



OPEN Isokinetic knee strength profiles, conventional hamstring-to-quadriceps ratio, and performance decrement in weightlifting and wrestling athletes: a cross-sectional study

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Lower extremity strength characteristics, particularly the hamstring-to-quadriceps (H/Q) ratio and performance decrement-related variables, play a critical role in both injury prevention and athletic performance. However, few studies have compared these isokinetic knee strength characteristics according to sport type and athletic career duration. This cross-sectional study, recruited 40 weightlifting and wrestling athletes. Classified them into a ≤ 5 -year experience group ($n, 15; 20.33 \pm 1.84$ years) and a ≥ 6 -year group ($n, 25; 31.40 \pm 3.51$ years). Using a Biodex System IV dynamometer, bilateral knee flexion/extension peak torque was measured at angular velocities of $60^\circ/s$ (3 trials), $180^\circ/s$ (5 trials), and $240^\circ/s$ (26 trials), from which the H/Q ratio, explosive, and performance decrement percentage were derived. The ≥ 6 -year career group was older than the ≤ 5 -year group ($p < 0.001$), with no significant differences in other body-composition variables. Weightlifters exhibited higher H/Q ratios than wrestlers at $60^\circ/s$ bilaterally (right, $p = 0.036$; left, $p = 0.015$) and higher explosive ratios in right knee extension at $60^\circ/s$ ($p < 0.001$) and $180^\circ/s$ ($p = 0.023$). Career-duration groups differed significantly in right knee flexion measures, with the largest difference at $240^\circ/s$ average peak torque ($p = 0.006$). Knee strength variables were significantly correlated with strength-related factors, including performance decrement % (all $p < 0.001$). In this cross-sectional study, isokinetic knee strength-related characteristics varied according to sport type and athletic career duration. Regular monitoring of isokinetic strength profiles, including the H/Q ratio and performance decrement index, may help inform individualized training programs and support injury prevention strategies.

Keywords Isokinetic strength, H/Q ratio, Fatigue, Power, Exercise load

Functional performance and competitive success in sports are closely tied to mechanical efficiency, defined as the ability to maximize external force, speed, and power production during a given exercise¹. In this context, biomechanical approaches have become increasingly important not only for enhancing athletic performance but also for mitigating injury risk and optimizing athlete physiotherapy. Isokinetic strength testing is one of the methods used to evaluate these aspects of mechanical efficiency, as it allows the assessment of muscle strength and endurance across different angular velocities, full ranges of motion, and contraction modes². Accordingly, these tests are widely used in both sports and clinical settings to evaluate performance, identify injury risk factors, monitor physiotherapy outcomes, and detect muscular imbalances that may contribute to athletic injury³. This broader role of biomechanics in sports performance, injury mitigation, and physiotherapy has also been emphasized in recent literature⁴.

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Isokinetic strength tests at low concentric angular velocities are commonly used to evaluate maximum muscle strength, while higher angular velocities are used to assess muscle endurance through multiple repetitions⁵. These assessments are most commonly performed at the knee joint, with specific test velocities corresponding to different neuromuscular attributes: 60°/s for maximal strength, 180°/s for muscular power, and 240°/s for muscular endurance⁶. The knee joint is one of the most frequently injured anatomical sites in athletes, due to its complex structure and the substantial mechanical stress it experiences during physical activity⁷. Over 50% of muscle injuries affect the thigh muscles, with hamstring muscle injuries representing the most common type, accounting for 12% of all injuries⁸. To prevent knee injuries, ensuring that athletes produce sufficient strength during functional activities may be beneficial⁹.

The hamstring-to-quadriceps (H/Q) ratio plays a critical role in knee joint injury prevention and is an important indicator of overall knee joint muscle balance¹⁰. A well-balanced H/Q ratio enhances joint stability and is used to detect muscle imbalances, monitor knee joint stability, strength characteristics, and assess knee function. It is especially a valuable tool in anterior cruciate ligament (ACL) injury, for both injury prevention and physiotherapy. Conversely, an imbalanced H/Q ratio increases the risk of muscle strain or ligament damage during high-intensity or high-speed movements¹¹. Furthermore, the measurement of dynamic H/Q ratio changes under performance decrement is also an important factor¹².

