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ORIGINAL ARTICLE

A Biomechanical Case Study of the Taekwondo Roundhouse Kick Focused on Preparatory Motion

Madoka Kinoshita[1]*, Norihisa Fujii[2]

[1]Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tuskuba, Japan
[2]Humanitas Falcuty of Health and Sport Sciences, University of Tsukuba, Tuskuba, Japan

Abstract

The purpose of this study was to determine the relationships between pelvic motion during the READY phase of the Taekwondo roundhouse kick and the actual kicking speed and time. Understanding these relationships will provide greater coaching and training opportunities to improve athletes' success in scoring points with roundhouse kicks time. It was hypothesized that the contribution to kicking speed and time from the connective joints adjacent to the pelvis would be explained by the mechanical energy generation, flow, and transfer determined through kinematic and kinetic analyses. Thirteen (13) male Japanese Taekwondo athletes participated in this study. The results were summarized as follows: 1) the key factor to transfer the mechanical energy to pelvis efficiently is to establish the posture quickly as it is easy for the extension of hip joint in the support leg, 2) the motion timing of the hip joint in the support leg was quite different between the GOOD and POOR groups, 3) the GOOD athletes utilized the techniques of pelvic motion in the support leg, 4) it is better to train a quick motion with a narrow hip joint movement range while in standing position, and 5) the Taekwondo player should feel as if they are pushing the hip joint of their support leg and moving the pelvis in the kicking direction to facilitate the mechanical energy transfer in order to kick faster. Taken together, the data suggested that coaches should pay greater attention to the support leg and the READY phase in order to improve the players' kicking speed.

***Keywords*:** martial arts, kicking speed, kinematics, kinetics, energetics

Introduction

Taekwondo is a Korean martial art characterized by a diverse array of kicks that has been an Olympic event since the Sydney 2000 Summer Olympic Games. Taekwondo rules encourage kicking techniques by limiting punches to the head and awarding no points for continuous punching. To achieve high scores and to win competitions, it is necessary to kick an opponent precisely. Accurate kicking has become even more important with the recent introduction of a new electric scoring system. However, a combination of many motion factors is required to kick accurately, such as kicking speed, kicking time, timing, and distance. It is therefore critical to clarify the mechanisms of kicking techniques that affect these factors.

According to previous studies, the roundhouse kick is one of the most basic and critical kicks in Taekwondo (13) and is frequently used in competitions (7, 16). There are numerous reported biomechanical analyses of Taekwondo kicking techniques, including the effects of target distance (3, 6, 8, 10), effects of rhythmic hop (12), effects of stance position (4, 5), leg dominance (18), and types of kicking skills (11). Some studies have demonstrated that the roundhouse kick mechanisms are concerned with the kicking leg from toe-off-the-floor period (TOF) to the impact impact-on on-the the-target (IMP) period. Estevan et al. (5) analyzed selected biomechanical parameters in the Taekwondo roundhouse kick according to the stance position. They considered reaction and execution times, peak ground reaction force, and peak velocity in the kicking leg. Tang et al. (18) concluded that Taekwondo elite athletes had no differences in sequences of peak joint velocities between preferred and non-preferred kicking legs when executing roundhouse kicks. Kim et al. (13) proposed the new inter-joint coordination index. They also indicated that the Taekwondo back kick utilized a combination of hip and knee extension to produce the kicking velocity and was characterized by a push-like movement.

There are many coaching methods for the kicking leg from TOF to IMP, because it is a dynamic motion phase and a dynamic part of the body is used. On the other hand, there are few studies and coaching methods for the before TOF, which is related to the preparatory phase (READY phase) and involves slow movement speed. The motion during the READY phase is critical to kicking with a high speed and short time, because the initial motion affects the succeeding motion, and the duration of the READY phase is longer than that of the from TOF to IMP.

The importance of the READY phase was clarified by the following studies. Uzu, Shinya, and Oda (19) said that in some sports, players use a preparatory motion before executing a movement to improve the quality of the movement. Kim and Kim (12) indicated that a rhythmic hop before kicking is recommendable to increase kicking velocity. Kinoshita and Fujii (14, 15) elucidated the possibility of a relationship between producing a pelvic motion during the READY phase and techniques for increasing kicking speed and decreasing kicking time. Therefore, additional investigation is needed to analyze the pelvic motion during the READY phase to better understand the relationship between pelvic motion, kicking speed, and kicking time.

The purpose of this study was to determine the relationships between pelvic motion during the READY phase of the roundhouse kick and actual kicking speed and time. Understanding these relationships will provide greater coaching and training opportunities in order to improve athletes' ability to score points with roundhouse kicks. It was hypothesized that the contribution of the connective joints adjacent to the pelvis to kicking speed and time would be explained by the mechanical energy generation, flow, and transfer determined through kinematic and kinetic analyses.

Methods

Participants

Thirteen (13) male Japanese Taekwondo athletes (aged: 21.7 ± 3.3 yr, height: 1.72 ± 0.05 m, body mass: 65.2 ± 11.4 kg, experience: 6.3 ± 5.3 yr.) participated in this study after informed consent. The Ethics Committee for the Institute of Health and Sport Sciences, University of Tsukuba, Japan approved all study procedures. The participants had diverse performance levels including athletes who competed in national-level competitions.

