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ORIGINAL RESEARCH

Asymmetry of conventional and functional strength ratios in youth male taekwondo players

Yo-Han Cheon[1], Tae-Young Park[1], Jong-Kook Song[1], Myong-Won Seo[2], Kyung-Min Kim[3], Hyun Chul Jung[4,5,]*

[1]Department of Physical Education, Graduate School, Kyung Hee University, 17104 Yongin, Republic of Korea
[2]Departments of Sport & Leisure Studies, College of Physical Education, Keimyung University, 42601 Daegu, Republic of Korea
[3]Department of Sport Science, Sungkyunkwan University,16491 Suwon, Republic of Korea
[4]Sports Science Research Center, College of Physical Education, Kyung Hee University, 17104 Yongin, Republic of Korea
[5]Department of Sports Coaching, College of Physical Education, Kyung Hee University, 17104 Yongin, Republic of Korea

***Correspondence**
jhc@khu.ac.kr
(Hyun Chul Jung)

Abstract

Muscular imbalance increases the risk of non-contact injuries among youth athletes. This study aimed to examine the isokinetic hamstring-to-quadriceps strength (H/Q) ratios between the dominant and non-dominant legs in youth taekwondo (TKD) players. Sixty-three youth TKD players voluntarily participated in this study. The isokinetic muscle strength test was performed at three different angular velocities ($60°{\cdot}s^{-1}$, $120°{\cdot}s^{-1}$ and $240°{\cdot}s^{-1}$) with concentric (Con) and eccentric (Ecc) contraction modes. The conventional (H_{Con}/Q_{Con}) and functional (H_{Ecc}/Q_{Con}) H/Q strength ratios were determined. Hamstring muscle strength was significantly greater in the dominant leg than in the non-dominant leg at $60°{\cdot}s^{-1}$ (Con contraction) and at $120°{\cdot}s^{-1}$ and $240°{\cdot}s^{-1}$ (Ecc contraction). Conventional and functional H/Q strength ratios were higher in the dominant leg than in the non-dominant leg at $240°{\cdot}s^{-1}$, and the strength ratios increased with angular velocity. The asymmetry of conventional and functional H/Q strength ratios between the dominant and non-dominant legs may affect the risk of non-contact injuries among youth TKD players; thus, coaches should include specialized training programs to balance the H/Q strength ratios between legs. In particular, unilateral eccentric hamstring exercises for the nondominant leg are important for preventing noncontact injuries.

Keywords

Hamstring to quadriceps strength ratio; Hamstring strain injury; Non-contact injury; Young athletes

1. Introduction

Taekwondo (TKD) is characterized by a combination of high-speed movements, such as jumping, turning, punching, and kicking [1–4]. In particular, the muscle strength of knee extensors and flexors is an important factor in maintaining a high level of performance [5, 6]. Training programs, such as high-intensity interval training, have been introduced to develop muscle strength and power in TKD athletes [7, 8]. However, imbalanced development of muscle strength between the agonist and antagonist or dominant and non-dominant legs may increase the risk of non-contact injuries (*e.g.*, anterior cruciate ligament (ACL) injury and hamstring strain injury, HSI) [9]. The quadriceps muscles are significantly stronger than the hamstring muscles in TKD athletes [10], and imbalanced muscle strength between the knee extensors and flexors is a predominant risk factor for non-contact injuries [11–13]. A previous study reported that 46.8% of TKD athletes out of 146 athletes had noncontact ACL injuries that occurred mostly during training [14].

The hamstring-to-quadriceps strength ratio (H/Q ratio) has been used to evaluate the risk of noncontact injuries in athletes [15]. The strength ratios are determined as the maximal hamstring strength divided by the maximal quadriceps strength and calculated separately based on the angular velocity and contraction mode [16]. The concentric H/Q strength ratio is a commonly used protocol, which is called the conventional strength ratio (H_{Con}/Q_{Con} strength ratio) [15–17]. Studies reported that the risk of non-contact injuries increased when athletes had a relatively low conventional strength ratio [18, 19]. However, a conflicting result was observed in a previous study, where no significant relationship was observed between the level of conventional strength ratio and the risk of HSI [20]. Additionally, the assessment of the conventional strength ratio may be limited to reflect the nature of knee joint motion; thus, the eccentric hamstrings to concentric quadriceps strength ratio, which is known as the functional strength ratio (H_{Ecc}/Q_{Con} strength ratio), must be evaluated simultaneously to evaluate the strength ratio [21, 22] adequately. The normal range of conventional strength ratios is approximately 50–80% [23, 24]. Other studies have also suggested that the muscle strength of the knee extensors commonly surpasses that of the knee flexors by a ratio of 3:2 (66%). This relationship has led to the establishment of a normative measure, with the limit value set at 60% [15, 22]. However, weakness and inadequate activation of the posterior muscles limit their ability to contract effectively, thereby diminishing their capacity to protect the ligaments [15, 24].

