©Journal of Sports Science and Medicine (2021) **20**, 457-465
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2021.457

Research article

Differences in Pivot Leg Kinematics and Electromyography Activation in Various Round House Kicking Heights

Wei-Gang Chang [1]✉, Kuan-Yu Lin [1], Mu-Yen Chu [2] and Tong-Hsien Chow [3]
[1] Department of Athletic Training and Health, National Taiwan Sport University, Taoyuan, R.O.C., Taiwan
[2] Department of Sports Training Science-Combats, National Taiwan Sport University, Taoyuan, R.O.C., Taiwan
[3] Department of Leisure Sports & Health Management, St. John's University, New Taipei City, R.O.C., Taiwan

Abstract

The round house kick (RHK) is a common technique in taekwondo (TKD). The kicking action originates from the dynamic stability of the pivot leg. However, some knee injuries are caused by more difficult kicking strategies, such as kicks to the opponent's head. This study analyses the effects on TKD players in the lower extremity kinematic and neuromuscular reactions fr om different kicking heights. This study recruited 12 TKD players (age=20.3 ± 1.3 years, height = 1.72 ± 0.09 m, mass = 62.17 ± 9.45 kg) with no previous lower extremity ligament injuries. All athletes randomly performed 3 RHK at different heights (head, chest, and abdomen), repeating each kick 5 times. During the RHK action, the kinematics and muscle activations of the pivot leg were collected using six high-speed cameras and electromyography devices. The results found that during the RHK return period a high kicking position demonstrated larger knee valgus with the straight knee, and more hamstring activation on the pivot leg. The RHK pivot foot for TKD players encountered more risk of injury from high target kicking. The hamstring muscle played an important stabilizing role. It is recommended that sports medicine clinicians or sports coaches use this information to provide further protective injury prevention strategies.

Key words: Taekwondo, anterior cruciate ligament injury, knee valgus, co-contraction activation.

Introduction

As an Olympic sport, competitive Taekwondo (TKD) is one where players accumulate points based on their kicking technique and strategies (Estevan and Falco, 2013). TKD athletes tend to emphasize head-height kicks, which are harder to execute, because they are worth more points. According to current Olympic rules, a valid kick to the head is awarded three points, whereas a kick to the abdomen is awarded only one point (Evelyn Watta, 2020). Thus, head kick strategies are frequently adopted by TKD players, with the round house kick (RHK) being the most popular technique (Ho, 2018; Estevan and Falco, 2013). RHK requires stable support from the pivot leg for the attacking leg to land the kick (Figure 1). A previous study showed that gradually increasing hip displacement of the pivot leg as the target distance increased was associated with the pivot foot rotation (Kim et al., 2010a). This implies that difficult kicks (e.g., kicks aimed at a high target) are especially demanding on the pivot-leg. Because kicks aimed at a high target require mature skill and excellent motor coordination (Kim et al., 2010a), TKD beginners are advised against performing such kicks (Estevan and Falco, 2013).

According to recent sports injury studies, TKD kicks can cause serious injuries to the pivot leg, such as anterior cruciate ligament (ACL) injuries (Kasbparast et al., 2014a; 2014b; Kim et al., 2010b). Some scholars have suggested that this type of injury mechanism may be associated with the requisite planting and spinning motion during the RHK (Kasbparast et al., 2014a; 2014b; Amraee et al., 2013; Park and Song, 2018). Injury-causing motions have been mostly observed in the pivot leg (Kasbparast et al., 2014b). A study from Kobayashi et al. (2010) showed that ACL injuries of the pivot leg commonly occurred in athletes when they were performing knee valgus movements with the toe pointing outward and the knee inward, the toe pointing inward and the knee pointing outward and with knee hyperextension during dynamic alignment. For example, when chasing or performing spinning kicks, players are susceptible to noncontact injuries to the knee joint (Kasbparast et al., 2014a; 2014b). Excessive knee valgus is a major cause of ACL injuries (Cortes et al., 2011; Hewett et al., 2005; Kellis et al., 2004). To avoid such injuries, dynamic stability at the hip and knee are necessary to achieve the desirable joint stability, especially in the performance of difficult kicks (Estevan and Falco, 2013). The co-contraction of muscles must also be increased to provide joint stability and protection against awkward, injury-inducing angles (Kellis et al., 2003; Opar and Serpell, 2014). Muscles that have been confirmed to be effective in protecting the hip and ensuring knee stability are the hamstring muscles and gluteus medias (GM) (Distefano et al., 2009; Petersen et al., 2011). These muscles that exhibit higher activation ratios relative to the quadriceps muscle and adductor muscles also provide high levels of stability protection for the hip and knee of the pivot leg during a kicking motion (Brophy et al., 2010; Monajati et al., 2016; Opar and Serpell, 2014; Ruan et al., 2017).

Despite the risk for noncontact injuries in the knee joint on the pivot leg resulting from TKD kicks, most studies focused on the attacking leg (Estevan and Falco, 2013; Gavagan and Sayers, 2017). Because of the current Olympic rules, head-height kicks have been popular point-scoring strategies (Ho, 2018; Tornello et al., 2014). However, the increase in kick height obviously affects the coordinated movement of the pivot foot in TKD athletes. (Kim et al., 2010a). Few studies have focused on the pivot leg when performing TKD kicks. The relevant mechanism remains unknown. Based on the needs identified, this study analysed the effects of (three instances of) RHK heights on kinetic and neuromuscular functions, at the hip and knee on

Received: 23 November 2020 / Accepted: 24 May 2021 / Published (online): 01 June 2021

the pivot leg. It was hypothesised that higher RHKs resulted in increased load on knee dynamic stability in the pivot leg. Such increased load may reflect in the return phase by increased dynamic knee valgus angles as well as the co-activation of the biceps femoris (BF), rectus femoris (RF), GM, and hip adductor muscles.