Experimental trial

The experimental trial consisted of a roundhouse kick to a target (a hand-held kicking pad) with a preferred leg (Figure 1). There were nine (9) right-footed and four (4) left-footed participants. The target height was the same as the participant's torso. The distance from the front leg to the target, and stance position were adopted voluntarily. The ratio of distance to the body height was nearly the same among the participants. They had no influence on the results. We instructed the participants to kick as fast and in as short of time as possible. Each

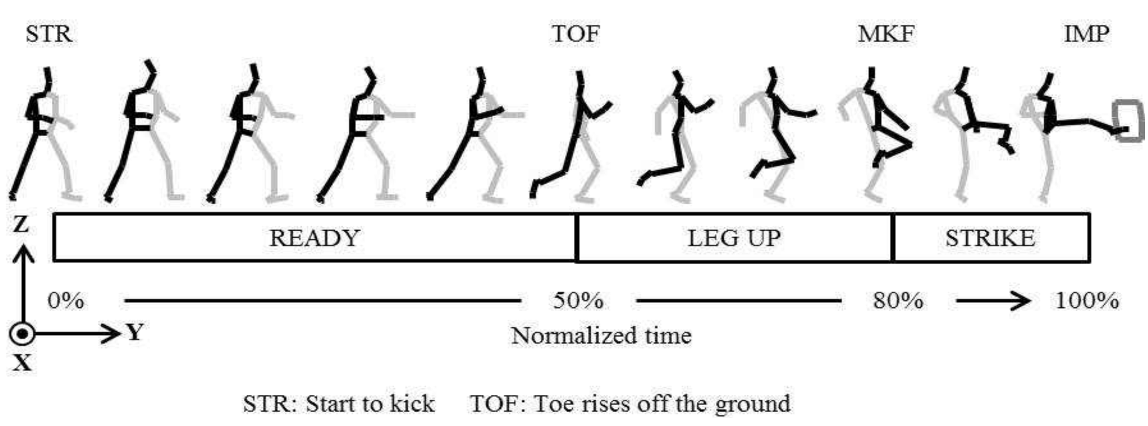


Figure 1. The motion events and analysis phases of a Taekwondo roundhouse kick. STR = when the player started to kick, TOF = when the players' toes rose off the ground, MKF = maximum knee flexion, IMP = the impact on the target.

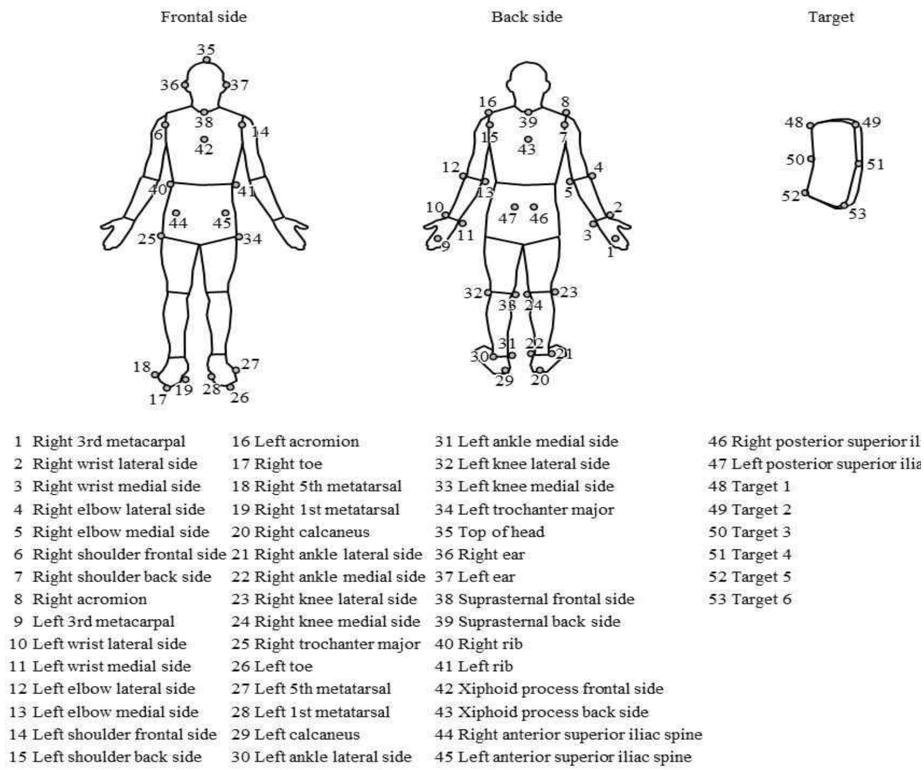


Figure 2. The location of the reflective markers.

participant performed six (6) roundhouse kicks with the maximum effort.

Data collection

The 3D coordinates of the reflective markers on body segments (47 points) and the target (6 points) were captured by a motion capture system (Vicon MX+, 250 Hz) (Figure 2). The ground reaction forces of both right and left legs were obtained by two (2) force platforms (Kistler, 1000 Hz). The global coordinate system was defined (Figure 1) as follows: the Y (anteroposterior) axis was horizontal to the ground in the direction of the kicking pad, the Z (longitudinal) axis was the vertical axis, and the X (mediolateral) axis was in the direction of the cross product between the Y and Z axes.

Data calculation

The captured 3D data were filtered with a Butterworth digital filter (12.5-25 Hz) (20). The kicking speed was defined as the time derivative of the middle point between the first and the fifth metatarsal heads in the kicking leg (Figure 2). The kinematics (the angular velocity of the hip joint in the support leg), kinetics (the torque of the hip joint and moment of the hip joint force in the support leg), and energetics (the energy flow of the connective joints and segments adjacent to the

Table 1. Axis of motion.

Segment	Joint	x-axis	y-axis	z-axis
FOOT	ANKLE	Plantar flexion-dorsi flexion	Inversion-eversion	Adduction-abduction
SHANK	KNEE	Flexion-extension		
THIGH	HIP	Flexion-extension	Adduction-abduction	Internal rot.-External rot.
PELVIS	TORSO	Flexion-extension	Leftward bending-Rightward bending	Leftward rot.-Rightward rot.