For athletes who experience sufficient stress imposed by a specific discipline, long-term preferred and excessive loads on the dominant side are known to affect asymmetric muscle development during the growth period [25]. For instance, in addition to running and jumping, kicking is a basic skill in TKD that requires unilateral movement patterns [26]. As this pattern is repeated mainly on the dominant side, it may be strong enough to develop functional asymmetry [27]. Lower extremity muscle imbalance caused by training is believed to influence specific skills negatively (*e.g.*, kicking accuracy) [26]. Although preference on one side is likely to influence the direction of force asymmetries (*i.e.*, which leg is stronger) [28], it is unknown whether the sports-specific optimal range of muscle asymmetries affects the risk of noncontact injuries and a high level of performance. In addition, whether this asymmetric muscle development between the dominant and non-dominant sides would affect conventional and functional strength ratios, particularly in young athletes, needs to be investigated.

Till date, information on muscle strength and strength ratios is limited to sports other than TKD, such as soccer, futsal, basketball, and gymnastics [29–32]. Therefore, this study aimed to examine muscular strength and strength ratios between the dominant and non-dominant legs of young TKD players. We hypothesized that muscle strength and strength ratios are better in the dominant leg than in the non-dominant leg and that the ratios increase with angular velocity.

2. Materials and methods

2.1 Participants

Initially, 68 youth male TKD players, aged 14–17 years old, voluntarily participated in this study. Participants included those who (a) were currently registered as young TKD athletes in the Korea Taekwondo Association, (b) did not experience any non-contact injuries (*i.e.*, ACL injuries, hamstring strain) in the lower extremity, and (c) could participate in TKD training or exercise. The participants who did not complete the study were excluded. During the study period, five participants did not complete the study for personal reasons; thus, data from 63 youth TKD athletes were used in the study. The age distribution of the youth TKD players used in this study is as follows: 17 males of U14, 18 males of U15, 13 males of U16 and 15 males of U17. The participants included in this study exhibited a diverse range of training experience, spanning from a minimum of 1 year to a maximum of 4.8 years, with an average of 2.5 years as a TKD athlete. All participants performed TKD training five times a week for 2–3 hours per session. TKD programs include various strength and conditioning programs, such as flexibility, strength, plyometric, and cardiorespiratory training, as well as TKD skill training. All participants and their parents received oral explanations of the study procedure, its benefits, and potential risks. The participants' basic information is presented in Table 1.

TABLE 1. Participants' physical characteristics and body composition (N = 63).

Variables	Mean ± Standard Deviation
Chronological age (yr)	15.74 ± 1.57
Height (cm)	172.03 ± 5.89
Weight (kg)	63.46 ± 9.57
Fat mass (kg)	8.21 ± 3.78
Lean mass (kg)	51.18 ± 7.10
% Body fat	13.09 ± 4.99
Bone mineral content (kg)	2.49 ± 0.47
Bone mineral density (g·cm^{-2})	1.18 ± 0.13

2.2 Measure

2.2.1 Physique and body composition

Physical measurements included standing height and body weight with minimal clothing and no shoes. Standing height was measured to the nearest 0.1 centimeters by using a stadiometer (T.K.K. Takei Scientific Ins Co., Tokyo, Japan). The participants' heels, hips, and shoulders were placed in contact with the stadiometer, and their gaze was directed forward horizontally. Body weight was measured to the nearest 0.01 kg using a digital weighing meter (150A, CAS, Seoul, South Korea). All participants stood naturally on the scale with their eyes facing forward. Body mass index (BMI) was calculated using body weight in kilograms (kg) and standing height (H) in meters (m) (BMI = kg·m^{-2}). Body composition was measured using Dual X-ray Absorptiometry (DXA; QDR-4500W, Hologic, Marlborough, MA, USA). The participants lay down on the DXA table in the supine position and completed 7 min of whole-body scans. Lean body mass (LBM), fat mass (FM), and body fat percentage (% fat) were measured. All participants in this study abstained from lower-limb exercises for a minimum of 48 hours before the test day to optimize strength measurements. All measurements were performed in our laboratory under identical conditions at 5:00 PM. Each measurement session, comprising strength assessments, lasted approximately 1 h 30 min per participant.

