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THE EFFECTS OF DEFENSIVE FOOTWORK ON THE KINEMATICS OF TAEKWONDO ROUNDHOUSE KICKS

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ABSTRACT

The roundhouse kick is the most frequently used in Taekwondo sparring matches. In order to execute the kicks, footwork techniques are critical, especially for players' counterattack. Therefore, the purpose of this study was to biomechanically examine the effects of different defensive footwork on the Taekwondo roundhouse kicks. Ten male university elite Taekwondo athletes executed roundhouse kicks with seven back-step conditions. The duration of the phases of the kick, the center of mass displacement, trunk angle, left-foot-axis-angle, and kicking foot velocity were obtained through a three-dimensional video motion analysis. These variables were compared to the conditions using repeated measure analysis of variance, and they changed significantly in response to different back-step conditions. It was concluded that the most effective back-step angle for defense and attack was 2/3 of 90° between the x- and y-axes. Also, as the one-step-back-step's angle increases, foot velocity could be increased; on the contrary, when the one-step-back-step's angle was reduced, the Taekwondo athlete could execute a fast counterattack, but it could be exposed to the opponent's attack. Therefore, it would be necessary to make efforts to compensate for the strengths and weaknesses of the types of back-step techniques so as to avoid the opponent's attack.

Key words: taekwondo roundhouse kick, kinematics, footwork

EFECTOS CINEMÁTICOS DE LAS TÉCNICAS DEFENSIVAS DE PIERNAS, EN LA PATADA CIRCULAR DE TAEKWONDO

RESUMEN

La patada circular es la más utilizada en los combates de Taekwondo. Para ejecutar las patadas, las técnicas de juego de pies son fundamentales, especialmente para el contraataque de los jugadores. Por lo tanto, el propósito de este estudio fue examinar biomecánicamente los efectos de diferentes movimientos defensivos en las patadas circulares de Taekwondo. Diez atletas masculinos de élite universitarios de Taekwondo ejecutaron patadas circulares con siete condiciones de retroceso. La duración de las fases de la patada, el desplazamiento del centro de masa, el ángulo del tronco, el ángulo del eje izquierdo y la velocidad del pie de patada se obtuvieron a través de un análisis de movimiento de video tridimensional. Estas variables se compararon con las condiciones utilizando el análisis de varianza de medida repetida, y cambiaron significativamente en respuesta a diferentes condiciones de retroceso. Se concluyó que el ángulo de retroceso más efectivo para defensa y ataque fue 2/3 de 90 ° entre los ejes x e y. Además, a medida que el ángulo de un paso hacia atrás aumenta, la velocidad del pie podría aumentar; por el contrario, cuando se reduce el ángulo de un paso atrás, el atleta de Taekwondo podría ejecutar un contraataque rápido, pero podría estar expuesto al ataque del oponente. Por lo tanto, sería necesario hacer esfuerzos para compensar las fortalezas y debilidades de los tipos de técnicas de retroceso para evitar el ataque del oponente.

Palabras clave: control motor, biomecánica, neuropsicología, marcha, tarea dual

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INTRODUCTION

Taekwondo is a traditional Korean martial art and a full-contact combat sport. It is also well-known for its various and powerful kicking techniques. Among a variety of kicking skills, the roundhouse kick is the most frequently used in Taekwondo sparring matches (Koh & Watkinson, 2002) because it can be simply adjusted based on the opponent's movements. Furthermore, it is suitable for scoring points in an unexpected attack (Kim, Kwon, Yeunga, & Kwon, 2010). Pieter and Pieter (1995) concluded that the roundhouse kick is the fastest kicking technique, which may explain the use of roundhouse kicks in competitions.

The roundhouse kick is performed by first raising the kicking leg's knee straight up in a chambered position; then, the hip is rotated, and the knee is extended in a snapping forward movement to strike the opponent with an instep surface (Falco et al., 2009). The kicking leg performs the kick while the supporting leg tolerates the body weight and provides hip pivoting and the trunk and support leg serve an essential role regarding counter-movement and stability (Kim, Kwon, Yeunga, & Kwon, 2010). Especially, the movement of the supporting leg's ankle is vital for maintaining kick balance. Research on the roundhouse kick has explored a wide range of biomechanical variables, such as impact force (Estevan, Alvarez, Falco, & Molina-Garcia, 2011; Estevan, Falco, Alvarez, & Molina-Garcıa, 2012; Falco, et al., 2009), kicking speed (Liu, Tan, An, & Wang, 2000; Tang, Chang, & Nien, 2007), and execution time (Estevan, Alvarez, Falco, & Molina-Garcia, 2011; Falco et al., 2009; Liu, Tan, An, & Wang, 2000; Tang, Chang, & Nien, 2007). Researchers also focused on the participant characteristics: skill level of the participants (Shin & Choi, 2001) and weight category (Estevan, Falco, Alvarez & Molina-Garcia, 2012). In terms of trial conditions that can affect kick performances, previous research has focused on stance positions (Estevan, Falco, & Jandacka, 2011), dominant leg (Falco, et al., 2009; Tang, Chang, & Nien, 2007), the effect of the existence of a target (Oh & Choi, 2004), and the proximity of the kicking foot (Kong, Luk, & Hong, 2000; Li, Yan, Zeng, & Wang, 2005).

Recently, Menescardi and colleagues (2015) found that winners in the National University Taekwondo Championship games executed more counterattacks, which indicates that Taekwondo athletes may need to perform the counterattack as efficiently as possible to win. During the sparring match, taekwondo athletes can often be forced to execute kicks by reacting their opponent's attack and in this counterattack process, footwork can affect the roundhouse kick performance (Kim, Chung, & Lee, 1999).