Rot. = Rotation.

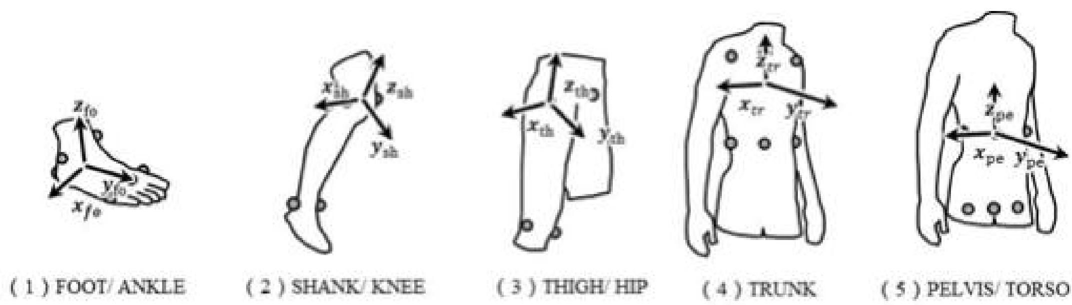


Figure 3. The segment and joint coordinate systems.

pelvis) data were used to evaluate the contribution of the connective joints adjacent to the pelvis during the READY phase.

Energetic data were calculated based on previous studies (21, 22). The mechanical energy generation and absorption of the muscles, called the joint torque power (JTP_j), was calculated by:

[1]
$JTP_j = \boldsymbol{T_j} \cdot \omega_j$

The mechanical energy flowing into or out of the muscles, called the segment torque power (STP_s), was calculated by:

[2]
$STP_s = \boldsymbol{T_j} \cdot \omega_s$

The mechanical energy transfer between segments across the joint, called the joint force power (JFP_j), was calculated by:

[3]
$JFP_j = \boldsymbol{F_j} \cdot V_j$

where $\boldsymbol{T_j}$ is the joint torque, ω_j is the joint angular velocity, ω_s is the segment angular velocity, $\boldsymbol{F_j}$ is the joint force, and $\boldsymbol{V_j}$ is the joint velocity. To unify a preferred leg, the participants kicking with their left legs were recalculated as kicking with their right legs.

Analysis phase

The roundhouse kick was divided into three (3) phases with four events, as shown in Figure 1. The first event was the moment when the speed of the player's body's center of gravity surpassed 0.5 m/s (STR). The second event occurred when the players' toes rose off the ground (TOF). The next event, maximum knee flexion (MKF), occurred at the moment when the knee flexion of the kicking leg was at its maximum. The impact-on-the-target period (IMP) was the final event and occurred when the kicking leg impacted the target. These phases were identified as the READY, LEG UP, and STRIKE phases, respectively. To normalize the kicking motion, the STR, TOF, MKF, and IMP were defined as 0%, 50%, 80%, and 100% of the kicking time, respectively.

Local coordinate system

The segments of the rigid body model (feet, shanks, thighs, pelvis, and trunk) were adopted. Figure 3 represents the local coordinate system of each segment. Each axis of the local coordinate system in the foot, shank, thigh, and pelvis was the same as the axes of the joint motion in the ankle, knee, hip, and torso joints (Table 1). There was a connection between the trunk, pelvis, and torso, and each segment (Figure 3) had a right-handed local coordinate system (14) as follows:

1) Foot
The $\boldsymbol{y_{fo}}$ axis was the unit vector directed from the right heel to the middle point between the right first and fifth metatarsal head. The z_{fo} axis crossed the unit vector directed from the right first metatarsal head to the right fifth metatarsal head and the $\boldsymbol{y_{fo}}$ axis. The $\boldsymbol{x_{fo}}$ axis crossed the $\boldsymbol{y_{fo}}$ and z_{fo} axes, respectively.

2) Shank
The z_{sh} axis was the unit vector directed from the center of the right ankle joint to the center of the right knee joint. The $\boldsymbol{x_{sh}}$ axis crossed the unit vector directed from the center of the right hip joint to the center of the right knee joint and the z_{sh} axis. The $\boldsymbol{y_{sh}}$ axis crossed the z_{sh} and $\boldsymbol{x_{sh}}$ axes, respectively.

3) Thigh
The z_{th} axis was the unit vector directed from the center of the right knee joint to the center of the right hip joint. The $\boldsymbol{x_{th}}$ axis crossed the unit vector directed from the center of the right ankle joint to the center of the right knee joint and the z_{th} axis. The $\boldsymbol{y_{th}}$ axis crossed the z_{th} and $\boldsymbol{x_{th}}$ axes, respectively.

Table 2. Mechanical energy generation/absorption by joint torque power and flow inflow/outflow by the segment torque power of the kicking and support legs during the READY phase.