2.2.2 Isokinetic muscle strength test

Prior to the isokinetic strength test, the participants were instructed to warm up for 10 min. First, they performed a 5-minute cycling on a Monark cycle ergometer at a resistance of 50 W while maintaining 58–63 rpm. They then performed 5-minute low-intensity dynamic stretching of the lower extremity muscles. After sufficient warm-up, the participants were seated on an isokinetic dynamometer (Humac Norm 770, Cybex, Stoughton, MA, USA) with their hips flexed at approximately 85–90°, and standard stabilization strapping was placed across the trunk, waist, and distal femur of the limb to minimize additional movement and ensure the same conditions [33, 34]. The axis of the dynamometer was visually aligned with the lateral condyle femer, and the range of motion (ROM) of the knee was 0° (flexion) to 115° (extension) for all participants. The maximum isokinetic muscle strength of knee extension and flexion was measured at three different angular velocities ($60°·s^{-1}$, $120°·s^{-1}$ and $240°·s^{-1}$) and two different contraction modes (concentric and eccentric contractions) and two sides (dominant and non-dominant leg). The participants' dominant and non-dominant lower limbs were directly surveyed using a questionnaire before measuring the isokinetic strength. Before the assessment, all participants were familiarized with the test protocol for knee extension and flexion, which involved three submaximal trials for the quadriceps and hamstrings, respectively.

Participants performed maximal knee flexions and extensions at $60°·s^{-1}$, $120°·s^{-1}$ and $240°·s^{-1}$ for five times. All participants were allowed 60 s of rest between angular velocities, and at least 30 min of rest was allowed between the concentric and eccentric contraction modes to prevent the build-up of fatigue. The investigator provided consistent verbal commands during the test to ensure maximal effort with the established full ROM, and feedback on the recorded torque was provided prior to each test.

2.2.3 Conventional and functional strength ratios

All data were normalized with each participant's body mass (BM) and calculated as peak torque ((Nm) ÷ (kg)). Conventional and functional H/Q strength ratios were established for different contraction modes at all angular velocities. The conventional strength ratio includes the concentric H/Q strength ratio (H_{Con}/Q_{Con}), whereas the functional strength ratio includes the eccentric and concentric H/Q strength ratios (H_{Ecc}/Q_{Con}).

2.3 Statistical analyses

Data were analyzed using SPSS version 26 for Windows (IBM SPSS Inc., Chicago, IL, USA). The normality of the data was confirmed using the Kolmogorov-Smirnov test. All data are presneted as mean (M) ± standard deviation (SD). Factorial ANOVA with repeated measures was used to determine the effects of dominancy and angular velocity on peak torque and H/Q ratios. When significant interactions or main effects were present, a paired *t*-test or one-way ANOVA was performed as a *post-hoc* test. The effect size was presented using partial eta-squared values ($\eta_p{}^2$) where 0.01 ≤ indicated small effect size, 0.06 ≤ medium effect size, and 0.14 ≤ large effect size [35, 36]. The effect size for the *post-hoc* test was measured using eta squared (η^2) for the one-way ANOVA and Cohen's d (*d*) for the paired sample *t*-test. The effect size was presented using *d* where 0.20 ≤ indicated small effect size, 0.50 ≤ medium effect size, and 0.80 ≤ large effect size [36]. The statistical significance level was set at 0.05.

3. Results

3.1 Isokinetic hamstring and quadriceps muscle strength

The results for isokinetic hamstring and quadriceps muscle strengths at different contraction modes, velocities, and dominances are presented in Table 2. In the concentric contraction mode, there were no significant interaction effects of velocity and dominance on hamstring or quadriceps muscle strength. However, there were main effects where the muscle strength increases with velocity ($p < 0.001$), and hamstring muscle strength in the dominant leg was significantly greater than that in the non-dominant leg at $60°·s^{-1}$ ($p = 0.01$, $d = 0.35$). In the eccentric contraction mode, there was a significant interaction effect between velocity and dominance on hamstring muscle strength ($p = 0.02$). Hamstring muscle strength in the dominant leg was greater than that in the non-dominant leg at $120°·s^{-1}$ and $240°·s^{-1}$ ($p = 0.04$, $d = 0.30$; $p = 0.02$, $d = 0.33$, respectively). However, the quadriceps muscle strength did not differ between the dominant and non-dominant legs.