Typical Taekwondo stances with their legs front and back along the direction of attack are used by Taekwondo athletes, and they frequently switch their stance back and forth during the sparring match. If the opponent attacks in an open stance, the defender usually counterattacks after stepping back to avoid the opponent's attack. Therefore, the researchers need to analyze attack and defensive motions simultaneously. Studying counterattack using roundhouse kicks executed from various angles of defensive back-steps may provide a better understanding of the ideal back-step footwork on roundhouse kick performances and practical training methods. However, to date, there has not been a study that combines both the defensive footwork and the attack in the analysis. Therefore, the purpose of this study was to biomechanically examine the effects of different angles of one-step-back-step footwork which is used for defense as the attack of the counterpart in Taekwondo roundhouse kick performances. The research questions were: 1) how different footwork angles would change the duration time and the distance of the center of mass; 2) how different footwork angles would change the trunk angle and left-foot-axis-angle; 3) how different footwork angles would change the kicking foot's velocities. It was hypothesized that the footwork would affect the temporal and spatial parameters in Taekwondo athletes.

METHOD

Participants

Ten male university elite Taekwondo athletes were recruited for this study. The mean body mass, height, age, and Taekwondo career years of the participants were 60.6±3.7 kg (54.9 to 66.7 kg), 173.1±4.3 cm (167.0 to 179.0 cm), 21.7±0.5 years (21 to 22 years), and 8.9±1.1 years (7 to 10 years), respectively. All participants were free of serious muscular or joint/ligament problems within 6 months prior to the study. Informed consent was obtained from all participants before the experiment. The study followed the policy statement with respect to the Declaration of Helsinki.

Instrumentation

An MX-13 Vicon™ motion capture system (Vicon, Ltd., Oxford, UK), comprised of seven high-speed (Sampling frequency: 250 Hz) and MX control interfaces were used to capture the locations of the reflective markers on the participants' extremities and trunk. A calibration frame with 36 control points (1m wide, 2m high, and 2m long) was used for camera calibration based on the Direct linear transformation (DLT) method (Abdel-Aziz et al., 2015). The calibration frame was aligned in such a way that the kicking direction was used as the anteroposterior axis (Y) while the longitudinal axis (Z) was aligned vertically upward, and the transverse axis (X) was aligned left to right. For the kinematic analysis, 38 retro-reflective markers of 14 mm diameter were attached to specific anatomical landmarks of all participants and the target mitt. Three-dimensional coordinates of the 38 markers were reconstructed with the

Kwon3D software (Version 4.1, Visol, Seoul, Korea). The anatomical landmarks were as follows (Figure 1): the left and right forehead; left and right back of the head; the 7th cervical vertebrae; the 10th thoracic vertebrae; the clavicle; sternum; the right scapula; the left and right shoulder at the acromio-clavicular joint; the lateral epicondyle of the left and right elbow; the left and right forearm between the elbow and wrist; the medial and lateral left wrist; the left and right hand second metacarpal head; the left and right anterior superior iliac spine; the left and right posterior superior iliac spine; the lateral epicondyle of the left and right knee; the left and right thigh between the lateral epicondyle of the knee and greater trochanter; the left and right lateral malleolus; the left and right tibia between the lateral epicondyle of the knee and lateral malleolus; the left and right foot second metatarsal head; and the left and right heel placed on the calcaneous. The marker coordinates were used to model the body as a combination of multiple rigid segments connected by frictionless joints, including each pelvis, trunk, right thigh, right lower leg, and foot segments. The target was a hand-held kicking pad (All-Star®, Tae Hwa Sports, Seoul, Korea). An assistant held the target with one hand, and the target was set at waist level for the roundhouse kick. One reflective marker was placed on the target in order to determine the onset of the foot contact to the target.

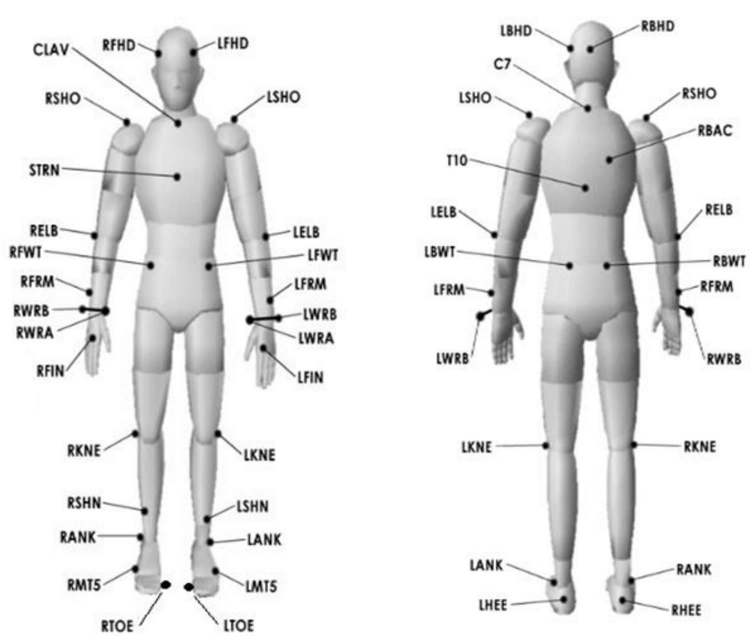

FIGURE 1: *Anterior (Left) and posterior (Right) views of the reflective markers.*