As previously noted, the H/Q ratio, muscle strength, and neuromuscular performance decrement are well-established risk factors for musculoskeletal injury¹³. However, these factors do not fully capture other important neuromuscular variables that may affect the dynamic relationship between agonist and antagonist muscles, including torque, explosive force, muscle size, muscle performance decrement, and muscle activation across varying joint angles¹⁴. Although studies in specific sports, particularly ball games such as soccer and basketball, are relatively well established^{15,16}, fewer studies have examined how long-term cumulative mechanical loading influences functional symmetry. Repeated exposure to sport-specific mechanical loads may progressively affect bilateral strength characteristics and agonist–antagonist balance, especially in sports characterized by asymmetrical or repetitive high-intensity lower-limb actions. This highlights the importance of investigating the association between long-term training history and isokinetic knee strength profiles. In this context, athletes exposed to continuous, high-intensity, and repetitive training may be particularly susceptible to asymmetric loading when structured recovery, individualized biomechanical monitoring, and injury prevention strategies are insufficient¹⁷.

Although isokinetic knee testing has been widely used to assess peak torque and agonist–antagonist balance, prior studies have largely focused on isolated variables or single-sport settings. Comparatively few studies have comprehensively examined torque generation, conventional H/Q balance, and performance decrement-related indices in athletes from sports with distinct lower-limb loading characteristics. Weightlifting and wrestling both require substantial lower-limb force production, yet they provide an informative comparative model because they differ markedly in movement symmetry, loading direction, and task-specific neuromuscular demands.

Therefore, the primary aim of this cross-sectional observational study was to compare isokinetic knee strength profiles, including peak torque, the conventional hamstring-to-quadriceps ratio, and performance decrement-related variables, according to athletic career duration in weightlifting and wrestling athletes. The secondary aim was to compare these variables between sport types. We hypothesized that sport type and athletic career duration would be associated with differences in peak torque, the conventional H/Q ratio, and performance decrement-related characteristics.

Materials and methods

Participants

The study included 40 athletes engaged in high-intensity training for at least 5 days per week. Sample size was calculated a priori using G*Power based on the original study design. Assuming an effect size of 0.25, a significance level of 0.05, and statistical power of 0.80, the required minimum sample size for the planned between-group comparison was 34 participants. A 2 × 2 factorial ANOVA under the same assumptions would generally require a substantially larger sample. However, the present study involved a specific population of elite wrestlers and weightlifters, and participant recruitment was limited by the availability of eligible athletes. Therefore, the two-way ANOVA was interpreted as a supplementary analysis, whereas the original sample size justification was based on the primary framework of simple group comparisons^{18,19}. Considering potential dropout, a total of 40 participants were included. Eligible participants were actively competing weightlifting or wrestling athletes who were engaged in regular supervised training and had no current musculoskeletal condition that would preclude maximal isokinetic testing. The median age of participants was 27.23 ± 6.17 years, and the median training experience was 5.95 ± 1.13 years. The event consisted of weightlifting and wrestling. Participants were categorized into two groups according to their training experience: a ≤ 5-year group ($n = 15$; age: 20.33 ± 1.84 years) and a ≥ 6-year group ($n = 25$; age: 31.4 ± 3.51 years). Among the athletes with ≤ 5 years of experience, 9 were weightlifters and 6 were wrestlers, whereas among those with ≥ 6 years of experience, 11 were weightlifters and 14 were wrestlers.