3.2 Conventional and functional H/Q strength ratios

The results for the conventional and functional H/Q strength ratios are presented in Table 3 and Fig. 1. There was no significant interaction effect between velocity and dominance on the conventional H/Q strength ratio. However, significant main effects were observed where the ratio was higher in the dominant leg than in the non-dominant leg at $60°·s^{-1}$ and $240°·s^{-1}$ ($p = 0.02$), and the ratio increased with velocity ($p < 0.001$).

A significant interaction effect between velocity and dominance on the functional H/Q strength ratio was observed ($p = 0.01$). *Post-hoc* analyses showed that the functional H/Q strength ratio was significantly higher in the dominant leg than in the non-dominant leg at $240°·s^{-1}$ ($p = 0.04$, $d = 0.34$), and the ratio also increased with velocity.

4. Discussion

This study examined the differences in isokinetic muscle strength and H/Q strength ratios between the dominant and non-dominant legs of youth TKD players. The main findings of this study indicated that hamstring muscle strength was significantly greater in the dominant leg than in the non-dominant leg, particularly during eccentric contractions. Additionally, the conventional and functional H/Q strength ratios were higher in the dominant leg than in the non-dominant leg at $240°·s^{-1}$.

4.1 Isokinetic hamstring and quadriceps muscle strength

In this study, we hypothesized that the muscle strength in the dominant leg would be superior to that in the non-dominant leg, regardless of the contraction mode and angular velocity. However, a significant difference was observed only in hamstring muscle strength (knee flexors) and not in quadriceps muscle strength (knee extensors). Notably, the increased strength asymmetry was observed between the legs during eccentric contractions as compared with concentric contractions.

TKD athletes typically exhibit well-developed knee extensors compared to knee flexors because of the nature of their TKD skills [37]. This discrepancy arises because TKD training predominantly activates the quadriceps over the hamstrings, increasing the risk of noncontact acute injuries [38, 39]. The hip flexors and knee extensors of the kicking leg are the main muscles responsible for generating force [39]. Our study found

TABLE 2. Effects of angular velocity on peak torque and asymmetry of legs (N = 63).

Categories	Angular velocity	Dominant	Non-dominant	*Post-hoc*		F-value (η_p^2)	p
Concentric contraction ($Nm\cdot kg^{-1}$)							
Hamstring	$60°\cdot s^{-1}$	1.74 ± 0.41	1.64 ± 0.32	**	Velocity	375.63 (0.86)	<0.001
	$120°\cdot s^{-1}$	1.51 ± 0.36	1.45 ± 0.35		Dominance	6.65 (0.10)	0.012
	$240°\cdot s^{-1}$	1.10 ± 0.28	1.05 ± 0.28		Interaction	1.61 (0.03)	0.206
	Post-hoc	A > B/C, B > C	A > B/C, B > C				
Quadriceps	$60°\cdot s^{-1}$	3.07 ± 0.62	3.08 ± 0.58		Velocity	598.16 (0.91)	<0.001
	$120°\cdot s^{-1}$	2.52 ± 0.58	2.48 ± 0.45		Dominance	0.02 (<0.01)	0.901
	$240°\cdot s^{-1}$	1.73 ± 0.36	1.75 ± 0.32		Interaction	0.72 (0.01)	0.490
	Post-hoc	A > B/C, B > C	A > B/C, B > C				
Eccentric contraction ($Nm\cdot kg^{-1}$)							
Hamstring	$60°\cdot s^{-1}$	2.07 ± 0.52	2.06 ± 0.58		Velocity	6.29 (0.09)	0.002
	$120°\cdot s^{-1}$	2.23 ± 0.57	2.13 ± 0.55	*	Dominance	4.40 (0.07)	0.040
	$240°\cdot s^{-1}$	2.24 ± 0.61	2.10 ± 0.49	**	Interaction	4.63 (0.07)	0.016
	Post-hoc	A < B/C					
Quadriceps	$60°\cdot s^{-1}$	3.72 ± 0.91	3.63 ± 0.87		Velocity	6.39 (0.09)	0.002
	$120°\cdot s^{-1}$	3.81 ± 0.89	3.79 ± 0.86		Dominance	0.22 (<0.01)	0.643
	$240°\cdot s^{-1}$	3.84 ± 0.77	3.88 ± 0.72		Interaction	1.31 (0.02)	0.275
	Post-hoc		A < B/C				