Group	Torso		K-Hip		S-Hip	
	Generation-absorption	Energy flow	Generation-absorption	Energy flow	Generation-absorption	Energy flow
GOOD	0.43 ± 0.33	Trunk	0.09 ± 0.11	Pelvis	0.36 ± 0.11	Pelvis
	0.20 ± 0.15		0.42 ± 0.23		0.98 ± 0.26	
	-0.23 ± 0.19	Pelvis	0.33 ± 0.19	Thigh	0.62 ± 0.16	Thigh
POOR	0.40 ± 0.03	Trunk	0.06 ± 0.07	Pelvis	0.34 ± 0.14	Pelvis
	0.16 ± 0.04		0.27 ± 0.06		0.71 ± 0.15	
	-0.24 ± 0.04	Pelvis	0.21 ± 0.12	Thigh	0.37 ± 0.03	Thigh
OTHER	0.32 ± 0.19	Trunk	0.04 ± 0.10	Pelvis	0.34 ± 0.09	Pelvis
	0.19 ± 0.14		0.32 ± 0.22		0.80 ± 0.12	
	-0.13 ± 0.13	Pelvis	0.27 ± 0.17	Thigh	0.46 ± 0.11	Thigh

Curved arrows are the directions of mechanical energy flow.
/ Large, solid black arrows = 0.45 < absolute values.
/ Medium, gray arrows = 0.2 < absolute values < 0.45.
/ Small, white arrows = absolute values < 0.2.
Unit: [J/kg].
K- = kicking leg.
S- = support leg.
Data are means (± SD).

4) Trunk

The z_{tr} axis was the unit vector directed from the bottom end of the ribs to the upper margin of the sternum. The y_{tr} axis crossed the z_{tr} and the unit vector directed from the center of the left shoulder joint to the center of the right shoulder joint. The x_{tr} axis crossed the y_{tr} and z_{tr} axes, respectively.

5) Pelvis

The z_{pe} axis was the unit vector directed from the middle of the left and right hip joints to the bottom end of the ribs. The y_{pe} axis crossed the z_{pe} and the unit vector directed from the center of left hip to the joint center of right hip. The x_{pe} axis crossed the y_{pe} and z_{pe} axes, respectively.

Statistics

No statistical data is provided in this study due to the small sample size.

Group selection

As with previous studies (14, 15), all subjects were divided into three groups: GOOD (N = 4), POOR (N = 3), and OTHER (N = 6) (Figure 4).

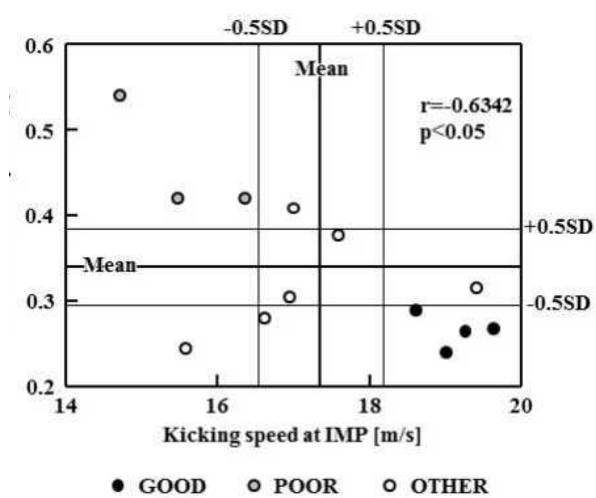


Figure 4. Group selection. The GOOD group could kick over the average kicking speed, plus half of the standard deviation, and below the average time during the READY phase minus half of the standard deviation. The POOR group could kick below the average kicking speed, minus half of the standard deviation, and over the average time during the READY phase, plus half of the standard deviation. The OTHER group belongs to neither. SD = Standard deviation, IMP = Impact on the target.

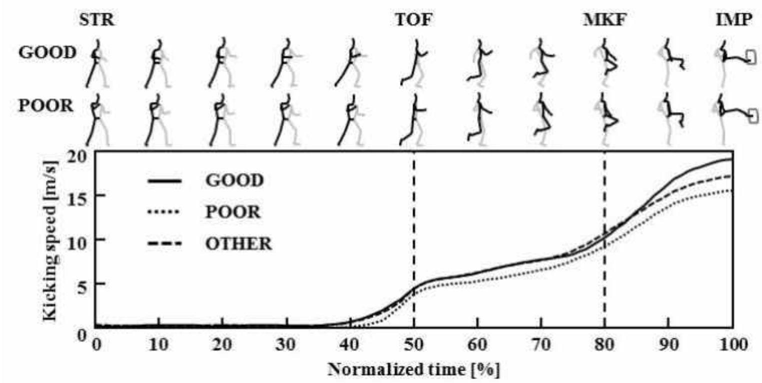


Figure 5: Kicking speed. The solid line is the GOOD group, the dotted line is the POOR group, and the dashed line is the OTHER group. The two dashed vertical lines are the points of TOF and maximum knee flexion, respectively. STR = when the player started to kick, TOF = when the players' toes rose off the ground, MKF = maximum knee flexion, IMP = the impact on the target.

In this study, the GOOD group kicked 19.08 m/s, the POOR group kicked 15.47 m/s, and the OTHER group kicked 17.14 m/s at impact (Figure 5). Participants in a previous study (17) kicked 17.66 m/s and had over ten (10) years of experience in Korea. Thus, according to previous studies, our group selection was suitable to find techniques for increasing kicking speed and decreasing kicking time.

Results

Mechanical energy is absorbed or generated at each joint (joint torque power), and energy flowed to or from each segment of the kicking leg and support leg (segment torque power) during the READY phase (Table 2). For generation and absorption values, a positive value implied mechanical energy generation, whereas a negative value implied mechanical energy absorption. For mechanical energy flow values, a positive value implied mechanical energy flowed into the segment from the adjacent connective joint, whereas a negative value implied the mechanical energy flowed out of the segment from the adjacent connective joint. The curved arrows in Table 2 indicate the direction of mechanical energy flow.

As in Table 3, mechanical energy was generated or absorbed by the hip joint motion (flexion/extension, adduction/abduction, and internal rotation/external rotation) of both legs. Mechanical energy was transferred through each joint (joint force power) during the READY phase (Table 4). For the joint force power, a positive value implied the mechanical energy transferred to the distal segment from the proximal segment, whereas a negative value implied the mechanical energy transferred to the proximal segment from the distal segment. The arrows in Table 4 indicate the direction of mechanical energy transfer.