None of the participants had musculoskeletal or neurological conditions that could affect joint function or performance in the tests. All participants voluntarily gave informed consent after receiving a detailed explanation of the study's purpose, procedures, and potential risks. Ethical approval was obtained from the Institutional Bioethics Committee of Gachon University (approval date: November 28, 2024; approval number: 1044396-202410-HR-169-01), and the study was conducted in accordance with the Declaration of Helsinki. Additionally, the study was registered.

Isokinetic strength testing of the knee

The dominant limb was defined as the leg identified by each participant, through the initial questionnaire, as the preferred limb for forceful unilateral actions. The isokinetic knee strength of the lower limbs was measured using a Biodex System IV dynamometer (Biodex Medical Systems, Shirley, NY, USA). Prior to testing, participants completed a standardized 15-minute warm-up consisting of 10 min of stationary cycling followed by 5 min of dynamic stretching. This was followed by a 1-minute familiarization session, after which participants rested for 1 min. During testing, participants were positioned with both the hip and knee joints stabilized at 90° of flexion, and the legs elevated. Knee extension was restricted to 0°, and flexion to 110°. All isokinetic assessments were performed in the concentric–concentric mode for both knee extension and knee flexion. The system automatically calibrated gravitational compensation and mechanical axis alignment. The assessment focused solely on the knee joint, with stabilization provided by straps across the thighs, hips, and chest. A specialized apparatus facilitated movement between 90° and 180° at angular velocities of 60°/s (3 trials), 180°/s (5 trials), and 240°/s (26 trials)²⁰. Each trial was separated by a 1-minute rest. The highest peak torque values recorded across the trials were used for data analysis. Testing alternated between the dominant and non-dominant legs, with a 3-minute rest period between sides. Peak torque (Nm) and H/Q ratio were recorded for both limbs. Verbal motivation was consistently provided to optimize maximal strength and velocity performance.

Outcome variables

After completing all measurements, the collected data were processed to analyze the lower-extremity strength characteristics, H/Q ratio, and performance decrement index. Three key performance metrics were calculated using standardized formulas:

H/Q ratio

The H/Q ratio was calculated by dividing the peak torque generated by the hamstring muscles during knee flexion by the peak torque produced by the quadriceps muscles during knee extension at the same angular velocity²¹.

- $H/Q \text{ ratio} = \text{hamstring (flexion) peak torque} \div \text{quadriceps (extension) peak torque}$.

Rate of torque development

The rate of torque development, often referred to as the explosive ratio, is defined as the quotient of the peak torque and the time required to reach the peak torque during muscle contraction²².

- $\text{Rate of torque development (Nm}\cdot\text{s}^{-1}) = (\text{peak torque} \div \text{time to peak torque})$.

Performance decrement

Performance decrement index or performance decrement percentage (performance decrement %) quantifies the percentage decline in muscle performance over a series of repeated contractions. This was calculated by comparing the average power output during the initial third of the test protocol to that in the final third²⁰.

- $\text{Performance decrement (\%)} = [(\text{first third power} - \text{last third power}) \div \text{first third power}] \times 100$.

Statistical analysis

All statistical analyses were conducted using R software (version 4.3.4; R Foundation for Statistical Computing, Vienna, Austria). Normality was assessed using the Shapiro–Wilk test, and descriptive statistics and frequency analyses were used to summarize participant characteristics. Continuous variables are presented as means \pm standard deviations (SD). To reduce the risk of type I error due to multiple comparisons, adjusted *p*-values were additionally examined for the principal outcome analyses using the Holm procedure. Paired *t*-tests were used to assess side-to-side differences within the same participant. Independent *t*-tests were initially applied for simple between-group comparisons of asymmetry-related variables according to sport type and career duration. In addition, given that the study design included two grouping factors, sport type and career duration, two-way analysis of variance (ANOVA) was performed for the principal asymmetry-related and isokinetic variables to examine the main effects of sport type and career duration and their interaction. Cohen's *d* effect size was calculated using the pooled standard deviation of the change scores, with values < 0.2 considered small, ≥ 0.5 medium, and ≥ 0.8 large. Pearson's correlation analysis was performed to examine the relationship between lower extremity strength and career duration. Statistical significance was set at $p < 0.05$.