**p < 0.05, **p < 0.01.*
*Data are presented as mean ± standard deviation, *indicates a significant difference in peak torque of dominant and non-dominant legs.*
Angular velocities at 60, 120 and 240°·s^{-1} are capitalized A, B and C, respectively.

TABLE 3. Effects of angular velocity on hamstring to quadriceps ratio and asymmetry of legs (N = 63).

Categories	Angular velocity	Dominant	Non-dominant	*Post-hoc*		F-value (η_p^2)	p
Conventional H/Q ratio							
	$60°\cdot s^{-1}$	0.57 ± 0.12	0.54 ± 0.08	*	Velocity	22.80 (0.27)	<0.001
	$120°\cdot s^{-1}$	0.61 ± 0.12	0.59 ± 0.11		Dominance	5.37 (0.08)	0.024
	$240°\cdot s^{-1}$	0.64 ± 0.13	0.61 ± 0.13	*	Interaction	0.71 (0.01)	0.490
	Post-hoc	A < B/C, B < C	A < B/C				
Functional H/Q ratio							
	$60°\cdot s^{-1}$	0.68 ± 0.16	0.67 ± 0.16		Velocity	369.53 (0.86)	<0.001
	$120°\cdot s^{-1}$	0.89 ± 0.18	0.86 ± 0.17		Dominance	4.42 (0.07)	0.040
	$240°\cdot s^{-1}$	1.32 ± 0.30	1.21 ± 0.25	*	Interaction	5.65 (0.08)	0.010
	Post-hoc	A < B/C, B < C	A < B/C, B < C				

**p < 0.05.*
*Note. Data are presented as mean ± standard deviation, *indicates a significant difference in the H/Q ratio of dominant and non-dominant legs.*
Angular velocities at 60, 120 and 240°·s^{-1} are capitalized A, B and C, respectively.

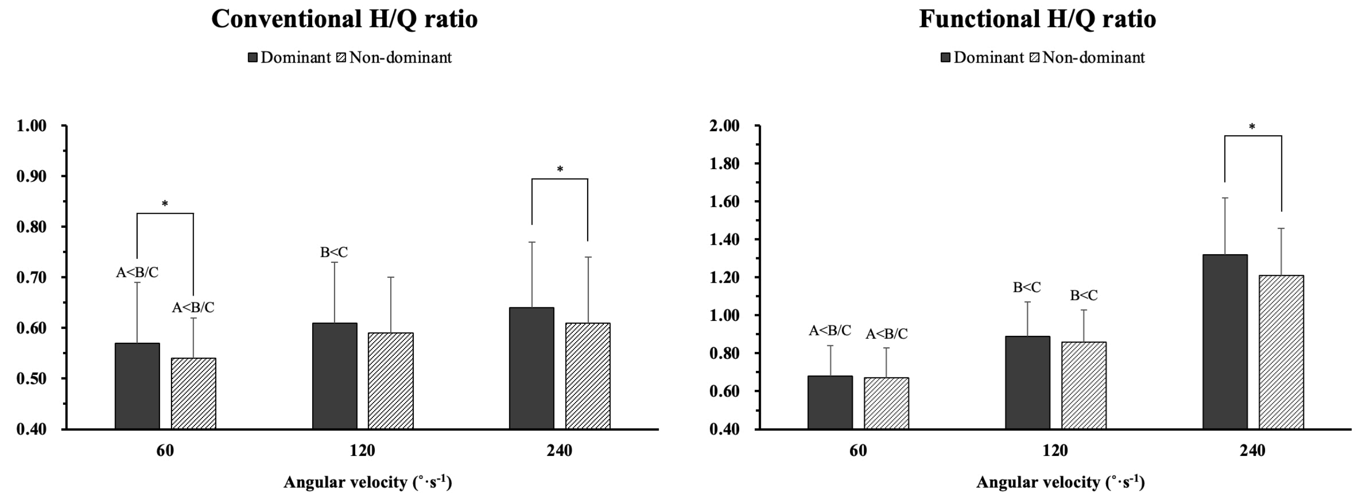

FIGURE 1. Changes in the hamstring to quadriceps strength ratio according to angular velocity (N = 63). Note. *Indicates a significant difference in the H/Q ratio of dominant and non-dominant legs, Angular velocities at 60, 120 and 240°·s^{-1} are capitalized A, B and C, respectively.