Table 3. Mechanical energy generation/absorption by the joint torque power of the hip joint of the kicking and support legs during the READY phase.

Group	K-Hip			S-Hip		
	Flexion Extension	Adduction Abduction	Internal rot. External rot.	Flexion Extension	Adduction Abduction	Internal rot. External rot.
GOOD	0.31 ± 0.15	0.13 ± 0.11	-0.02 ± 0.02	0.88 ± 0.18	0.07 ± 0.10	0.03 ± 0.06
POOR	0.14 ± 0.04	0.15 ± 0.04	-0.01 ± 0.03	0.59 ± 0.17	0.11 ± 0.03	0.02 ± 0.02
OTHER	0.20 ± 0.10	0.13 ± 0.12	-0.02 ± 0.03	0.70 ± 0.18	0.08 ± 0.05	0.01 ± 0.04

Unit: [J/kg].
K- = kicking leg.
S- = support leg.
Rot. = Rotation.

Mechanical energy generation/absorption

The hip joint of the kicking leg and hip joint of the support leg are the connective joints adjacent to the pelvis. In the hip joints of both legs, the magnitudes of mechanical energy generation were greater than that in other joints (Table 2). In the hip joint of the support leg, the flexion/extension motion generated the highest mechanical energy (Table 3). Conversely, the flexion/extension motion in the hip joint of the kicking leg did not always generate the highest mechanical energy (Table 3). The GOOD group generated the highest mechanical energy among the three groups.

Mechanical energy flow

The trunk and thighs in both legs are segments adjacent to the pelvis. The mechanical energy flowed out of the trunk from the pelvis. The mechanical energy flowed into the pelvis from the thighs in both legs. The magnitude of flowing mechanical energy from the thigh of support leg was greater than that of the kicking leg. The greater magnitude of mechanical energy flowed into the thighs in both legs. There was a difference in the flow ratio among the groups. In the GOOD group, a greater magnitude of mechanical energy flowed into the thighs and pelvis than in the POOR and OTHER groups.

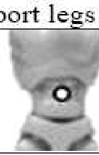
Mechanical energy transfer

The magnitude of mechanical energy transferred from the pelvis to the thigh of the kicking leg as well as the thigh of the support leg to the pelvis were greater than other mechanical energy transfers. In the GOOD group, the mechanical energy transfers were greater than that in the POOR group (Table 4).

Angular velocity

Considering the energetics data, the motion of the hip joint of support leg that produced the motion of the thigh in the support leg was the key to find the techniques of kicking fleetly. During the READY phase, the hip joint of the support leg has three axes of angular velocity: flexion (+)/extension (-), adduction (+)/abduction (-), and internal rotation (+)/external rotation (-) (Figure 6). Although the timing of the peak differed, their magnitude of angular velocity was almost the same in all three groups. In the GOOD group, the angular velocity of the flexion pattern changed extension earlier, within 25% of the time. On the contrary, the angular velocity of the flexion pattern in the POOR group changed extension almost within 40% of the time. The angular velocity of the adduction patterns almost maintained a positive value in the POOR and OTHER groups. After 20% of the kicking time, the peak magnitude of adduction in the GOOD group appeared earlier than in the other two groups. For the angular velocity of internal

Table 4. Mechanical energy transfer inflow/outflow by the joint force power of the kicking and support legs during the READY phase.

Group	Torso 		K-Hip 		S-Hip 	
	Trunk	Pelvis	Pelvis	Thigh	Pelvis	Thigh
	Energy transfer		Energy transfer		Energy transfer	
GOOD	⇦	0.17 ± 0.51	➡	0.48 ± 0.38	⬅	-0.49 ± 0.27
POOR	⇨	-0.10 ± 0.11	⇨	0.17 ± 0.13	⇦	-0.25 ± 0.02
OTHER	⇨	-0.05 ± 0.12	➡	0.47 ± 0.26	⬅	-0.47 ± 0.15

Arrows indicate the direction of mechanical energy transfer.
➡ / Large, solid black arrows = 0.3 < absolute values.
⇨ / Medium gray arrows = 0.15 < absolute values < 0.3.
⇨ / Small, white arrows = absolute values < 0.15.
Unit: [J/kg].
K- = kicking leg.
S- = support leg.
Data are means (± SD).