Results

Demographic characteristics of participants

Among participants with ≤ 5 -year experience ($n = 15$), 9 (60.00%) were weightlifters and 6 (40.00%) were wrestlers. In the ≥ 6 -year experience group ($n = 25$), 11 (44.00%) were weightlifters and 14 (56.00%) were wrestlers.

The mean age was 20.33 ± 1.84 years in the ≤ 5 -year group and 31.40 ± 3.51 years in the ≥ 6 -year group, indicating a statistically significant difference between the groups (*effect size*, 3.7; $p < 0.001$). No significant between-group differences were observed in body composition variables other than age. The marked age difference between the career-duration groups should be taken into account when interpreting all career-based comparisons (Table 1).

Variable	≤5-year (n, 15)	≥6-year (n, 25)	Cohen's d	p
Age (year)	20.33 ± 1.84	31.4 ± 3.51	3.7	<0.001***
Height (cm)	172.42 ± 5.31	174.61 ± 5.25	0.4	0.212
Weight (kg)	78.43 ± 9.23	81.40 ± 8.06	0.3	0.212
Skeletal muscle mass (kg)	56.82 ± 5.50	58.98 ± 5.95	0.4	0.261
Body Fat mass (%)	21.50 ± 4.28	21.60 ± 5.14	0.0	0.952
Body mass index (kg/m ²)	26.40 ± 3.17	26.74 ± 3.00	0.1	0.733
Weightlifters	9 (60.00%)	11 (44.00%)	3.7	-
Wrestlers	6 (40.00%)	14 (56.00%)	0.4	-

Table 1. Demographic characteristics of participants. Values are expressed as mean ± SD, *** $p < 0.001$ by t-test

Isokinetic strength test outcomes by sports

Analysis of sport-related differences revealed that the H/Q ratio was generally higher in weightlifters than in wrestlers at 60°/s and 180°/s, whereas no clear difference was observed at 240°/s. Significant between-sport differences were observed on both the right (*effect size*, 0.6; $p = 0.036$) and left (*effect size*, 0.9; $p = 0.015$) sides at 60°/s.

In most measurements, the rate of torque development also indicated more rapid performance in weightlifters than in wrestlers. Statistically significant differences were observed in right knee extension at both 60°/s (*effect size*, 1.2; $p < 0.001$) and 180°/s (*effect size*, 0.7; $p = 0.023$).

However, for performance decrement (%), wrestlers generally showed lower values than weightlifters across most variables, although none of these differences reached statistical significance (Table 2).

Isokinetic Strength Test Outcomes by Career

Figure 1 presents the peak torque and average peak torque values for the career-duration groups. In right knee flexion, significant between-group differences were observed for all peak torque variables and for average peak torque, except for peak torque at 240°/s. The largest difference was observed for average peak torque at 240°/s (≤5-year group, 51.44 ± 7.76; ≥6-year group, 60.76 ± 10.83; *effect size*, 1.0; $p = 0.006$) (Fig. 1). In the isokinetic strength factor analysis, significant between-group differences in the rate of torque development were found for right knee extension at 60°/s (*effect size*, 0.7; $p = 0.040$) and left knee flexion at 240°/s (*effect size*, 1.0; $p = 0.005$) (Table 3). These career-group differences should be interpreted cautiously because the groups also differed substantially in age and were not fully balanced in sport distribution. (Fig. 1).

Isokinetic strength test outcomes by sports and career

In the two-way ANOVA, significant main effects of sport type were observed for the 60°/s H/Q ratio on both the right ($p = 0.009$) and left sides ($p = 0.008$), indicating higher values in weightlifters than in wrestlers. Significant sport-type effects were also found for the 60°/s rate of torque development in extension on the right side ($p = 0.003$), the 60°/s rate of torque development in flexion on the right side ($p = 0.009$), and the 180°/s rate of torque development in flexion on the right side ($p = 0.027$).