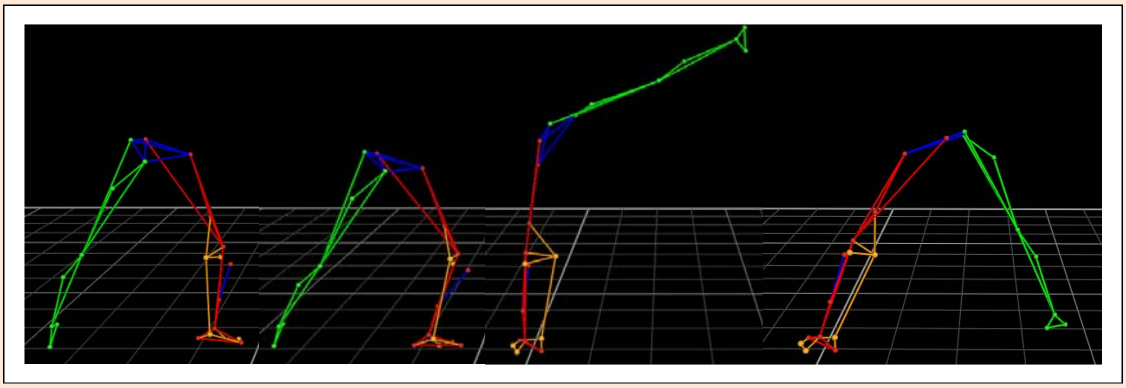

Figure 1. The moment events of the RHK (A) prepare position (B) The moment of toe leave ground (C) The moment of attack touch target (D). The moment of the attack foot contact ground.

Methods

Participants

Twelve junior elite college TKD players (6 males and 6 females) were recruited to participate in this study. Mean subject height, weight and age were 172.08 ± 9.32 cm, 62.17 ± 9.45 kg, and 20.33 ± 1.27 years old. The amount of time dedicated to the sport was 11.25 ± 2.83 years. The participants with severe lower extremity skeletal and nerve disease, a history of ACL injury, a history of surgery, or knee pain or functional limitations for the last two months were excluded. The participant's usual pivot and attacking feet were determined by their self-experience. Participants were asked not to exercise vigorously or perform lower limb training one week before each experimental session to prevent fatigue from affecting the experimental results. This study was reviewed and approved by the Fu Jun Catholic University Human Research Ethics Committee, Taiwan (C106192). This study conforms to the Declaration of Helsinki for studies involving humans.

Trial conditions

Dynamic trails

This study designed three different height dynamic kicking tests (the navel (low), xiphoid (middle) and nose (high) positions of the body, referred to as HT, MT and LT). Each kick was executed randomly 5 times. Before the experiment began, the participant was prepared to execute the kick by assuming a consciously comfortable stride distance. When the preliminary command was issued, the researcher quickly moved the target to the pre-event set height within 1 to 10 seconds. The subject struck the target with the utmost effort. In the experiment participants could perform a kick by pivoting or jumping on their pivot leg. However, for a valid kick, the front foot must not move forward, backward, or to the side more than 5 cm from the start position when the kick is executed. In our study, we use the reflective maker fixed to the second metatarsal head of the pivot leg to detect an accurate distance. The participant could rest for at least 30 seconds after each kick.

Maximum isometric voluntary contraction

The athletes were then required to complete a series of maximum voluntary isometric contractions (MVIC) to quantify the EMG as a normalisation factor for each muscle in accordance with the usual practice. The participant first assumed a sitting position (the hips and knees were flexed 90 degrees). A buckled strap was used to fix the distal tibia to resist knee extension (RF). In the same way, in the subject assumed a lying position (the hips were 0 degree, and the knees were flexed 90 degrees) to resist knee flexion (BF), and hip abduction (GM) and hip adduction (adductor).

Data collection

The Vicon motion analysis system (VICON Motion Systems Ltd., United States) and six high-speed cameras (Vicon Vero 2.2, United States) were used to record the kinematic data. The sampling frequency was set at 100 Hz. The participants were required to perform a specific anatomical movement by a qualified athletic trainer to adhere to the reflective markers (Cappozzo et al., 1995). The coordinate position during the operation was captured by six high-speed red line cameras. The Delsys SDK 2.5+ TrignoTM system (Delsys, Boston, USA) was used mainly in the capture of human muscle EMG signals, were captured at the sampling rate of 2000 Hz. After the neural signal was converted into an analogue signal via the amplifier, it was transmitted into the Delsys multi-function neural signal capture box. Finally, together with the reflective marker coordinate data, the Neurox 2.5.0 processing software was used to output the ASCII data for analysis and processing.

Testing procedures

Before the start of the experiment, the participants performed a complete large muscle stretch procedure, including the lumbar muscles, gluteus maximus, quadriceps, hamstring, gastrocnemius, and tibialis anterior muscles. Each muscle was stretched at least 30 seconds. The researchers then measured the actual leg length data (navel to internal haemorrhoids) with a tape measure as described and used by Um and Bae (2011). This was followed by setting myoelectric receiver devices onto the lower limb muscle belly, including the RF, BF, GM or adductor femoris (AD), was referenced from the book by Criswell (2010). After the device attachment was completed, the maximum isometric contraction value of the electromyogram was collected. Each muscle group was subjected to two 5 second maximum isometric contractions to collect EMG data. Twenty-two reflective markers were then attached to a particular anatomical site on the adhesive sheet body, including the anterior superior iliac spine, the posterior superior iliac spine on both legs, the external and medial femoral condyles, the fibula head, the tibial tuberosity, the fibula styloid process, tibia styloid process, fifth metatarsal base, the calcaneus, and the second metatarsal head on the pivot leg. In addition, a fifth metatarsal styloid was attached to the attacking foot (Cappozzo et al., 1995).

Data reduction and processing

Kinematic

All marker trajectories were filtered using a fourth-order, zero-phase-shift low-pass Butterworth 9 Hz by Matlab 2016a. The 3-dimensional coordinates of the hip joint centre were calculated as described from a previous study (Seidel et al., 1995). The centre of the knee joint was calculated as the midpoint between the medial and lateral femoral condyles, while the centre of the ankle joint was calculated as the midpoint between the medial and lateral malleoli (Cappozzo et al., 1995). The hip joint centre, left, and right anterior superior iliac spine and posterior superior iliac spine were used to define the pelvic reference frame. The hip centre, knee centre, and femoral epicondyle were used to define the femur reference frame. The knee joint centre, the centre of the ankle joint, the fibula head and tibial tuberosity were used to define the tibia reference frame (Cappozzo et al., 1995). The order of rotation through the Euler angle formula between the pelvis-femoral and the femoral-tibia coordinate systems were (1) flexion-extension (x-axis), (2) abduction-adduction (y-axis), (3) internal-external rotation (z-axis). Dynamic anatomical angles were calculated referenced to a static standing neutral position.

This study used the kinematic information to stage each kicking process. The kick attack phase was defined as the duration from the time of initial toe-off to the moment the target was struck. The kick return phase was defined as from the moment the target was struck to the moment the attacking foot touched the ground. In addition, the reflective marker displacement on the attacking leg's 5th styloid process was used to calculate the velocity and acceleration maximum values. These values were used to determine the athletes kicking quality.