Experimental procedure

Participants were allowed to warm up until they felt comfortable with kicking movements. The routine warm-up was followed by their own preferred method of stretching and performance of practice kicks. Since all participants were right-footed, the left leg was used as the support leg while the right was used as the kicking leg in trials. A double-handed target mitt was leveled to the participant's waist and tilted down slightly for a comfortable kick performance. For the different-angle roundhouse kicks especially, all participants practiced until they were accustomed to the specific angles of step-back. Then, the participants were asked to execute kicks immediately after the LED flashing which was the start signal and to hit the given target as fast as possible with the barefoot of their right leg. Five trials were performed, and a 2-minute break was given before collecting data in the next trial. A static trial was collected with the participant standing in the anatomical position. Medial markers (medial epicondyles and malleoli) were detached after the static trial was finished to prevent any interferences during the kicking trials.

Trial conditions

All participants performed the roundhouse kick with/without the one-step-back-step movement. In the one-step-back-step movement, a participant's back foot became a pivot. While both knees were bent, the forefoot had to move backward quickly and step back. The upper body changed its position to be ready for the roundhouse kick as a counterattack. Seven conditions were used (Figure 2): the roundhouse kick without footwork, preferred-back-step (PBS) roundhouse kick, and the one-step-back-step roundhouse kick at different angles (0°, 22°, 45°, 67°, 90°). The angle between the left foot and the x-axis is 0°, 22°, 45°, 67°, and 90° clockwise. Also, each participant's preferred target distance was used.

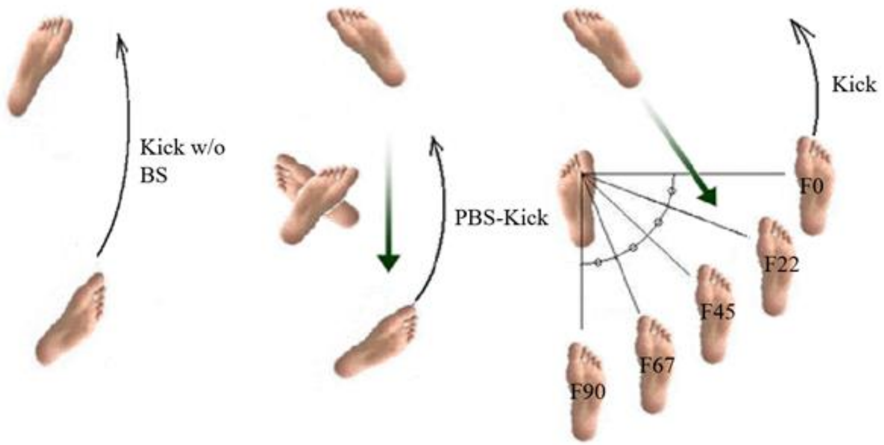

FIGURE 2: *Type of kicks.*

Data reduction and analysis

To facilitate data analysis, a group of meaningful events was defined: Signal, Start, Preparation, Kick, Minimum Knee Flexion (MKF), and Impact (Figure 3). Among the events, Start (the beginning of the motion for back-step) was visually identified based on the velocities of the right toe and heel markers. Preparation was defined as the back-step was finished and was ready to kick. Kick was defined as the instant the kicking foot toe left the ground. MKF was the time point at which the kicking leg showed minimum knee flexion. Impact was defined as the marker on the target mitt started to move. Also, five phases were defined based on the events: Reaction (Signal to Start), Back-step (Start to Preparation), Toe-off (Preparation to Kick), Flexion (Kick to MKF), and Extension (MKF to Impact). The Back-step phase was excluded in the kick without back-step.

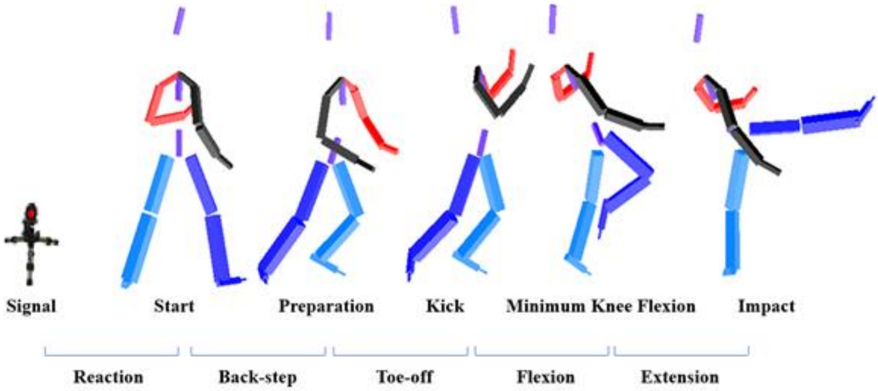

FIGURE 3: *The roundhouse kick task and the events and phases of the kick.*

One best trial per condition was selected for marker tracking. Motion capture data were digitized to track reflective markers by the Kwon3D software. The three-dimensional coordinates of the reflective markers were generated via a DLT algorithm (Abdel-Aziz et al., 2015) and smoothed using an 8 Hz low-pass fourth-order Butterworth filter. The kinematic variables used in this study were the duration of the phases of the kick, joint and body angles, and center of mass displacement. The duration of the phases of the kick variable of the kicking performance was analyzed from the event of Preparation to each event and total time. The duration of the phases of the kick variable was calculated using the following formula:

$$t(i\sim f) = (F_f - F_i) \times \frac{1}{frame\ \ rate}$$

where, $t(i\sim f)$ = the time required, F_f = the frame number of each event end, F_i = the frame number of each event start

Also, the angular variable in this study was trunk angle, and the angle between two adjacent segments was obtained by using the dot product of the vector. That is, the angle θ between two vectors U (X_i, Y_i, Z_i) and V (X_j, Y_j, Z_j) was calculated using the following formula:

$$\theta = \cos^{-1}\frac{U \cdot V}{|U| \cdot |V|} \qquad \theta = \cos^{-1}\left[\frac{a_x b_x + a_y b_y + a_z a_z}{\sqrt{a_x^2 + a_y^2 + a_z^2}\sqrt{b_x^2 + b_y^2 + b_z^2}}\right]$$

In addition, the definition of the left-foot-axis-angle, which could identify the hip, knee, ankle joint angle, and left foot movements in the body segments, was shown in Figure 4.