that the dominant hamstring strength of young TKD players was significantly higher than the non-dominant hamstring strength. This strength imbalance is probably attributable to biased training that focuses on preferred movements and the dominant leg. Additionally, the absence or insufficient use of compensatory exercises can disrupt motor patterns, form muscle asymmetries, and result in incorrect body posture among youth TKD players. These findings align with those of a previous study [9], which reported significantly higher strength levels of knee extensors and flexors on the dominant side than on the non-dominant side. Furthermore, the observed eccentric hamstring weakness on the nondominant side suggests that the hamstring muscle group may struggle to counter effectively during rapid knee extension [40].

Our study suggests that muscle asymmetries or weakness in the hamstring muscles of young TKD players may elevate the risk of non-contact injuries, such as HSI and ACL injuries [41]. In the concentric contraction mode, the isokinetic strength of the knee extensors and flexors decreased with increasing velocity, which is consistent with the findings of other studies [19, 26, 42]. This decline in strength during concentric contractions correlates with the general principle that force decreases as movement speed increases. However, our study revealed an opposing trend: muscle strength during eccentric contraction was maintained or even increased with increasing velocity (240°·s^{-1}). The strength gains from the eccentric contractions tended to persist or be amplified at high velocities. This finding aligns with the previous theoretical understanding that the strength levels of muscle groups in the lower limbs exhibit greater strength during eccentric motions than during concentric motions [43].

Overall, this study confirmed significant differences in hamstring muscle strength (knee flexors) between the dominant and non-dominant legs, particularly during eccentric contractions. This underscores the importance of evaluating the lower-extremity muscles in youth TKD players by validating the difference in the maximum muscular strength of the knee joints.

4.2 Conventional and functional H/Q strength ratios

In this study, the conventional H/Q strength ratio was higher in the dominant leg than in the non-dominant leg at 60°·s^{-1} and 240°·s^{-1}, while the functional H/Q strength ratio was significantly higher in the dominant leg than in the non-dominant leg at 240°·s^{-1}. Youth TKD players in this study showed lower conventional strength ratios at all three velocities than those observed in previous study performed on collegiate TKD athletes (60°·s^{-1} dominant: 0.63 ± 0.09, non-dominant: 0.59 ± 0.08; 120°·s^{-1} dominant: 0.66 ± 0.09, non-dominant: 0.64 ± 0.08; and 240°·s^{-1} dominant: 0.68 ± 0.09, non-dominant: 0.65 ± 0.09) [44]. This is particularly due to differences in muscle development during the growth spurt and sports-specific adaptation. Morphological studies have shown that the quadriceps is more developed than the hamstring during the growth spurt and that the ratios are positively correlated with age [45]. This can be explained by a training principle known as specific adaptation to imposed demand. Although TKD training includes balanced movements between the left and right sides of the body, most players focus on the dominant side. Thus, hamstring weakness could be more severe, which in turn leads to a bilateral imbalance in the H/Q strength ratios between the sides. The H/Q strength ratio was not only affected by angular velocity but also by a significant correlation between the dominant and non-dominant sides. Nevertheless, the ratio of young TKD players included in this study did not meet the standard index of the conventional ratio presented (*i.e.*, 60% or more at 60°·s^{-1} and 70% or more at 240°·s^{-1}). The reason for the low conventional strength ratio of growing young TKD players is that the rate of development of the antagonist hamstring strength is significantly lower or slower than that of the agonist quadriceps in concentric contraction.