Electromyography

The myoelectric data was bandpass filtered with a 4th-order-zero-butterworth filter of 20 to 450 Hz. The root mean square (RMS) of each period was calculated after deducting the myoelectric activation value at rest. The MVIC took the maximum root mean square activation value obtained from the single-length maximum contraction of each muscle for 5 seconds in a 1-second window range. The muscle myoelectric activation values of each dynamic motion phase were normalised to obtain the myoelectric activation (MVIC). In addition, the co-contraction index (CI) formulas of BF-RF and GM-AD are BF/(RF+BF) and GM/(GM+AD), respectively (Kellis et al., 2003).

Statistical analysis

This study used the IBM SPSS Statistics 20.0 statistical computing software for statistical testing. The basic participant information, kicking speed, as well as the joint angle, muscle contraction ratio and co-activation values, on pivot foot were taken using repeated measures with the least significant difference (LSD) multiple comparison procedure. The post-hoc test was then used to compare results from the variables at three different kicking heights. The alpha level was set at 0.05.

Results

Participant testing performance

The maximum kick velocity and acceleration for three different kick heights are presented in Table 1. There was no significant difference between the maximum kick velocity ($p = 0.370$) and acceleration ($p = 0.408$) of the players at different heights, indicating that the three RHK heights have similar kick quality.

Kinetic effects of different RHK heights on the pivot leg

Tables 2 and 3 present the dynamic joint angles of the pivot leg, for different RHK heights, during attack and return.

The attack phase during kicking

There were significant differences on the pivot leg in the attack phase for angles of average hip flexion ($p < 0.05$), average hip abduction ($p < 0.05$), the range of hip frontal motion ($p < 0.05$). Furthermore, according to a post hoc comparison, HT values were greater than LT values ($p < 0.05$). The frontal motion hip range at HT significantly exceeded those at MT. On the pivot leg, the angles of average knee valgus ($p < 0.05$), maximum knee valgus ($p < 0.05$), the knee range at sagittal ($p < 0.05$) and frontal motions ($p < 0.05$) were significantly different. According to a post hoc comparison, the values at HT were all significantly smaller than those at LT during attack ($p < 0.05$). The other kinetic parameters exhibited no significant difference.

Table 1. **Mean (SD) of the maximum velocity and acceleration on attack foot in the RHK process between three different RHK heights.**

Variables	LT	MT	HT	*F* value	*p value*
Maximum velocity (m/s)	9.75 (1.68)	9.95 (1.72)	9.55 (1.71)	1.040	0.370
Maximum acceleration (m/s^2)	150.80 (54.51)	144.99 (52.02)	139.58 (34.67)	0.934	0.408

RHK, round house kicking; SD, standard deviation; LT, low height; MT, middle height; HT, high height.

Table 2. Means (SD) of kinematics for the pivot leg at three different RHK heights during the attack period.

Variables	LT	MT	HT	*F* value	*p value*
Average hip flexion (°) #	10.23 (6.36)	11.23 (5.06)	13.21 (5.50)	5.503	0.012 *
Average hip abduction (°)	14.01 (5.73)	14.00 (4.84)	17.07 (4.62)	2.485	0.141
Average hip external rotation (°)	5.63 (12.41)	6.41 (12.20)	7.13 (12.74)	2.514	0.104
Maximum hip flexion(°)	33.04 (8.17)	34.14 (5.99)	37.39 (6.97)	0.236	0.792
Maximum hip extension (°)	5.53 (6.36)	4.95 (5.17)	5.54 (5.85)	4.358	0.125
Maximum hip abduction (°) #	40.30 (4.86)	42.21 (6.17)	49.00 (5.53)	12.987	0.000**
Minimum hip abduction (°)	-3.35 (6.02)	-2.95 (4.96)	-3.37 (5.78)	0.137	0.872
Maximum hip external rotation (°)	20.95 (11.55)	21.65 (12.51)	23.34 (12.71)	1.425	0.262
Maximum hip internal rotation (°)	5.61 (14.16)	3.68 (12.44)	3.85 (13.45)	2.067	0.150
Hip range of sagittal motion (°)	38.57 (10.47)	39.09 (8.67)	42.93 (8.53)	3.260	0.058
Hip range of frontal motion (°) #†	43.64 (8.74)	45.17 (4.01)	52.37 (4.27)	12.782	0.001**
Hip range of horizontal motion (°)	26.56 (8.33)	25.32 (8.85)	27.19 (10.94)	0.560	0.579
Average knee flexion(°)	31.40 (6.86)	31.04 (4.73)	31.22 (4.74)	0.029	0.972
Average knee valgus (°) #†	0.12 (4.00)	0.34 (3.44)	1.66 (3.56)	8.054	0.009**
Average knee external rotation (°)	-7.35 (6.10)	-6.83 (6.99)	-6.38 (6.56)	1.939	0.168
Maximum knee flexion (°)	40.54 (6.86)	40.92 (7.29)	41.72 (6.66)	1.223	0.313
Minimum knee flexion (°)	23.63 (5.04)	22.81 (4.37)	19.12 (8.91)	1.980	0.162
Maximum knee valgus (°) #†	7.57 (4.08)	8.24 (3.27)	10.66 (2.87)	10.160	0.003 *
Maximum knee varus (°)	3.97 (4.28)	4.05 (4.26)	3.75 (4.64)	5.05	0.610
Maximum knee external rotation (°)	5.09 (8.44)	4.80 (10.12)	6.83 (7.85)	1.214	0.316
Maximum knee internal rotation (°)	16.63 (5.84)	16.00 (5.87)	15.11 (7.23)	2.464	0.108
Knee range of sagittal motion (°) †	16.91 (5.55)	18.10 (6.74)	22.61 (11.52)	3.783	0.039 *
Knee range of frontal motion (°) #†	11.54 (3.61)	12.29 (3.45)	14.42 (3.79)	7.592	0.003 *
Knee range of horizontal motion (°)	21.72 (7.46)	20.81 (8.09)	21.95 (7.28)	0.247	0.783

* $p < 0.05$; ** $p < 0.01$; δ LT vs HT $p < 0.05$; μ MT vs HT $p < 0.05$; RHK, round house kicking; SD, standard deviation; LT, low height; MT, middle height; HT, high height.

Table 3. Means (SD) of kinematics for the pivot leg at three different RHK heights during the return period.