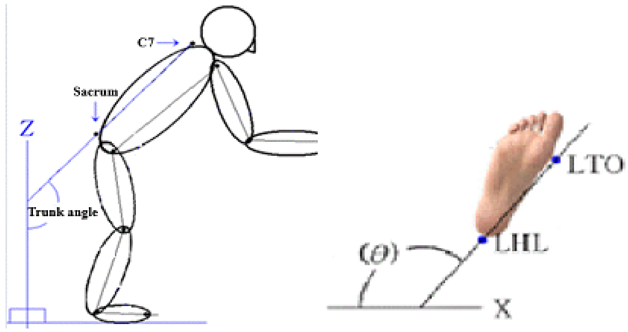

FIGURE 4: *Definition of trunk and left-foot-axis-angle.*

The linear velocity variable used in this study was the kicking foot. The velocity was first calculated for each of the X, Y, and Z components using the following equation, and then the X, Y, and Z components were synthesized in order to obtain the resultant velocity:

$$X_{i=}\frac{X_{i+1}-X_{i-1}}{2\Delta t}$$

where X_{i+1}: *i*-first *X* coordinates, X_{i+1}: *i*+first *X* coordinates, X_i: i^{th} *X* component velocity

$$V=\sqrt{X_i'^2+Y_i'^2+Z_i'^2}$$

where V: i^{th} resultant velocity, X'_i: i^{th} *X* component's velocity, Y'_i: i^{th} *Y* component's velocity, Z'_i: i^{th} *Z* component's velocity.

The center of gravity coordinate (C_i) of Segment *i* was calculated by the following formula:

$$c_i = (1 - p_i) \,.\, P_i + p_i \,.\, D_i$$

p_i: The ratio of the center-of-gravity distance from the proximal end to the segment length,

P_i, D_i: Coordinates of segmental proximal and distal ends.

The location of the center of mass was calculated by the following formula:

$$\frac{\sum_i (c_i \cdot m_i)}{M}$$

m_i: Mass of the segment, *M*: Whole body mass.

One-way repeated ANOVA with the footwork being a within-subject factor was used to compare dependent variables among the footwork conditions (PBS kick, F0, F22, F45, F67, and F90). Post-hoc tests were conducted with the Bonferroni adjustment. Alpha was set at 0.05 in all statistical analyses.

RESULTS

The duration of the phases of the kick

The duration of the phases of the roundhouse kicks is shown in Table 1. The roundhouse kick without back-step took 0.25 sec (35.5%) in the Reaction phase, 0.21 sec (31.9%) in the Toe-off phase, 0.12 sec (19.0%) in the Flexion phase, and 0.09 sec (13.6%) in the Extension phase. The back-step and roundhouse kicks took 1.12 sec (PBS roundhouse kick), 0.92 sec (F0), 22.12 sec (F22), 45.11 sec (F45), 1.16 sec (F67), and 1.23 sec (F90), respectively, and the duration of the phases of the kick statistically significantly increased as the back-step angles increased. Although there were no statistically significant differences in the duration of the phases of the kick required for the reaction phase and the extension phase, the duration of the phases of the kick required increased as the back-step angle increased. Therefore, there were significant differences in the Toe-off phase and Flexion phase.

TABLE 1
Duration of time required by each phase.

	Reaction	Back-step	Toe-off	Flexion	Extension	Total
Kick W/O BS	0.23 ±0.03		0.21±0.06	0.12±0.02	0.09±0.01	0.65±0.08
PBS Kick #2	0.22±0.07	0.57±0.11	0.12±0.06	0.11±0.01	0.10±0.01	1.12±0.23
F0 #3	0.20±0.04	0.49±0.10	0.08±0.03	0.09±0.02	0.10±0.02	0.96±0.15
F22 #4	0.21±0.05	0.52±0.12	0.09±0.05	0.11±0.02	0.10±0.03	1.02±0.21
F45 #5	0.23±0.04	0.56±0.12	0.11±0.05	0.11±0.02	0.11±0.02	1.11±0.18
F67 #6	0.22±0.05	0.60±0.11	0.13±0.05	0.12±0.02	0.10±0.02	1.16±0.20
F90 #7	0.22±0.05	0.64#3±0.08	0.16#3±0.07	0.13#3±0.03	0.09±0.02	1.23#3±0.17
f	.388	2.580	2.860	3.398	.703	2.533
sig.	.855	.036*	.023*	.010**	.624	.039*

In the table, the notation '#n' indicates a significant level (p <0.05) between the corresponding types
*Unit: sec, *** : p<.001, ** : p<.01, * : p<.05*

The center of mass displacement

As a result of examining the center of mass displacement in each phase of the roundhouse kick without back-step, the center of the mass moved about 9.3 cm toward the target point and the left side by 2.6 cm in the Toe-off phase where the right foot took off the ground. In the Flexion phase, the center of mass moved about 13.0 cm toward the target point, 2.6 cm to the left, and upward by 9.8 cm. In the Extension phase, the center of mass moved about 9.7 cm to the target point, 1.7 cm to the left, and 3.1 cm upward.