Regarding career duration, significant main effects were identified for the 60°/s rate of torque development in extension on the left side ($p = 0.028$) and the 240°/s rate of torque development in flexion on the left side ($p = 0.003$), with higher values in the ≥6-year group than in the ≤5-year group.

In addition, significant sport type × career duration interaction effects were found for the 60°/s rate of torque development in flexion on the right side ($p = 0.019$) and the 180°/s performance decrement in flexion on the left side ($p < 0.001$), suggesting that the pattern of group differences for these variables varied according to the combined influence of sport type and career duration (Table 4).

Correlation between knee strength and strength factors

Pearson's correlation analysis revealed strong positive correlations between the strength-related variables and knee strength across all angular velocities. Strong correlations were also observed between the angle of peak torque and time to peak torque across all angular velocities (60°/s, 180°/s, and 240°/s) during both knee extension and flexion ($p < 0.001$).

Notably, at all three angular velocities, flexion showed a positive correlation, whereas extension showed a negative correlation. Furthermore, significant correlations were observed between performance decrement (%) and strength-related variables, with the strongest associations found at 60°/s during right knee flexion ($p < 0.001$) and at 240°/s during left knee extension ($p < 0.001$) (Fig. 2).

Discussion

This study aimed to assess isokinetic knee strength-related characteristics in athletes, with a particular focus on the H/Q ratio and performance decrement-related variables, and to examine differences according to sport type and athletic career duration. In the United States, over 8.6 million injuries are reported annually, with up to 42% involving the lower extremities⁶. The lower extremities are critical for athletic performance and provide a foundation for force production, stability, and movement efficiency²³. Consequently, they play a crucial role in both injury prevention and supporting athletic performance and career longevity during competition. Moreover, comparisons across sports and career stages are essential.

Variable	Weightlifters (n, 20)	Wrestlers (n, 20)	Cohen's d	p	
60°/s	HQ Ratio (R)	0.53 ± 0.10	0.46 ± 0.12	0.6	0.036 [†]
	HQ Ratio (L)	0.53 ± 0.08	0.46 ± 0.08	0.9	0.015 [†]
	Rate of torque development (E.R)	427.50 ± 121.74	577.00 ± 128.31	1.2	< 0.001 ^{***}
	Rate of torque development (E.L)	522.00 ± 163.60	560.50 ± 170.22	0.2	0.470
	Rate of torque development (F.R)	432.00 ± 190.06	556.50 ± 237.89	0.6	0.075
	Rate of torque development (F.L)	407.00 ± 155.26	518.20 ± 263.94	0.5	0.115
	Performance decrement % (E.R)	-3.48 ± 15.89	-5.08 ± 13.28	0.1	0.732
	Performance decrement % (E.L)	-3.91 ± 18.23	1.13 ± 10.38	0.3	0.291
	Performance decrement % (F.R)	25.20 ± 20.96	20.23 ± 18.89	0.2	0.436
	Performance decrement % (F.L)	20.11 ± 23.44	44.66 ± 118.43	0.3	0.374
180°/s	HQ Ratio (R)	0.53 ± 0.08	0.51 ± 0.14	0.2	0.483
	HQ Ratio (L)	0.52 ± 0.07	0.51 ± 0.11	0.1	0.738
	Rate of torque development (E.R)	238.00 ± 25.87	262.50 ± 38.51	0.7	0.023 [†]
	Rate of torque development (E.L)	247.50 ± 30.07	236.00 ± 34.70	0.4	0.270
	Rate of torque development (F.R)	270.50 ± 60.22	322.50 ± 121.91	0.6	0.098
	Rate of torque development (F.L)	265.50 ± 64.68	278.50 ± 69.00	0.2	0.542
	Performance decrement % (E.R)	11.94 ± 18.02	9.26 ± 22.20	0.1	0.677
	Performance decrement % (E.L)	8.58 ± 15.50	17.66 ± 11.59	0.7	0.042 [†]
	Performance decrement % (F.R)	34.38 ± 38.42	25.96 ± 22.30	0.3	0.404
	Performance decrement % (F.L)	39.86 ± 18.59	31.07 ± 28.76	0.4	0.258
240 °/s	HQ Ratio (R)	0.54 ± 0.09	0.56 ± 0.10	0.2	0.418
	HQ Ratio (L)	0.52 ± 0.09	0.55 ± 0.08	0.4	0.201
	Rate of torque development (E.R)	188.00 ± 29.13	191.50 ± 34.53	0.1	0.731
	Rate of torque development (E.L)	195.50 ± 26.65	189.51 ± 34.40	0.2	0.542
	Rate of torque development (F.R)	197.50 ± 48.76	211.50 ± 52.94	0.3	0.390
	Rate of torque development (F.L)	205.50 ± 56.71	188.50 ± 57.06	0.3	0.351
	Performance decrement % (E.R)	35.12 ± 12.04	39.48 ± 9.23	0.4	0.208
	Performance decrement % (E.L)	34.23 ± 12.86	36.83 ± 14.72	0.2	0.555
	Performance decrement % (F.R)	44.34 ± 19.86	39.13 ± 14.67	0.3	0.351
	Performance decrement % (F.L)	42.24 ± 14.10	39.80 ± 16.38	0.2	0.615