Variables	LT	MT	HT	*F* value	*p value*
Average hip flexion #	14.10 (11.33)	15.92 (8.48)	29.80 (11.94)	23.482	0.000**
Average hip abduction #	36.46 (5.09)	37.68 (6.78)	42.78 (6.67)	9.645	0.001**
Average hip external rotation	2.55 (10.18)	2.39 (9.13)	3.01 (10.57)	0.088	0.916
Maximum hip flexion #$^{\mu}$	23.68 (13.46)	25.35 (11.56)	40.13 (14.77)	17.237	0.000**
Minimum hip flexion #†	3.74 (11.33)	5.82 (9.13)	16.13 (9.08)	15.418	0.000**
Maximum hip abduction #	46.02 (3.51)	47.04 (5.39)	53.28 (6.19)	13.168	0.000**
Minimum hip abduction #	19.10 (7.73)	20.67 (9.63)	24.88 (8.63)	5.640	0.011 *
Maximum hip external rotation	12.66 (12.11)	13.01 (10.75)	15.74 (13.79)	1.495	0.246
Maximum hip internal rotation	8.55 (10.73)	8.18 (11.85)	8.05 (11.62)	0.035	0.966
Hip range of sagittal motion	19.94 (11.88)	19.52 (11.38)	23.99 (10.31)	2.171	0.138
Hip range of frontal motion	26.92 (5.99)	26.37 (5.76)	28.40 (5.54)	0.874	0.431
Hip range of horizontal motion	21.21 (9.59)	21.20 (10.96)	23.79 (10.41)	1.010	0.380
Average knee flexion #	20.03 (9.62)	19.70 (6.77)	16.31 (9.25)	3.829	0.037 *
Average knee valgus #†	6.07 (4.05)	6.38 (3.86)	7.69 (3.10)	4.224	0.028 *
Average knee external rotation #†	-6.21 (4.19)	-6.51 (5.21)	-3.12 (4.30)	7.873	0.003 *
Maximum knee flexion	33.64 (9.62)	33.50 (10.19)	32.42 (9.47)	0.452	0.642
Minimum knee flexion †	13.97 (6.97)	13.30 (8.09)	8.90 (11.73)	4.217	0.028 *
Maximum knee valgus #†	10.37 (3.67)	10.52 (3.64)	12.06 (2.89)	5.124	0.015 *
Maximum knee varus	-0.39 (4.48)	-0.44 (4.16)	-1.27 (4.12)	1.881	0.176
Maximum knee external rotation #†	-0.12 (5.83)	0.11 (6.71)	3.94 (5.87)	9.556	0.001**
Maximum knee internal rotation #	12.77 (5.06)	12.35 (5.92)	9.61 (4.67)	3.917	0.035 *
Knee range of sagittal motion †	20.87 (7.54)	21.90 (11.78)	24.45 (11.99)	2.137	0.142
Knee range of frontal motion #†	10.16 (2.22)	9.95 (2.30)	10.70 (2.47)	1.276	0.299
Knee range of horizontal motion	13.36 (6.01)	13.37 (6.62)	14.60 (7.06)	0.722	0.497

* $p < 0.05$; ** $p < 0.01$; # LT vs HT $p < 0.05$; † MT vs HT $p < 0.05$; RHK, round house kicking; SD, standard deviation; LT, low height; MT, middle height; HT, high height.

The return phase during kicking

At the return phase, there were significant differences on the pivot leg for angles of average hip flexion ($p < 0.05$), average hip abduction ($p < 0.05$), maximum hip flexion ($p < 0.05$), minimum hip flexion ($p < 0.05$), maximum hip abduction ($p < 0.05$), and minimum hip abduction ($p < 0.05$). Furthermore, according to a post hoc comparison, HT values were greater than LT values ($p < 0.05$). Maximum hip flexion and minimum hip flexion at HT significantly exceeded those at MT. On the pivot leg, the angles of average knee flexion ($p < 0.05$), average knee valgus ($p < 0.05$), average knee external rotation ($p < 0.05$), minimum knee flexion ($p < 0.05$), maximum knee valgus ($p < 0.05$), maximum knee external rotation ($p < 0.05$), and maximum knee internal rotation ($p < 0.05$) were significantly different. According to a post hoc comparison, the angles of average knee flexion ($p < 0.05$), minimum knee flexion ($p < 0.05$), and maximum knee internal rotation ($p < 0.05$) at HT were significantly smaller than those at LT during deceleration ($p < 0.05$). By contrast the angles of the average knee valgus, minimum knee external rotation, maximum knee valgus, and maximum knee external rotation were larger than those at MT. The other kinetic parameters exhibited no significant differences.

Muscle activity effects of different RHK heights on the pivot leg

Tables 4 and 5 presented the hip muscle activities on the pivot leg, for different RHK heights, during attack and return.

The attack phase during kicking

During the RHK attack at different heights, this study detected no significant differences in all muscle ($p = 0.103$, $p = 0.295$), except CI_{BF-RF} ($p < 0.01$). A post hoc comparison demonstrated that the CI_{BF-RF} value at HT was significantly lower than that at LT ($p < 0.05$). The other EMG parameters exhibited no significant difference.

The return phase during kicking

During RHK return at different heights, this study detected significant differences in RF_{EMG} ($p < 0.05$), CI_{BF-RF} ($p < 0.01$), and CI_{GM-AD} ($p < 0.05$). A post hoc comparison demonstrated that the RF_{EMG} value at HT was significantly smaller than that at LT ($p < 0.05$). The CI_{BF-RF} value at HT was significantly greater than the values at MT ($p < 0.05$) and LT ($p < 0.05$). The CI_{GM-AD} values at MT were significantly greater than values at HT ($p < 0.05$). The other EMG parameters exhibited no significant difference.

Table 4. Mean (SD) of electromyography of muscle for the pivot leg at three different RHK heights during the attack period.

Variables	LT	MT	HT	*F* value	*p value*
RF_{EMG} (MVIC)	0.47(0.24)	0.52(0.24)	0.54(0.27)	2.527	0.103
BF_{EMG} (MVIC)	0.32(0.15)	0.29(0.11)	0.29(0.10)	1.290	0.295
AD_{EMG} (MVIC)	0.43(0.22)	0.43(0.24)	0.43(0.23)	0.032	0.969
GM_{EMG} (MVIC)	0.56(0.23)	0.56(0.23)	0.57(0.24)	0.205	0.698
CI_{BF-RF} #	0.42(0.17)	0.37(0.14)	0.36(0.13)	4.292	0.027 *
CI_{GM-AD}	0.51(0.18)	0.52(0.18)	0.53(0.18)	0.592	0.498

* $p < 0.05$; # LT vs HT $p < 0.05$; RHK, round house kicking; SD, standard deviation; LT, low height; MT, middle height; HT, high height; EMG, electromyography; MVIC, maximum autonomous isometric contractions; RF, rectus femoris; BF, biceps femoris; AD, adductor femoris; GM, gluteus medius; CI, co-contraction index.