The preferred-back-step kick moved in the opposite direction to the target point in the y-axis-46.1 cm and in the z-axis -9.5 cm in the Back-step phase; this means the center of mass was lowered due to the knee bending for absorbing the impulse generated by the movement. Also, in the Toe-off phase, the center of the mass moved the x-axis -2.1 cm, the y-axis 5.0 cm, and the z-axis 7.9 cm; in the Flexion phase the center of mass moved -2.0 cm, 10.0 cm, and 11.7 cm; and in the Extension phase, it moved -1.6 cm, 10.0 cm, and 3.8 cm, respectively. Assuming that Preparation was the origin and upon converting the coordinate values, in the MKF event, the x-, y-, z-axes were -4.1 cm, 15.1 cm, and 19.6 cm, respectively; in the Impact event, the x-, y-, z-axes were -5.7 cm, 25.1 cm, and 23.4 cm, respectively, which showed that the displacement in the vertical direction was larger than the horizontal displacement. There were statistically significant differences in the displacements of the center of mass with the increase of the angle of footwork in the Back-step, Toe-off, and Flexion phases.

TABLE 2
The center of mass displacements.

		Back-step	Toe-off	Flexion	Extension	Total
Kick W/O BS	x		-2.6±0.9	-2.6±0.8	-1.7±0.5	-6.9±1.3
	y		9.3±4.5	13.0±2.6	9.7±2.0	32.1±7.3
	z		1.4±3.0	9.8±1.8	3.1±1.7	14.4±2.4
PBS Kick #2	x	0.1±4.9	-2.1±1.4	-2.0±1.2	-1.6±1.0	-5.6±5.2
	y	-46.1±11.2	5.0±4.3	10.0±2.4	10.0±2.7	-21.1±7.9
	z	-9.5±3.7	7.9±2.7	11.7±1.3	3.8±1.1	13.9±1.9
F0 #3	x	9.0±5.4	-1.6±1.4	-3.3±0.8	-3.3±0.7	0.8±5.1
	y	-19.6#2±4.1	-0.8#2±1.3	2.1#2±1.7	3.5±2.4	-14.7#2±6.2
	z	-2.0#2±3.1	3.0±1.5	7.2±1.7	3.6±1.3	11.9±3.7
F22 #4	x	8.0±11.2	-2.1±1.9	-4.0±0.7	-3.2±1.4	-1.3±9.2
	y	-25.0#2±8.9	0.5#2±2.3	4.3±1.7	5.0±2.8	-15.2#2±6.7
	z	-3.5#2±2.0	3.2±1.3	8.8±1.3	3.5±1.2	12.1±2.5
F45 #5	x	13.0#2±5.3	-3.8#2±1.9	-5.2±0.9	-4.3±1.3	-0.2±4.9
	y	-38.5#3±8.0	3.1#3±3.4	7.7±2.7	8.3±2.7	-19.4#3±7.4
	z	-6.7#3±1.8	6.3±2.5	10.6±2.0	3.7±1.3	13.8±1.9
F67 #6	x	6.7±6.7	-3.5±1.5	-4.3±1.7	-3.0±1.4	-4.1±8.2
	y	-45.5#3,4±11.8	4.9#3,4±4.0	10.6±3.7	9.5±3.3	-20.6#3,4±9.2
	z	-10.7#3,4±2.4	7.2±2.4	11.6±1.7	3.4±1.2	11.6±3.7
F90 #7	x	0.3#4±3.5	-2.1#5±2.1	-2.2±1.9	-1.1±1.2	-5.2±5.1
	y	-53.7#3,4,5±9.0	8.2#3,4±4.6	13.6#3±4.2	10.6±3.5	-21.3#3,4±10.1
	z	-11.3#3,4,5±2.2	8.7±3.5	11.9±3.2	2.9±2.1	12.2±2.1
f	x	5.917	5.695	3.542	1.749	4.075
	y	20.877	16.756	5.582	1.401	10.936
	z	21.992	3.011	.848	1.267	2.931
sig.	x	.000***	.000***	.008**	.139	.003**
	y	.000***	.000***	.000***	.239	.000***
	z	.000***	.018*	.522	.292	.021*

In the table, the notation '#n' indicates a significant level (p <0.05) between the corresponding types
*Unit: cm, *** : p<.001, ** : p<.01, * : p<.05*

Trunk angle

As shown in Table 3 and Figure 5, the upper body starts with 167.7° which did not change much until the Kick event. In the Flexion phase, the trunk angle began to decrease to the end. This is because the body was pushed backward to kick farther. Also, there was a statistically significant difference among the different angle footwork in the Preparation event: F0 (166.8°), F22 (167.2°), F45 (162.1°), F67 (159.3°), and F90 (158.3°). The trunk angle of the PBS Kick in the Preparation event was 157.7°, and it decreased as the rotation angle increased. During the Toe-off phase, the trunk angle increased due to the rotational motion of the pelvic. In particular, F0 showed a lower trunk angle than the other footwork, which was thought to be due to the backward movement of the trunk along with the trunk rotation.

