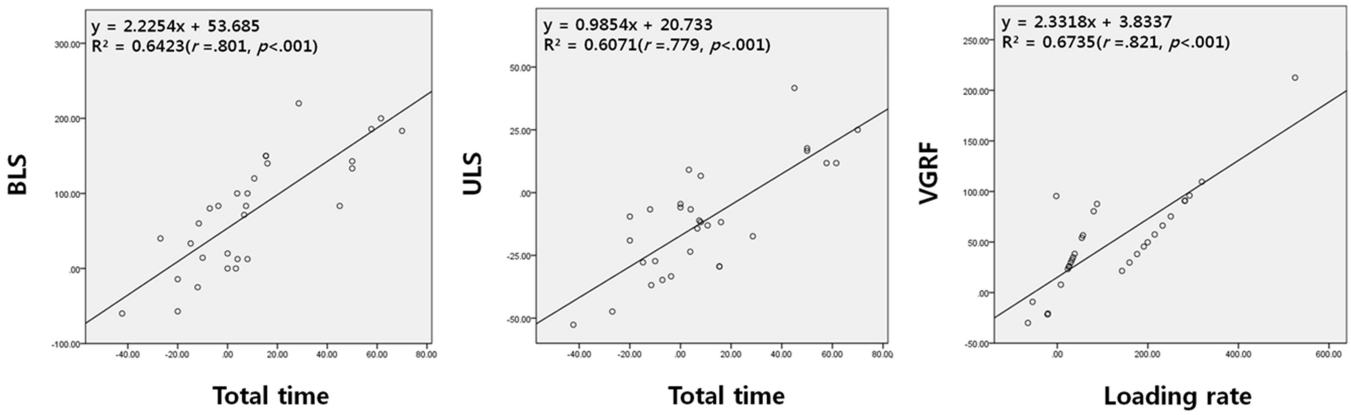

Figure 4. Scatter plot and regression equation. BLS: bilateral leg support, ULS: unilateral leg support, VGRF: vertical ground reaction force

DISCUSSION

Outstanding Kendo fighters perform fast and consistent attacks on the target (Ogle & O'Donoghue, 2015). It is important to estimate the opponent's abilities in combat sports and to process data effectively to make quick and effective decisions during attacks (Delignières, Brisswalter, & Legros, 1994; Guizani, Bouzaouach, & Tenenbaum, & Kheder, 2006). In this study, the timing and the GRF variables during counter-attacks were quantitatively analyzed in accordance with the position of the attacker's hand segments. A correlation analysis was conducted between each variable.

The results show that the average attack time, with an optimal distance between the fighter and the target (1 m 70 cm), was 0.42 sec for the standard attack (A) and 0.45 sec for counter-attack type C, which was faster than those for types B and D. Although the attack times of the counter-attacks did not significantly differ in accordance with the position of the hand segments, type D was the slowest at 0.50 sec. In the BLS, type A had a shorter attack time than types B, C, and D. Since a head attack is performed without predicting the opponent's attack, it can be inferred that the restriction of accompanying unnecessary movements yielded the shorter attack time. When the bamboo sword undergoes backswing or struck down, highly skilled fighters use the epicenter of the sword, i.e., inertia, to convert potential energy into kinetic energy (Yoo, 2014). Moreover, the linear and angular velocities are closely correlated during the head attack motion of Kendo. The angular velocity of the body extremities and the force distribution in the segments affect the maximum swing speed (Yoo, 2014).

When a BLS is followed by a ULS, type A shows the slowest speed. It can be inferred that this is because of the conversion of potential energy into kinetic energy using the sword's inertia at the highest point of backswing. Conversely, since counter-attacks are performed by attacking the head after defending from the opponent's attack, it relies more on the velocity rather than the strength and kinetic energy of the sword. As observed in type B, the hand segments upregulated by +10 cm restricted the movement of the wrist and ineffectively used the inertia of the sword. Although type D could easily use the backswing trajectory since the position of the hand segments are at -10 cm, an unnecessary spatial movement was added, which delayed the attack time.