Table 5. Mean (SD) of electromyography of muscle for the pivot leg at three different RHK heights during the return period.

Variables	LT	MT	HT	*F* value	*p value*
RF_{EMG} (MVIC) †	0.25(0.14)	0.26(0.14)	0.20(0.16)	3.578	0.045 *
BF_{EMG} (MVIC)	0.15(0.08)	0.13(0.08)	0.15(0.09)	1.296	0.286
AD_{EMG} (MVIC)	0.29(0.14)	0.27(0.16)	0.30(0.18)	1.127	0.286
GM_{EMG} (MVIC)	0.31(0.15)	0.35(0.13)	0.29(0.11)	1.137	0.339
CI_{BF-RF} #†	0.40(0.16)	0.36(0.16)	0.47(0.16)	9.163	0.001**
CI_{GM-AD} †	0.48(0.15)	0.53(0.18)	0.47(0.17)	3.812	0.038 *

* $p < 0.05$; ** $p < 0.01$; # LT vs HT $p < 0.05$; † MT vs HT $p < 0.05$; RHK, round horse kicking; SD, standard deviation; LT, low height; MT, middle height; HT, high height; EMG, electromyography; MVIC, maximum autonomous isometric contractions; RF, rectus femoris; BF, biceps femoris; AD, adductor femoris; GM, gluteus medius; CI, co-contraction index.

Discussion

This study investigated the RHK height effect on hip–knee joint kinematics on the pivot leg and activation of the surrounding stabilizer muscles. According to the results, RHK height substantially affected the hip–knee joint angles at the pivot leg as well as co-activation of the surrounding stabilizer muscles. The results more specifically reveal the following: (1) During attack and return, compared with lower kicks, a higher kick resulted in greater maximum and average dynamic hip abduction and knee valgus angles. (2) During attack but not return of a high kick, joints on the pivot leg have a greater range of motion at the hip frontal plane as well as the knee sagittal and frontal planes. At the return phase, a high kick resulted in greater dynamic knee abduction and abduction angles and lesser minimum and average knee flexion angles. (3) During a high kick, the GM activation decreased, but the hamstring muscles co-contraction reaction considerably decreased during attack but substantially increased during return.

During attack, a higher RHK resulted in a larger dynamic hip abduction, knee valgus angles, as well as larger joint ranges of motion at the hip frontal plane, knee sagittal plane, and knee frontal plane. Previous studies observed that during an RHK, the body's centre of mass tended to move horizontally and vertically toward the target, during which the body moved forward with an axial rotation at the pelvis (Gavagan and Sayers, 2017; Kinoshita and Fujii, 2014). At this moment, the hip joint at the attacking leg bent and extended to achieve knee extension, thus finishing the kick (Gavagan and Sayers, 2017; Kim et al., 2010b; Kinoshita and Fujii, 2014). In the preparation phase, the pivot leg stored potential energy required for the kick, including hip extension and hip adduction (Kinoshita and Fujii, 2014). During attack, the pivot leg produced kinetic energy, which drove pelvis rotation and forward inclination.

This process improved kick performance (Gavagan and Sayers, 2017). The present study confirmed that an increase in kick height can greatly enhance the hip abduction and flexion angles on the pivot leg, thus enabling the practitioner to increase the kicking leg angles after pelvis rotation. Under these conditions, the kicking height can be increased without compromising kicking performance (Kim et al., 2010b).

Additionally, when the player attempted to increase their attacking range while maintaining the kicking speed, the pelvis on the pivot leg tended to push even further to increase the hip abduction angles (Cortes et al., 2011; Kim et al., 2010a; 2010b). This study also demonstrated that in the attack phase, the pivot leg was partly affected by increased kicking height, thus increasing the dynamic frontal plane movement (such as hip abduction and knee valgus), but not affecting the range of motion in the horizontal plane (es. Hip and knee external rotation). During this kicking process, the pivot leg was mainly responsible for pivoting and supporting the body. Before the attacking foot touches the target, the pivot hip quickly rotates and drives lower-limb rotation to prevent the pivot leg from being “locked” to the ground (Kasbparast et al., 2014b; Moreira and Paula, 2017). Therefore, before the player kicked the target, the heel of their pivot foot was already pointed forward or to the side (Kim et al., 2010b) to allow the attacking leg to smoothly execute the kick movement. However, the present study found that although a high kick does not impact the pivot leg horizontal angle; it does increase the hip and knee frontal plane angle. This shows that the player's foot was "locked" through the hip rotation and the release axis during the kick. Although the horizontal plane angle can be released, the hip and knee frontal plane angles are still relatively high. Previous scholars verified that the lower limb joints of the axial foot may increase joint mobility in the frontal plane synchronously. The purpose is to compensate for the increase in kicking difficulty (Kasbparast et al., 2014a).

This study observed that during the return, as the target height (and, by implication, kicking height) increased, the dynamic hip abduction, knee valgus and external rotation angles on the pivot leg also increased. Notably, compared with a low kick, a high kick resulted in higher dynamic knee valgus, tibia torsion angles and lower minimum knee flexion and average knee flexion angles. The increase in these processes may be related to the pivot foot return phase, which causes the body to decelerate. This deceleration force from the ground makes the planted pivot foot produce greater impact on the lower extremity kinematics (Cortes et al., 2011; Kasbparast et al., 2014a). Especially for higher kicks, this study found that there are more knee valgus and external rotation angles. This result was consistent with that of a previous study comparing the kinematics involved in three different moving tasks, as performed by Division-I soccer players (Cortes et al., 2011). The study observed that compared with a sidestep or drop-jump task, players had a lower knee flexion angle (pivot task 24.3 ± 5.7°, sidestep 38.8 ± 8.4°, drop-jump 30.3 ± 5.2°) and higher knee valgus angle (pivot task 12.0 ± 7.0°, sidestep 3.8 ± 10.0°, drop-jump 3.9 ± 8.0°) when performing a pivot task involving a 180° directional change at the moment of ground contact (Cortes et al., 2011). Generally, with a decreased angle of knee flexion and increased angles of knee valgus and external rotation, burden on the ACL increases, which increased the risk of ACL (Cortes et al., 2011; Kasbparast et al., 2014a; Norcross et al., 2010; Sam, 2010) and knee sprain in athletes (Ford et al., 2003). According to the angular data of the present study, the maximum knee valgus and average knee flexion of the pivot leg peaked at 12.2° and 16.3°, respectively, when performing a high kick, which were 1.7 degrees higher and 3.7 degrees lower than the valgus (10.5°) and flexion (20°), respectively, when performing a low kick. This result indicated that kicks increased the risk of noncontact injuries at knee joints (Cortes et al., 2011; Sam, 2010). This result also clarified the mechanisms underlying the finding of Kasbparast et al. (2014a), who discovered that common knee injuries among TKD players tended to occur when their pivot leg plants, loads and returns.