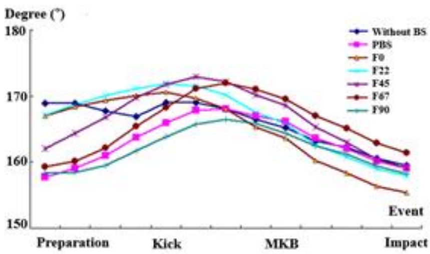

FIGURE 5: *Trunk motion pattern.*

TABLE 3
Trunk angles.

	Preparation	Kick	MKF	Impact
Kick W/O BS	167.7±4.6	169.0±3.7	165.3±5.2	160.1±5.3
PBS Kick #2	157.7±4.3	166.0±3.1	166.1±4.4	159.5±5.0
F0 #3	166.8#2±4.8	170.3±3.6	163.7±7.2	155.6±5.5
F22 #4	167.2#2±5.4	171.9#2±3.5	165.9±7.9	158.0±8.5
F45 #5	162.1±6.0	171.8±5.0	168.6±4.6	159.1±5.1
F67 #6	159.3±6.0	168.3±3.7	169.6±5.5	161.7±6.6
F90 #7	158.3#3,4±4.9	163.8#3,4,5±3.6	164.4±6.3	158.3±7.7
f	6.598	7.514	1.407	.892
sig.	.000***	.000***	.237	.493

In the table, the notation '#n' indicates a significant level (p <0.05) between the corresponding types
****: p<0.001*
Unit: degrees

Left-foot-axis-angle

During the left-foot-axis-angle of the kick without back-step, every event had the external rotation of the left foot. The angles were 144.2° at Preparation, 104.2° at Kick, 76.8° at MKF, and 40.1 ° at Impact, respectively.

TABLE 4
Left-foot-axis-angles.

	Preparation	Kick	MKF	Impact
Kick W/O BS	144.2± 8.8	104.2±15.7	76.8±11.6	40.1±11.8
PBS Kick #2	105.7±28.2	100.6±21.6	76.4±15.1	28.9±18.2
F0 #3	48.7#2±17.3	48.5#2±17.6	41.1#2±14.4	24.6±15.2
F22 #4	58.5#2±19.3	59.8#2±21.1	48.2#2±21.4	24.7±17.5
F45 #5	77.9#3±15.7	81.1#3±15.0	63.1#3±13.4	20.0±19.6
F67 #6	98.9#3,4±20.4	97.9#3,4±17.3	75.2#3,4±11.6	35.4±22.2
F90 #7	124.3#3,4,5±20.2	111.4#3,4,5±13.7	83.0#3,4±16.8	37.7±16.9
f	20.009	19.063	11.379	1.385
sig.	.000***	.000***	.000***	.244

In the table, the notation '#n' indicates a significant level (p <0.05) between the corresponding types
*Unit: Degree, *** : p<0.001*

In the Preparation event, the left-foot-axis-angles increased as the angle of footwork movement increased from 48.7° in F0, 58.5° in F22, 77.9° in F45, 98.9° in F67, and 124.3° in F90. It indicated that the left-foot-axis-angles were determined at Preparation based on the angle of back-step. In the kick event, the change of the left-foot-axis-angle was very small, but the PBS Kick type had an external rotation of 5°, and the F90 had an external rotation of 13°. In the Flexion phase, an external rotation of 7° ~ 28° occurred, and an external rotation of 16.5° ~ 47.5° occurred in the Extension phase. The left-foot-axis-angle continued to decrease, showing an angle of 20.0° to 37.7° at Impact.

Kicking foot velocity

As shown in Table 5 and Figure 6, the velocity of the foot segment for the Kick without back-step was 0.16 m/s at Preparation, 2.80 m/s at Kick, 9.71 m/s at MKF, and 12.03 m/s at Impact. And in different footwork angles' kicks, the foot velocity was 0.15 m/s to 0.49 m/s at Preparation and showed a gradual increase in the Toe-off phase; the sustained rate increased after the Kick event. In the Kick event, F0 was 3.29 m/s, F22 was 3.36 m/s, and F45 was 3.33 m/s while F67 was 3.12 m/s, F90 was 2.91 m/s, and the PBS kick was 2.8 m/s. The smaller angle of back-step was somewhat faster. However, at MKF, the segmental velocity of F0 was 7.77 m/s, F22 was 8.36 m/s, F45 was 8.98 m/s, F67 was 9.35 m/s, and F90 was 10.01 m/s. There were statistically significant differences between types of kicks, and the larger angle of back-step was faster. Also, at Impact, right foot segment velocities were 10.21 m/s, 11.15 m/s, 12.13 m/s, 12.66 m/s, 12.78 m/s, and 11.53 m/s, respectively, with statistically significant differences.

TABLE 5
Kicking foot velocity.

	Preparation	Kick	MKF	Impact
Kick W/O BS	0.16±0.15	2.80±0.91	9.71±1.04	12.03±1.57
PBS Kick #2	0.30±0.23	3.13±0.57	9.44±0.95	11.53±1.53
F0 #3	0.42±0.42	3.29±0.52	7.77#2±0.67	10.21±1.36
F22 #4	0.49±0.64	3.36±0.58	8.36±1.39	11.15±1.19
F45 #5	0.26±0.22	3.33±0.42	8.95±0.78	12.13±1.16
F67 #6	0.35±0.39	3.12±0.66	9.35#3±0.98	12.66±1.44
F90 #7	0.15±0.23	2.91±0.94	10.01#3,4±1.18	12.78#3±1.07
f	1.026	.625	6.072	3.772
sig.	.412	.681	.000***	.005**