Monitoring the functional strength ratio along with the conventional strength ratio can provide information on predisposition to injury and performance improvement in specific sports activities [31, 46]. To the best of our knowledge, this study is the first to compare bilateral differences in functional strength ratio in youth TKD players. A consistent result was observed in a previous study, in which no significant differences in functional H/Q strength ratios between legs were found at low velocities in soccer players (dominant: 0.79, non-dominant: 0.74) [47]. However, as per our findings, a significant difference in functional H/Q strength ratio between legs was observed at a high velocity ($240° \cdot s^{-1}$). This result may be explained by the selective inability mechanism [48] according to which the hamstring muscle is less activated during eccentric contraction. In addition, repeated loading, mainly on the dominant side, may limit training adaptation in the nondominant leg, especially eccentric adaptation, potentially affecting sarcomerogenesis [49].

In this study, youth TKD players showed a lower functional strength ratio (dominant: 0.68, non-dominant: 0.67) at $60° \cdot s^{-1}$ than athletes involved in other sports, such as soccer [47]. A relatively low functional strength ratio (<0.7) has been reported to increase the risk of noncontact injuries, such as hamstring strain and ACL injuries [50]. Although it is difficult to directly apply these findings to our results because of differences in age and sport type, specific training strategies aimed at improving eccentric hamstring strength may need to be developed for youth TKD players.

To the best of our knowledge, this is the first study to evaluate the conventional and functional strength ratios of young TKD players, and we believe that these data will provide valuable insights into the strength profiles of young TKD players. In addition, athletes in other sports, such as karate and soccer, can benchmark our lower limb strength profiles because the understanding of lower limb strength ratios between agonist and antagonist or dominant and non-dominant legs can be applied to optimize youth athletes' development. However, our findings have some limitations. First, the isokinetic test may have limitations in reflecting the nature of TKD kicking, as TKD kicking involves multi-joint movements performed at high angular velocities of $730° \cdot s^{-1}$ and $860° \cdot s^{-1}$ to $1720° \cdot s^{-1}$ [51, 52]. Second, this study was performed on young male TKD players; therefore, generalizing the findings to all youth TKD players may be challenging. Finally, while the H/Q strength ratio has been recognized as a risk factor for hamstring strain injuries, our findings do not conclusively confirm an association between the asymmetry of the H/Q strength ratio and non-contact injuries. Future studies may benefit from longitudinal observations aimed at exploring whether this asymmetry in H/Q strength ratios influences the risk of noncontact injuries. Additionally, based on our study findings, we suggest that unilateral eccentric hamstring exercises are important for reducing noncontact injuries, such as HIS and ACL injuries. Thus, Nordic Hamstring Curl training increases hamstring eccentric strength and helps maintain correct functional strength ratios [53].

This study has some limitations. First, the analysis of peak torque in this study was performed using BM, according to the methodology mentioned in previous studies. While this approach is conventional, it overlooks various biological factors, such as height, LBM, leg length, bone mineral content, and bone mineral density, which may influence muscle strength. Considering these factors, normalization *via* allometric scaling is a relatively robust method [54]. Moreover, a comprehensive examination of muscle strength levels should incorporate corrections for these factors, thus leading to a further nuanced understanding as compared with previous studies. Furthermore, a more comprehensive evaluation would entail examining additional parameters, such as maximal strength, strength ratio, muscle endurance, fatigue, and muscle activity. This holistic approach is essential for providing an accurate and applicable framework for assessing young TKD players and guiding coaches in their training strategies. Another limitation is that the maturity status of individual participants could not be assessed in this study.

5. Conclusions

This study confirmed that hamstring muscle strength was significantly greater in the dominant leg than in the nondominant leg, especially during eccentric contraction. Additionally, both the conventional and functional H/Q strength ratios were higher in the dominant leg than in the non-dominant leg at $240° \cdot s^{-1}$. Coaches should implement specialized training programs to achieve a balance in H/Q strength ratios between the dominant and non-dominant legs. Specifically, unilateral eccentric hamstring exercises for the nondominant leg are important for preventing noncontact injuries in youth TKD players.

ABBREVIATIONS

TKD, taekwondo; HSI, Hamstring Strain Injury; ACL, anterior cruciate ligament; H/Q ratio, hamstring-to-quadricep strength ratio; ROM, range of motion.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

YHC and HCJ—designed the study; analyzed the data; wrote the manuscript. YHC and TYP—performed the experiments. HCJ, JKS, MWS and KMK—provided assistance and advice regarding experiments. All authors contributed to the editorial changes in the manuscript. All the authors have read and approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Kyung Hee university's Institutional Review Board (IRB) (KHUIRB#21-175). Written informed consent was obtained from all participants and their parents.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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