This study demonstrated that compared with low kicks, high kicks trigger low levels of hamstring and quadriceps co-activation ratio (HQCR) during the attack phase. However, at the return phase, the HQCR level of high kicks substantially increased. This was possibly because the pelvis rotation and forward inclination generated at the kicking attack phase increasing kicking performance (Gavagan and Sayers, 2017). When the quadriceps exerted force and the hamstring relaxed, lateral pelvis rotation and hip flexion were facilitated. In other words, the co-activation reaction level decreased at the attack phase to create more space for the pivot leg, thereby ensuring that high kicks were as swift as lower kicks. By contrast, at the return phase, the co-activation reaction accelerated with RHK height, indicating that HQCR enhancement was affected by the kicking height. Previous research has argued that the HQCR level increased when the pivot leg sustained a strong impact from the dynamic knee valgus, thus the pivot leg functions as a provider of joint stability and mitigator of the valgus on ACL tension effects (Norcross et al., 2010; Sam, 2010).

This previous finding also implied that players must have a strong HQCR to withstand the impact from foot planting when performing a high kick. When entering the return phase, the ability to quickly induce a strong $CI_{BF\text{-}RF}$ force is crucial for knee joint stabilization (Kellis et al., 2004; Sam, 2010; Thibordee and Prasartwuth, 2014). According to this study’s observation of the activation of each muscle, decreased RF activation on the pivot leg during return was the main cause of the decrease in $CI_{BF\text{-}RF}$. Studies have also revealed that the force exerted by the hamstring can limit the forward tibia displacement when landing, thereby alleviating the burden sustained by the ACL and absorbing the landing shock (Kellis et al., 2003; Li et al., 1999; Norcross et al., 2010; Opar and Serpell, 2014; Shin et al., 2007). Yu et al. (2006) demonstrated that when the knee joint sustained pressure generated by the dynamic knee valgus, the knee joint was susceptible to injuries if the hamstring muscles did not facilitate the type of desirable contraction that provided dynamic stability. Opar and Serpell (2014) noted that stable hamstring contraction must be ensured to reduce the ACL load at the knee joint, demonstrating more generally that the hamstring muscles are essential stabilizer muscles that resist knee valgus load during high RHK deceleration. Moreover, when the knee joint was at full abduction angle, excessive activation of the quadriceps can intensify the shear force on the ACL (Brophy et al., 2010). Similarly, the present study discovered that when performing a high kick, quadriceps activation at the return phase decreased, possibly due to a protective muscle contraction aimed at lowering the burden on the knee ligaments.

This study observed that the magnitude of $CI_{GM\text{-}AD}$ did not increase with the kicking height at the xiphoid position despite an evident co-activation reaction. Few studies discussed the GM activation effects on different kicking heights. One study compared soccer players of different sexes with respect to their hip motions and hip abductor activation when kicking a ball (Brophy et al., 2010). According to the results from that study, the pivot leg of female players who were susceptible to ACL injuries exhibited less satisfactory lower-extremity alignment and GM–AD co-activation reactions (Brophy et al., 2010) relative to their non-susceptible counterparts. In general, the GM at the pivot leg must provide stability during the soccer kicking process if injury was to be avoided. If such stability was not provided, hip abduction and internal rotation were likely to intensify during support, where such intensification, in turn, increased the knee twisting force (Hanson et al., 2008)._Similarly, when the kicking height increased, the body tended to lean backward to increase the pelvic lateral inclination, thereby elevating the pelvis at the attacking leg (Kim et al., 2010b). This posture adjustment allowed the centre of gravity to move backward and help reduce the hip abductor burden at the pivot leg when performing a kick. The present study confirmed that GM activation was the most notable at the return phase of a moderate-height kick, indicating that hip abductor stabilization was required for kicks lower than head height to guarantee hip stability.

The implication of this study was that when players perform high kicks, their pivot leg induced a posture with greater dynamic knee valgus, knee straightening, and a high level of requisite HQCR (for lower-limb joint stabilization). TKD training should focus on hamstring training, where a strong hamstring might form the basis of injury-mitigating high-RHK technique (Opar and Serpell, 2014). Like FIFA 11+, an injury-prevention program designed for soccer players, involved exercises that progressively induced lower-limb neuromuscular functions (Daneshjoo et al., 2012; Monajati et al., 2016); FIFA 11+ has been proven to effectively prevent knee joint injuries (Barengo et al., 2014; Grooms et al., 2013). Accordingly, this study argues that a standard TKD warm-up program should be designed to condition the hamstring muscles, thereby reducing the risks for those injuries to the knee joints caused by pivot leg planting and spinning. Scholars have made similar arguments (Park and Song, 2018) involving a training regimen that facilitates knee injury prevention when kicking in TKD.

This study was limited in that the height of the kick, the displacement distance, and the pivoting foot, were primarily controlled by the athlete. However, a mark on the ground was used to confirm the sliding distance and the height of the kick target was based on the anatomical position of human body. Nonetheless, the situation was still potentially different from the kicking performance of athletes facing real opponents. In addition, the experimental design and laboratory-based nature of the study may have caused the athlete's performance to be over-regulated and distorted, and thereby not representative of the real phenomenon during competition (Gavagan and Sayers, 2017).

Furthermore, another limitation was that only high-level TKD athletes were recruited in the study. Recent studies have found that differences in the level of professional knowledge of TKD athletes were inconsistent with specific neuromuscular responses and technical aspects of high kicks (Moreira et al., 2018). Finally, the the recruitment and analysis of different genders in single group may have influenced the study’s findings. Subjects of different genders may have inconsistent lower-extremity neuromuscular control and knee movement behaviours when performing landing tasks (Brophy et al., 2010; Hewett et al., 2005) and the injury mechanism of female TKD athletes may be different from that of males (Yalfani et al., 2019). Therefore, further research should be done to explore the impact of genders on these currently examined outcome variables.

Conclusion

Elite TKD athletes perform head position kicks with greater hip and knee joint displacement in the pivot leg as compared with other positions, especially during the return period. Maximum dynamic knee valgus angle close to 12 degrees may be considered dangerous in the return phase. The hip hamstring and quadriceps co-contraction neuromuscular reaction decreased in executing head position kicks greater than other lower positions during the attack phase. In the return phase, the co-contraction increased significantly. The results showed that the knee joint load increased when players execute head position kicks in the return phase.