In the table, the notation '#n' indicates a significant level (p <0.05) between the corresponding types
*Unit: m/s , *** : p<0.001 ** : p<0.01*

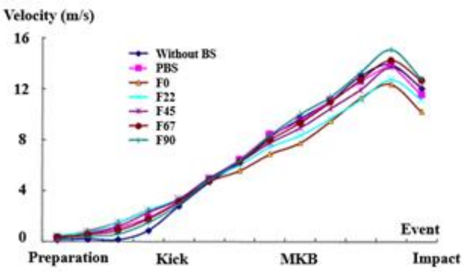

FIGURE 6: *Comparison of kicking foot segment velocity.*

DISCUSSION

This study aimed to quantitatively examine the effects of different angles of one-step-back-step footwork which was used for defense as the attack of the counterpart in a Taekwondo roundhouse kick. This study is also the first to include both the footwork and roundhouse kick in Taekwondo, because biomechanical researchers have not observed footwork variables which are the preparation of the kick execution as a counterattack skill. In this study, authors found that the footwork affected all temporal and spatial variables such as duration of the phases of the kick, center of mass displacement body angles, and kicking foot velocity.

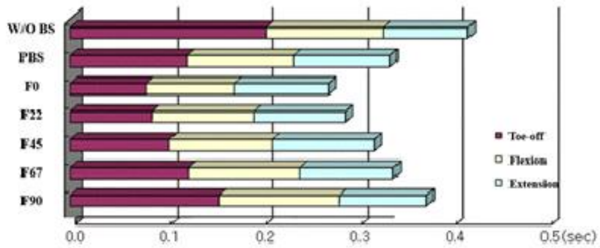

FIGURE 7: *Comparison of duration of time required excluding Reaction and Back-step phases.*

First of all, the duration of time required increased as the back-step angle increased. As shown in Figure 7, excluding the Reaction and Back-step phases which were for the preparation of kick, the roundhouse kick without back-step at Toe-off took the longest time (0.21 sec). The roundhouse kick without back-step was the only kick which showed a significant change in the left-foot-axis-angle in the Toe-off phase. This means that other types of footwork included some movement for the kick in the back-step phase, while the roundhouse kick without back-step involved external rotation of the left foot which caused more time. In addition, F0 and F22 at Toe-off were the shortest from 0.08 to 0.09 sec, and F90 was longer starting from 0.16 sec. The smaller the angle of movement, the smaller the momentum when moving, and the participants kicked faster in F0 after completing the footwork. Considering only the time required, F90 should be avoided in practice, and efforts should be made to shorten the time. In this study, all the types of roundhouse kicks' times required ranged from 0.19 sec to 0.22 sec in the Flexion and Extension phases.

The results of this study are similar to those of the following studies: 0.21 sec in Yang's (1999) study, 0.19 sec in Kang's (1999) study, and 0.22 sec in Kim's (1991) study in the Flexion and Extension phases. The center of mass displacement significantly increased with the increasing angle of movement in the Back-step, Toe-off, and Flexion phases. Also, the total distance from Preparation to Impact was -6.9 cm in the x-axis, 32.1 cm in the y-axis, and 14.4 cm in the z-axis. This is similar to the results of a previous study (Kang, 1999) which showed the following: 5.5 cm in the x-axis, 42.3 cm in the y-axis, and 15.7 cm in the z-axis. These results revealed that the center of mass movement in the left and right direction was small, but the movement in the up-front direction is large. In general, F0 and F22 had a small range of movement, and they were easily exposed to the opponent's attack range, which provided opportunities for scoring, and F67 and F90 had enough distance to avoid the opponent's attack though it depended on the distance from which the opponent attacked.

The trunk angle decreased with the increasing angle of footwork, and there were statistically significant differences at Preparation and Kick events. It was thought that bending the upper body forward is not a desirable posture because one of the hit targets, the face, can be exposed to the opponent. This finding provides an important implication for coaches and practitioners. The Taekwondo athletes need to develop the ability to control the trunk angle at Kick event with wide footwork angle to avoid yielding a clean hit to the opponent. Left-foot-axis-angles were significantly different at Preparation, Kick, and MKF events among types of footwork. However, except for the kick without back-step, there was no significant change in the left-foot-axis-angles during Toe-off which was between the Preparation and Kick events. It was presumed that plantar flexion of the left ankle joint was pulling the whole body. There was almost no change in terms of the velocity of the foot segment in the roundhouse kick without back-step until the middle of the Toe-off phase. However, it started to increase gradually as it passed through the middle of the Toe-off phase. It seemed that the velocity increase was slower than that of the thigh and shank segments because it rotated the waist first by pushing the ground with the right foot. The velocity increased sharply from the Kick event when the foot left the ground, and it reached the maximum speed just before Impact; then, it was reduced in the Impact phase. Also, the velocity of the right foot segment showed statistically significant differences in the MKF event and Impact event among the different angles of footwork. This is because the type with a small back-step angle lifted quickly from the ground while the type with a large back-step angle pushed the ground and lifted the foot, so the velocity of the Kick event was slow. However, it was considered that upon passing the MKF event, the effect of ground reaction force and uses of segment uses such as the trunk accelerated the kicking foot's velocity.

One limitation of the current study is that the footwork angles were pre-determined and kept on unaltered during the kick execution. In a sparring match, both competitors are continuously sliding or stepping forward and backward to react and execute the counterattack. As a result, the footwork angle can change during the execution of the kick, which requires the attacking contender to adjust the footwork motion to compensate for the opponent's move. Future studies need to conduct a more realistic footwork condition scheme such as execution of counterattack with dynamic footwork after real systematic alteration of attacking.