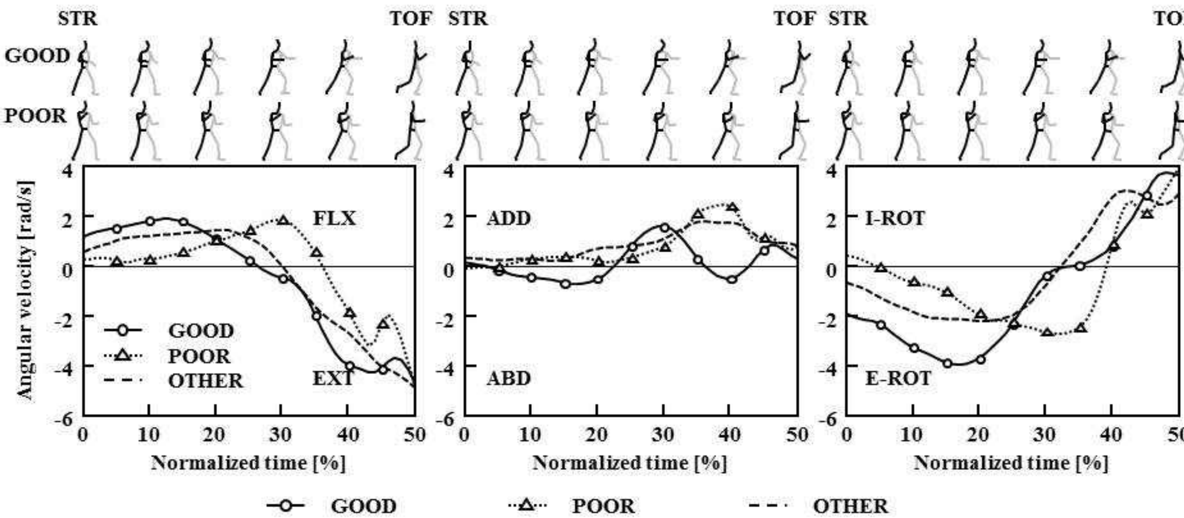


Figure 6. Angular velocity of the hip joint in the support leg during the READY phase. The solid line with circle mark is the GOOD group, the dotted line with triangle mark is the POOR group, and the dashed line is the OTHER group. The three figures show flexion (+)/extension (-), adduction (+)/abduction (-), and internal rotation (+)/external rotation (-), respectively. STR = when the player started to kick, TOF = when the players' toes rose off the ground, FLX = flexion, EXT = extension, ADD = adduction, ABD = abduction, I-ROT = internal rotation, E-ROT = external rotation.

rotation/external rotation, the peak magnitude of external rotation in the GOOD group appeared earlier than in the other two groups.

Joint torque and moment of joint force

Hip joint torque and the moment of hip joint force in the support leg were acted to flexion/extension, adduction/abduction, and internal rotation/external rotation during the READY phase (Figure 7). The absolute value of the joint torque or the moment of joint force acted flexion/extension was greater than that of the other joint axes. For the GOOD group, there was an increase in not only the hip joint extension torque but also the flexion moment of hip joint force. The hip joint extension torque was greater than the flexion moment of the hip joint force through the READY phase.

Discussion

Biomechanical theory

This study provided new insights into the relationships between the pelvic motion during the READY phase of the Taekwondo roundhouse kick and actual kicking speed and time. The data of mechanical energy generation, flow, and transfer determined through kinematic and kinetic analyses revealed the contribution of the connective joints adjacent to the pelvis to kicking speed and time. To summarize previous studies (14, 15), the pelvic motion during the READY phase might be critical to kick fleetly. Thus, in order to determine techniques for increasing kicking speed and decreasing kicking time, the motion factors producing the pelvic motion by the lower extremity during the READY phase must be analyzed and understood.

The greater magnitude of mechanical energy generation in the hip joints of both legs were elicited by high hip joint torque because of the many large muscles around the hip joint (Tables 2 and 3). The largest muscles of the hip joint are responsible for its flexion and extension; i.e., the quadriceps femoris muscle and gluteus maximus muscle are responsible for abduction and adduction or internal rotation and external rotation. In order to retain the greater mechanical energy in the pelvis during the READY phase, it is needed not only to generate the mechanical energy but also to flow and transfer the mechanical energy to the pelvis.

The magnitude of mechanical energy transferred to the pelvis from the thigh of the support leg by joint force power was great. This transfer resulted from the thigh of support leg rotating forwards (clockwise rotation around the x-axis of the thigh local coordination system) pulled up pelvis, which meant the increase in potential energy. The GOOD group exerted a greater hip joint torque and generated the greater mechanical energy. Thus, it is obvious that the transfer of mechanical energy was greater in the GOOD group than in the other two groups. At the same time, most of the generated energy flowed into the thigh of the support leg by the segment torque power, because it was required to produce the thigh motion of the support leg as discussed above. If the motion of the thigh in the support leg was less, the greater mechanical energy might not be transferred to the pelvis by the joint force power as seen in the POOR group. The magnitude of mechanical energy that flowed into the pelvis from the thigh of the support leg by the segment torque power was almost the same in the GOOD and POOR groups, but the mechanical energy transferred to the pelvis by joint force power indicated that the pelvis retained the greater mechanical energy in the GOOD group. Thus, the greater mechanical energy generation in the hip joint of the support leg might increase the speed of the Taekwondo roundhouse kick.

Although it is better to retain the mechanical energy in the pelvis at TOF, some mechanical energy flowed out and transferred from the pelvis for two reasons. Firstly, the trunk has the highest moment of inertia in the body segments. It rotates left before the pelvis rotates left and needs more mechanical energy than the pelvis to be rotated. Secondly, considering the stance position, the kicking leg is located behind the support leg. The thigh of the kicking leg is pulled by the pelvis rotation, thus resulting in a greater magnitude of pelvic speed, while the mechanical energy flowing out of the thigh of kicking leg is mutually influential.