Acknowledgements

We are grateful for support for this study from the Ministry of Science and Technology, Taiwan, under Grant MOST: 108-2410-H-179-008-. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

References

Barengo, N. C., Meneses-Echavez, J. F., Ramirez-Velez, R., Cohen, D. D., Tovar, G. and Bautista, J. E. (2014) The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *International Journal of Environmental Research and Public Health* **11,** 11986-2000. https://doi.org/10.3390/ijerph111111986

Brophy, R. H., Backus, S., Kraszewski, A. P., Steele, B. C., Ma, Y., Osei, D. and Williams, R. J. (2010) Differences between sexes in lower extremity alignment and muscle activation during soccer kick. *Journal of Bone and Joint Surgery-American Volume* **92,** 2050-2058. https://doi.org/10.2106/JBJS.I.01547

Cappozzo, A., Catani, F., Della Croce, U. and Leardini, A. (1995) Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics (Bristol, Avon)* **10,** 171-178. https://doi.org/10.1016/0268-0033(95)91394-T

Ho, C. H. (2018) Attack tactics analysis of taekwondo: A case study on the semifinals of women's division under 46 kg in 2015 summer universiade. *Sports & Exercise Research* **20,** 29-39. https://doi.org/10.5297/ser.201803_20(1).0003

Cortes, N., Onate, J. and Van Lunen, B. (2011) Pivot task increases knee frontal plane loading compared with sidestep and drop-jump. *Journal of Sports Sciences* **29,** 83-92. https://doi.org/10.1080/02640414.2010.523087

Criswell, E. (2010) *Cram's introduction to surface electromyography*. Jones & Bartlett Publishers, LLC.

Daneshjoo, A., Mokhtar, A. H., Rahnama, N. and Yusof, A. (2012) The effects of comprehensive warm-up programs on proprioception, static and dynamic balance on male soccer players. *PLoS One* **7,** e51568. https://doi.org/10.1371/journal.pone.0051568

Distefano, L. J., Blackburn, J. T., Marshall, S. W. and Padua, D. A. (2009) Gluteal muscle activation during common therapeutic exercises. *Journal of Orthopaedic & Sports Physical Therapy* **39,** 532-540. https://doi.org/10.2519/jospt.2009.2796

Estevan, I. and Falco, C. (2013) Mechanical analysis of the roundhouse kick according to height and distance in taekwondo. *Biology of Sport* **30,** 275-279. https://doi.org/10.5604/20831862.1077553

Watta, E. (2020). Know your sport: Taekwondo rules, scoring and equipment. Available from URL: https://www.olympicchannel.com/en/stories/features/detail/know-your-sport-taekwondo-rules-scoring-equipment/

Ford, K. R., Myer, G. D. and Hewett, T. E. (2003) Valgus knee motion during landing in high school female and male basketball players. *Medicine & Science in Sports & Exercise* **35,** 1745-1750. https://doi.org/10.1249/01.MSS.0000089346.85744.D9

Gavagan, C. J. and Sayers, M. G. L. (2017) A biomechanical analysis of the roundhouse kicking technique of expert practitioners: A comparison between the martial arts disciplines of muay Thai, Karate, and Taekwondo. *PLoS One* **12,** e0182645. https://doi.org/10.1371/journal.pone.0182645

Grooms, D. R., Palmer, T., Onate, J. A., Myer, G. D. and Grindstaff, T. (2013) Soccer-specific warm-up and lower extremity injury rates in collegiate male soccer players. *Journal of Athletic Training* **48,** 782-789. https://doi.org/10.4085/1062-6050-48.4.08

Hanson, A. M., Padua, D. A., Blackburn, J. T., Prentice, W. E. and Hirth, C. J. (2008) Muscle activation during side-step cutting maneuvers in male and female soccer athletes. *Journal of Athletic Training* **43,** 133-143. https://doi.org/10.4085/1062-6050-43.2.133

Hewett, T. E., Myer, G. D., Ford, K. R. and Heidt, R. S. (2005) Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *The American Journal of Medicine* **33,** 492-501. https://doi.org/10.1177/0363546504269591

Kasbparast, M., Koh, M., Keshavarzi, H. and Rezaei, M. (2014a) The some risk factors influencing of non-contact ACL injury in soccer, basketball and taekwondo players. *International Journal of Biosciences* **5,** 278-286. https://doi.org/10.12692/ijb/5.4.278-286

Kasbparast, M., Rahimi, A., Aghaei, F., Shokrgozar, A. and Sangachin, M. H. (2014b) Comparing the incidence of anterior cruciate ligament injury in collegiate male soccer, taekwondo and basketball players. *Biological Forum–An International Journal* **6,** 387-392.

Kellis, E., Arabatzi, F. and Papadopoulos, C. (2003) Muscle co-activation around the knee in drop jumping using the co-contraction index. *Journal of Electromyography and Kinesiology* **13,** 229-238. https://doi.org/10.1016/S1050-6411(03)00020-8

Kellis, E., Katis, A. and Gissis, I. (2004) Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Medicine & Science in Sports & Exercise* **36,** 1017-1028. https://doi.org/10.1249/01.MSS.0000128147.01979.31

Kim, J. W., Kim, J. M., Lee, S. W., Han, K. H. and Kwon Y. H. (2010a). The effect of target height on the trunk, pelvis, and thigh kinematics in the taekwondo roundhouse kick. In: *Available at: https://digitalcommons.wku.edu/ijesab/vol4/iss1/2.* Vol. 4, Article 2.

Kim, J. W., Kwon, M. S., Yenuga, S. S. and Kwon, Y. H. (2010b) The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kicks. *Sports Biomechanics* **9,** 98-114. https://doi.org/10.1080/14763141003799459

Kinoshita, M. and Fujii, N. (2014) Biomechanical analysis of taekwondo roundhouse kick focused on phase before toe off. *32th International Conference of Biomechanics in Sport*, *Johnson City, TN.*

Kobayashi, H., Kanamura, T., Koshida, S., Miyashita, K., Okado, T., Shimizu, T. and Yokoe, K. (2010) Mechanisms of the anterior cruciate ligament injury in sports activities: A twenty-year clinical research of 1,700 athletes. *Journal of Sports Science and Medicine* **9,** 669-675.