Conclusions

Summarizing the above, the back-step angle at which the forefoot moves should be 2/3 of 90° between the x- and y-axes, which will be effective for defense and attack. Also, as the back-step angle increases, the center of the body becomes lower, and the kick-leg can increase the foot speed by using the ground reaction force of the kick-leg and the center of the mass movement; however, it is likely to be vulnerable to the attack of the opponent. On the contrary, if the back-step angle was reduced, the time required for footwork was short, which may lead to a quick counterattack, but it could be exposed to the range of the opponent's attack, and the effective foot speed for the counterattack will not be obtained. Therefore, it would be necessary to make efforts to compensate for the strengths and weaknesses of the types so as to invalidate the opponent's attack and to increase the contribution of each body segment.

References

Abdel-Aziz, Y. I., Karara, H. M., & Hauck, M. (2015). Direct Linear Transformation from Comparator Coordinates into Object Space Coordinates in Close-Range Photogrammetry. *Photogrammetric Engineering & Remote Sensing, 81*(2), 103-107.

Estevan, I., Alvarez, O., Falco, C., Molina-Garcia, J., & Castillo, I. (2011). Impact force and time analysis influenced by execution distance in a roundhouse kick to the head in taekwondo. *Journal of Strength and Conditioning Research, 25*(10), 2851-2856.

Estevan, I., Falco, C., Álvarez, O., & Molina-García, J. (2012). Effect of Olympic Weight Category on Performance in the Roundhouse Kick to the Head in Taekwondo. *Journal of Human Kinetics, 31*, 37-43.

Estevan, I., Falco, C., & Jandacka, D. (2011). Mechanical analysis of roundhouse kick according to the stance position. A pilot study. *Portuguese Journal of Sport Sciences, 11*(2), 215–218.

Falco, C., Alvarez, O., Castillo, I., Estevan, I., Martos, J., Mugarra, F., & Iradi, A. (2009). Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. *Journal of Biomechanics, 42*, 242-248.

Falco, C., Alvarez, O., Estevan, I., Molina-Garcia, J., Mugarra, F., & Iradi, A. (2009). Kinematic and kinematical analysis of Dominant and Non-Dominant kicking leg in a roundhouse kick in taekwondo. In A. J. Harrion, R. Anderson & I. Kenny (Eds.), *Scientific proceedings of the 27th international conference on biomechanics in sports* (pp. 600–603). Limerik, Ireland: University of Limerik.

Kang S. (1999). *Analysis of the patterns of the Biomechanical Characteristics in Taekwondo Kicking Techniques.* Unpublished dissertation. Sungkyunkwan University, Korea.

Kim B. (1991). *The effect of Taekwondo dolryeochagi according to leg position.* Seoul National University, Korea.

Kim, J. W., Kwon, M. S., Yenuga, S. S., & Kwon, Y. H. (2010). The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kicks. *Sports Biomech, 9*(2), 98-114.

Kim, S. H., Chung, K. H., & Lee, K. M. (1999). *Taekwondo Kyorugi: Olympic Style Sparring*: Turtle Press.

Koh, J. O., & Watkinson, E. J. (2002). Video analysis of blows to the head and face at the 1999 World Taekwondo Championships. *The Journal of sports medicine and physical fitness, 42*(3), 348-353.

Kong, P. W., Luk, T. C., & Hong, Y. (2000). Difference between Taekwondo roundhouse kick executed by the front and back leg - a biomechanical study. In Y. Hong (Ed.), *Scientific Proceedings of XVIII International symposium on biomechanics in sports* (pp. 277–280). Hong Kong: The Chinese University of Hong Kong.

Li, Y., Yan, F., Zeng, Y., & Wang, G. (2005) Biomechanical analysis on roundhouse kick in Taekwondo. *In Scientific Proceedings of the xxiiird International Symposium on Biomechanics in Sports* (pp. 391–394). Beijing, China: The China Institute of Sport Science.

Liu, P., Tan, J., An, J., & Wang, G. (2000). A kinematic analysis of round kick in Taekwondo. In Y. Hong (Ed.), *Scientific Proceedings of XVIII International symposium on biomechanics in sports* (pp. 916–919). Hong Kong: The Chinese University of Hong Kong.

Menescardi, C., Lopez-Lopez, J. A., Falco, C., Hernandez-Mendo, A., & Estevan, I. (2015). Tactical aspects of a National University Taekwondo Championship in relation to round and match outcome. *Journal of Strength and Conditioning Research, 29*(2), 466-471.

Oh, C. H., & Choi, S. N. (2004). A kinematic analysis on reverse-turning kick of Taekwondo student-athletes. *Korean Journal of Sport and Leisure Studies, 22*, 497–509.

Pieter, F., & Pieter, W. (1995). Speed and force in selected taekwondo techniques. *Biology of Sport, 12*(4), 257-266.

Shin, J. M., & Choi, J. Y. (2001). The comparison of relative motion of distal segment about proximal segment of Dolyeochagi in Taekwondo. *Korean Journal of Sport and Leisure Studies, 15*, 545–556.

Tang, W. T., Chang, J. S., & Nien, Y. H. (2007). The kinematics characteristics of preferred and non-preferred roundhouse kick in elite taekwondo athletes. *Journal of Biomechanics, 40*(Supplement 2), S780.

Yang, C (1999). *Effect of target height on biomechanical factors during Taekwondo and Hapkido Dollyuchage motion*. Unpublished dissertation. Kookmin University, Korea.