In order to explain the efficiency of the GOOD group’s flexion/extension motion, Figures 6 and 7 show the kinematics and kinetics of the hip joint of the support leg. The key for clarifying how pelvic motion facilitates kicking speed is to observe the hip joint of the support leg motion. The extension of angular velocity and torque became greater after the angular velocity of the flexion changed the extension. However, in order to transfer the mechanical energy efficiently through the hip joint extension in the support leg, it was critical that the motions of adduction and external rotation in the hip joint of the support leg were performed before the extension motion. The motions of adduction and external

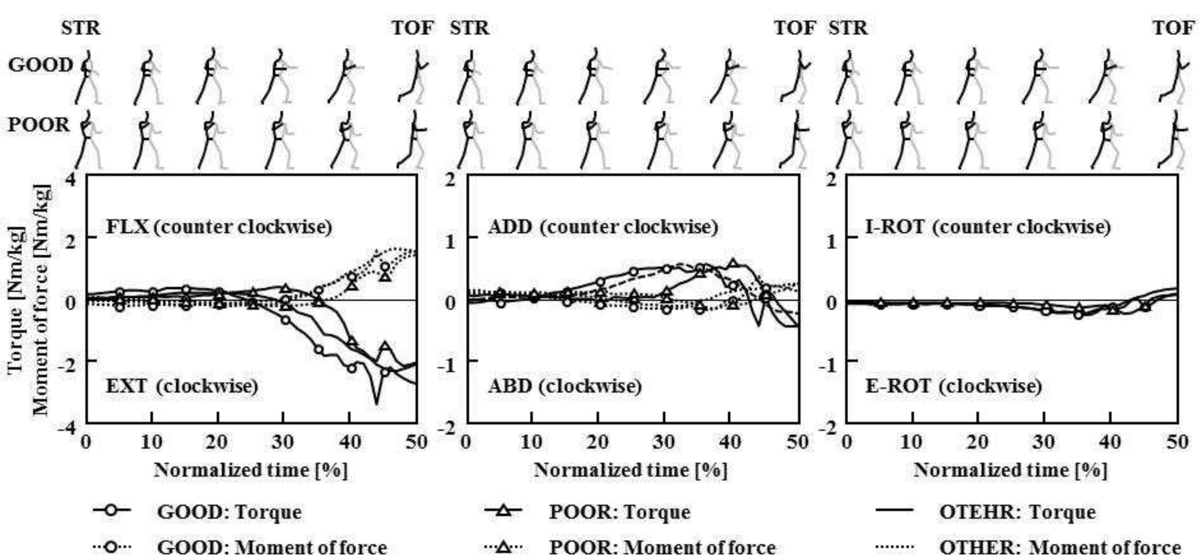


Figure 7. The hip joint torque and the moment of hip joint force in the support leg during the READY phase. The solid line with a circle mark is the torque of the GOOD group, the solid line with a triangle mark is the torque of the POOR group, and the solid line is the torque of the OTHER group. The dotted line with a circle mark is the moment of joint force of the GOOD group, the dotted line with a triangle mark is the moment of joint force of the POOR group, and the dotted line is the moment of joint force of the OTHER group. The three figures show flexion (counterclockwise [+])/extension (clockwise [-]), adduction (counterclockwise [+]/abduction (clockwise [-]), and internal rotation (counterclockwise [+])/external rotation (clockwise [-]), respectively. STR = when the player started to kick, TOF = when the players’ toes rose off the ground, FLX = flexion, EXT = extension, ADD = adduction, ABD = abduction, I-ROT = internal rotation, E-ROT = external rotation.

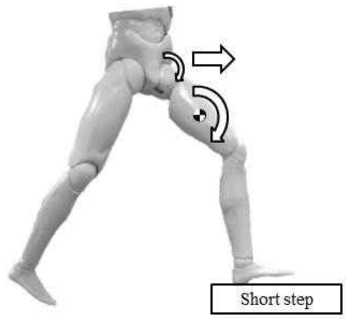


Figure 8. Schematic diagram of training. A continuous quick up-down motion using a short step and barbell (as necessary).

rotation facilitate the hip joint to be extended and produce the translational velocity of the pelvis. Moreover, in flexion/extension motion, athletes can exert greater torque than any other motions because of the body's muscular structure.

Thus, all motions of the hip joint in the support leg (extension, adduction, and external rotation) are necessary. The sequence pattern of the hip joint of the support leg motion is critical to the pelvic motion at TOF. As explained above, we have clarified the mechanisms of producing the pelvic motion during the READY phase.

Coaching applications

The motion of the support leg in other kicking sports, such as football (soccer), Australian football, American football, Gaelic football, and rugby, are described as an important role of kicking (1, 2, 9). However, there are few instructions for the support leg in Taekwondo, while there are numerous instructions for the kicking leg. Taekwondo coaches also should pay more attention to the support leg in order to improve the players' kicking speed.

Biomechanically speaking, in order to generate greater mechanical energy, mechanical energy is needed to increase angular velocity or joint torque. For muscle strength training, Taekwondo athletes have to train muscles related to the flexion/extension motion of the hip joint, especially those that focus on quick motions with a narrow range of motion while in a standing position. A continuous quick up-down motion using a short step and barbell (as necessary) (Figure 8) is a useful training method to improve the flexion/extension motion of the hip joint.

In order to transfer mechanical energy to the pelvis from the thigh of the support leg with joint force power, a Taekwondo player must move his or her hip joint correspondingly (Figure 9). Extending the hip joint of the support leg and creating the sense of pushing the hip joint of the support leg and moving the pelvis in the kicking direction helps mechanical energy transfer, which increases kicking speed.

Study limitations

One limitation of this study was the small sample size. Although statistical data was not provided, this study provided new insights into the mechanisms of the lower extremities in a roundhouse kick and the READY phase.