Li, G., Rudy, T. W., Sakane, M., Kanamori, A., Ma, C. B. and Woo, S. L. (1999) The importance of quadriceps and hamstring muscle loading on knee kinematics and in-situ forces in the ACL. *Journal of Biomechanics* **32,** 395-400. https://doi.org/10.1016/S0021-9290(98)00181-X

Monajati, A., Larumbe-Zabala, E., Goss-Sampson, M. and Naclerio, F. (2016) The effectiveness of injury prevention programs to modify risk factors for non-contact anterior cruciate ligament and hamstring injuries in uninjured team sports athletes: A systematic review. *Plos One* **11,** e0155272. https://doi.org/10.1371/journal.pone.0155272

Moreira, P. V., Franchini, E., Ervilha, U., Goethel, M., Cardozo, A. and Gonçalves, M. (2018) Relationships of the expertise level of taekwondo athletes with electromyographic, kinematic and ground reaction force performance indicators during the dolho chagui kick. *Archives of Budo* **14**, 02/23.

Moreira, P. V. S. and Paula, L. V. (2017) Kinesiologic description of the round house kick: A brief review. *Journal of Athletic Enhancement* **6,** 1-6.

Norcross, M. F., Blackburn, J. T., Goerger, B. M. and Padua, D. A. (2010) The association between lower extremity energy absorption and biomechanical factors related to anterior cruciate ligament injury. *Clinical Biomechanics* **25,** 1031-1036. https://doi.org/10.1016/j.clinbiomech.2010.07.013

Opar, D. A. and Serpell, B. G. (2014) Is there a potential relationship between prior hamstring strain injury and increased risk for future anterior cruciate ligament injury? *Archives of Physical Medicine and Rehabilitation* **95,** 401-405. https://doi.org/10.1016/j.apmr.2013.07.028

Amraee, D., Alizadeh, M., Razi, M., Yazdi, H. R. and Minoonejhad, H. (2013) Risk factors associated with noncontact injuries of the anterior cruciate ligament in male athletes. *Minerva Ortopedica e Traumatologica* **64**.

Park, K. J. and Song, B. B. (2018) Injuries in female and male elite taekwondo athletes: A 10-year prospective, epidemiological study of 1466 injuries sustained during 250 000 training hours. *British Journal of Sports Medicine* **52,** 735-740. https://doi.org/10.1136/bjsports-2017-097530

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jorgensen, E. and Holmich, P. (2011) Preventive effect of eccentric training on acute hamstring injuries in men's soccer: A cluster-randomized controlled trial. *The American Journal of Medicine* **39,** 2296-2303. https://doi.org/10.1177/0363546511419277

Ruan, M., Zhang, Q. and Wu, X. (2017) Acute effects of static stretching of hamstring on performance and anterior cruciate ligament injury risk during stop-jump and cutting tasks in female athletes. *The Journal of Strength & Conditioning Research* **31,** 1241-1250. https://doi.org/10.1519/JSC.0000000000001783

Sam, K. L. (2010) Valgus knee angle during drop landing in female and male physical education major undergraduate students. *Asian Journal of Physical Education & Recreation* **16,** 65-78. https://doi.org/10.24112/ajper.161901

Seidel, G. K., Marchinda, D. M., Dijkers, M. and Soutas-Little, R. W. (1995) Hip joint center location from palpable bony landmarks - A cadaver study. *Journal of Biomechanics* **28,** 995-998. https://doi.org/10.1016/0021-9290(94)00149-X

Shin, C. S., Chaudhari, A. M. and Andriacchi, T. P. (2007) The influence of deceleration forces on ACL strain during single-leg landing: A simulation study. *Journal of Biomechanics* **40,** 1145-1152. https://doi.org/10.1016/j.jbiomech.2006.05.004

Thibordee, S. and Prasartwuth, O. (2014) Effectiveness of roundhouse kick in elite Taekwondo athletes. *Journal of Electromyography and Kinesiology* **24,** 353-358. https://doi.org/10.1016/j.jelekin.2014.02.002

Tornello, F., Capranica, L., Minganti, C., Chiodo, S., Condello, G. and Tessitore, A. (2014) Technical-tactical analysis of youth olympic taekwondo combat. *The Journal of Strength & Conditioning Research* **28,** 1151-1157. https://doi.org/10.1519/JSC.0000000000000255

Um, K. M. and Bae, Y. S. (2011) The effect of spinal decompression therapy on the pain and posture in the patients with low back pain. *Journal of International Academy of Physical Therapy Research* **2,** 318-323. https://doi.org/10.5854/JIAPTR.2011.2.2.318

Yalfani, A., Taghizadeh, M. and Haji Ahmadi, A. (2019) Prevalencet and mechanism of sports injuries in poomsae premier league players. *Function and Disability Journal* **2,** 165-169.

Yu, B., Lin, C. F. and Garrett, W. E. (2006) Lower extremity biomechanics during the landing of a stop-jump task. *Clinical Biomechanics* **21,** 297-305. https://doi.org/10.1016/j.clinbiomech.2005.11.003

Key points

- Head position kicking will exhibit greater knee joint instability in the pivot leg during RHK, because TKD players must change the joint range of motion to add kicking range to increase their chance to score.
- BF and RF co-activation will promote pivot leg stability in RHK kicking, especially in the return phase, to avoid a more dangerous alignment.
- The RHK pivot foot for TKD players encountered greater risk for injury in high target kicking. The hamstring muscle played an important stabilizing role.

AUTHOR BIOGRAPHY

Wei-Gang CHANG

Employment

Department of Athletic Training and Health, National Taiwan Sport University, Taoyuan, R.O.C. (Taiwan).

Degree

PhD

Research interests

Biomechanics, Functional training, Sport injury, Acupressure therapy

E-mail: wgchang@ntsu.edu.tw

Kuan-Yu LIN

Employment

Department of Athletic Training and Health, National Taiwan Sport University, Taoyuan, R.O.C. (Taiwan).

Degree

BS

Research interests

Biomechanics, Lower extremity injuries

E-mail: juliaa86831@gmail.com

Mu-Yen CHU

Employment

Department of Sports Training Science-Combats, National Taiwan Sport University, Taoyuan, R.O.C. (Taiwan).

Degree

MS

Research interests

Taekwondo, Biomechanics, Exercise training

E-mail: muyen11111@ntsu.edu.tw

Tong-Hsien CHOW

Employment

Department of Leisure Sports & Health Management, St. John's University, New Taipei City, R.O.C. (Taiwan).

Degree

PhD

Research interests

Sport medicine, Lower extremity injuries, Foot

E-mail: thchow1122@mail.sju.edu.tw

✉ **Wei-Gang Chang**
Department of Athletic Training and Health, National Taiwan Sport University, 250, Wenhua 1st Rd., Guishan District, Taoyuan City 33301, Taiwan