The correlation analysis showed that the % time ratio of the BLS and ULS in the standard attack and counter-attack was very similar to the % time ratio of the total time. Conversely, no correlation was observed between each phase and finish. From the ready stance to the landing

of the foot after striking the target, the ki, sword, and body should be aligned (Min et al., 2001), and it should be performed as a single movement. However, it can be inferred that the alignment was unsuccessful in all the trials in this study. In other words, perfect attack timing can be defined as a simultaneous strike of the tip of the sword (E3) and landing of the right foot (E4) with a 0-sec lapse between the two. However, a discrepancy of 0.03 sec was observed in all counter-attacks. In further studies, factors such as changes in the hand segment position of the attacker, stance type, attack distance, and target location should be considered for more detailed analysis of the hit that connects at the same time the lead foot touches down the ground.

Among the muscles, tendons, ligaments, and skin that make up the segments of the body, the skin bears the gravitational force. The gravitational torque changes in accordance with the increase in velocity or acceleration of the arm segments (Kodek & Munih, 2003). Changes in the center of the body mass are affected by the postural regulation of each body segment (Benda, Riley, & Krebs, 1994). In this study, the GRF variables of the front foot when it came in contact with the ground surface after the sword tip struck the target were analyzed. The results show that the ML GRF values did not significantly differ between the different types of counter-attack. It can be inferred that since physical regulations on the AP directions are important for all attack types, lateral movements of the center of the body mass and the right leg are unnecessary. Although type A had the lowest AP GRF value, type B showed the highest braking force (−). Unlike type B, type D showed a (+) value, which is observed in the acceleration stage of gait or running. VGRF and loading rate showed a high direct correlation and were observed to be the highest in types B and D. Vertical changes in the hand segment positions affect the magnitude and direction of the GRF as well as the type of impact. Furthermore, the hand segment position affects the changes in the center of the mass of the upper arm, forearm, and body (Benda et al., 1994), which changes the postural regulation during attacks. The attacker's body has to transition into defense rapidly moving towards the opposite direction after attacking. However, type D shows a positive driving force, which can leave the attacker vulnerable to the opponent's attacks if the transition to defense fails. In Kendo, a large stress is applied to the lower limbs during the attacking lunge motion (hip flexion) and the postural recovery (hip extension) (Kishi & Morikita, 2009; Lee, Lee, & Lee, 2007; Lee & Lee, 2008). During this process, tangential shear stress is produced, which is a mechanical stimulus that can cause injuries (Kishi & Morikita, 2009; Kishi et al., 2009; Medved, 2000). The driving force observed in type B could increase the amount of shear stress applied on the joints of the lower limb.

In summary, counter-attack type C (preferred position) effectively regulated the GRF and showed the fastest attack time. Although Kendo is a combat sport where the position of the hand segments could vary in accordance with the different conditions set by the opponent, maintenance of the preferred hand segment position is an important factor that could increase the success rate of the attacks and decrease the possibility of lower limb injuries. To improve counter-attack techniques, not only the GRF variables but also the trajectory of the center of the mass of each segment should be considered, and the time coordination of the joint's maximum flexion/extension should be simultaneously investigated.

CONCLUSION

The goal of this study is to investigate the correlation between the attack time and the GRF variables according to the position of the hand segments in Kendo. Standard attack (A) and three types of counter-attacks (preferred position, +10 cm [B], 0 cm [C], and -10 cm [D]) were performed by 10 Kendo fighter subjects. Attack time, left/right GRF, AP GRF, maximum VGRF, and load factor were compared and analyzed. The following results were obtained. The total attack times were shorter in types A and C than in types B and D. The AP GRF, maximum VGRF, and load factor were higher in types A and C than in types B and D by a significant magnitude. The correlation analysis showed that the attack time (BLS, ULS, and total) and GRF variables (maximum VGRF and load factor) had high static correlations (r = 0.779). In similar sports, relatively more proficient athletes showed faster reaction times than athletes who are relatively not used to physical activities. To maintain optimal physical conditions, a high level of focus is needed (Guizani et al., 2006). Further studies should be conducted on attack movements to develop and apply a training program that improves the reaction speed of Kendo fighters.

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