Conclusions

The purpose of this study was to determine the relationships between the pelvic motion during the READY phase of the Taekwondo roundhouse kick and actual kicking speed and time. The main biomechanical conclusions were summarized as follows: 1) the key factor to transferring mechanical energy to the pelvis efficiently is to establish posture quickly as it facilitates the flow of energy through the extension of hip joint in the support leg, 2) the motion timing of the hip joint in the support leg is quite different between the GOOD and POOR groups, and 3) the GOOD athletes kicked by utilizing the pelvic motion in the support leg. The main coaching strategies concluded from this study are that it is 1) better to train quick motions with a narrow hip joint movement range in a standing position, and 2) it is important for the player to create the sense of pushing the hip joint of the support leg and moving the pelvis in

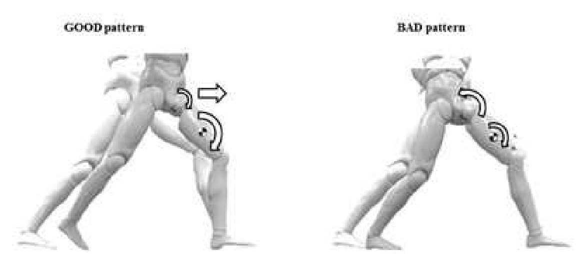


Figure 9. Schematic diagrams of GOOD and BAD motion patterns. The GOOD pattern can transfer the mechanical energy to the pelvis from the thigh of the support leg by joint force power. However, while the BAD pattern can generate the greater mechanical energy, a player cannot transfer mechanical energy to the pelvis from the thigh of the support leg with joint force power.

the kicking direction to help mechanical energy transfer to increase kicking speed. It is our view that coaches should pay more attention to the support leg and the READY phase in order to improve the players' kicking speed when executing the Taekwondo roundhouse kick.

References

(1) Ball K. Loading and performance of the support leg in kicking. Journal of Science and Medicine in Sport. 2013;16(5):455-59.

(2) Chew-Bullock TSY, Anderson DI, Hamel KA, Gorelick ML, Wallace SA, Sidaway B. Kicking performance in relation to balance ability over the support leg. Human Movement Science. 2012;31(6):1615-23.

(3) Estevan I, Alvarez O, Falco C, Molina-Garcia J, Castillo I. Impact force and time analysis influenced by execution distance in a roundhouse kick to the head in Taekwondo. Journal of Strength and Conditioning Research. 2011;25(10):2851–6.

(4) Estevan I, Jandacka D, Farana R, Falco C. Kinematical analysis of a roundhouse kick according to the stance position. Proceedings of the 30th Annual Conference of Biomechanics in Sports. 2012 Jul 2-6; Melbourne, Australia; 2012. p. 189–92.

(5) Estevan I, Jandacka D, Falco C. Effect of stance position on kick performance in Taekwondo. Journal of Sport Sciences. 2013;31(16):1815-22.

(6) Falco C, Alvarez O, Castillo I, Estevan I, Martos J, Mugarra F, Iradi A. Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. Journal of Biomechanics. 2009;42(3):242–8.

(7) Falco C, Landeo R, Menescardi C, Bermejo JL, Estevan I. Match analysis in a university Taekwondo championship. Advances in Physical Education. 2012;2(1):28–31.

(8) Falco C, Molina-García J, Alvarez O, Estevan I. Effects of target distance on select biomechanical parameters in Taekwondo roundhouse kick. Sports Biomechanics. 2013;12(4):381-8.

(9) Inoue K, Nunome H, Sterzing T, Shinkai H, Ikegami Y. Dynamics of the support leg in soccer instep kicking. Journal of Sports Sciences. 2014;32(11):1023-32.

(10) Kim JW, Kwon MS, Yenuga SS, Kwon YH. The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kick. Sports Biomechanics. 2010;9(2):98–114.

(11) Kim YK, Hinrichs RN. Biomechanical classification of Taekwondo kicks. Proceedings of American Society of Biomechanics Annual Conference; 2006.

(12) Kim YK, Kim YH. Effects of rhythmic hop on response times and kicking velocities of Taekwondo kicks. Korean Journal of Sport Biomechanics. 2014;24(4):367-73.

(13) Kim YK, Kim YH, Im SJ. Inter-joint coordination in producing kicking velocity of Taekwondo kicks. Journal of Sports Science and Medicine. 2011;10(1):31-8.

(14) Kinoshita M, Fujii N. Biomechanics of Taekwondo roundhouse kick. Biomechanism, 22. Tokyo: Keio University Press; 2014. 143-54 p. (Japanese).

(15) Kinoshita M, Fujii N. Biomechanical analysis of Taekwondo roundhouse kick focused on mechanical energy flow. Journal of the Society of Biomechanisms Japan. 2015;39(1):37-46. (Japanese).

(16) Luk TC, Hong Y, Chu DPK. Analysis of strategy used in Taekwondo competition. Proceedings of Biomechanics Symposia; University of San Francisco; 2001. p. 166-9.

(17) O'Sullivan D, Chung C, Lee K, Kim E, Kang S, Kim T, Shin I. Measurement and comparison of Taekwondo and Yongmudo turning kick impact force for two target heights. Journal of Sports Science and Medicine. 2009;8(CSSI3):13-6.

(18) Tang WT, Chang JS, Nien YH. The kinematic characteristics of preferred and non-preferred roundhouse kick in elite Taekwondo athletes. Journal of Biomechanics. 2007;40 Suppl 2: S780.

(19) Uzu R, Shinya M, Oda S. A split-step shortens the time to perform a choice reaction step-and-reach movement in a simulated tennis task. Journal of Sports Sciences. 2009;27(12):1233-40.

(20) Wells RP, Winter DA. Assessment of signal noise in the kinematics of normal, pathological and sporting gaits. Proceedings of the Special Conference of the Canadian Society for Biomechanics, Human Locomotion I; 1980 Oct 27-29; London, Ontario; p. 92-3.

(21) Winter DA. Biomechanics and motor control of human movement. 4th ed. New York: John Wiley &. Sons; 2009.

(22) Winter DA, Robertson DGE. Joint torque and energy patterns in normal gait. Biological Cybernetics. 1978;29(3),137-42.