Table 2. Analysis of the factors of isokinetic exercise test for knee by sports. Values are expressed as mean ± SD, * $p < 0.05$, *** $p < 0.001$ by t-test; Rate of torque development ($\text{Nm}\cdot\text{s}^{-1}$); R, right; L, left; E, extension; F, flexion

Previous studies comparing weightlifters and wrestlers have reported that wrestlers tend to exhibit greater bilateral imbalances in both lower limb muscle strength and femoral cartilage characteristics. This disparity is likely attributable to the dynamic, asymmetrical movements inherent in wrestling, which are presumed to induce a greater imbalance, in contrast to the relatively uniform and vertical movements of weightlifting. However, the results of this study indicate that wrestlers do not exhibit significant bilateral asymmetry in their explosive ratio. Interestingly, wrestlers displayed a higher average rate of torque development compared to weightlifters. Athletes involved in high-speed movements, such as combat sport athletes and sprinters, typically demonstrate higher explosive ratios during isokinetic testing, with the knee joint rate of torque development recognized as a key indicator of muscular power²⁴. While weightlifting also requires explosive strength, the sport-specific neuromuscular demands of wrestling may be associated with the pattern observed in the present study. Recent wrestler-specific evidence also suggests that lower-extremity isokinetic strength characteristics, particularly extensor-related capacity, are closely associated with performance-relevant outcomes in elite freestyle wrestlers.

Weightlifting is fundamentally characterized by a high reliance on maximal lower-body explosive power, particularly during the snatch and clean and jerk, which require rapid triple extension and substantial force generation by the hip and knee extensors²⁵. Accordingly, the present findings should not be taken to suggest that wrestling imposes greater absolute lower-body explosive demands than weightlifting. Instead, the higher average explosive ratio observed in wrestlers may be better understood as reflecting the distinct neuromuscular and task-specific demands of wrestling, such as repeated reactive lower-limb drive, force transmission under unstable and asymmetrical conditions, and rapid extensor-dominant actions during takedown and counteraction phases²⁶. In support of this interpretation, recent wrestler-specific evidence indicates that lower-extremity isokinetic strength characteristics, particularly extensor-related capacity, are closely linked to performance-relevant outcomes in elite freestyle wrestlers²⁷.

Furthermore, the results of the explosive ratio based on exercise experience revealed that the ≥ 6 -year group demonstrated higher results in all angles and almost all items than the ≤ 5 -year group. However, the ≥ 6 -year group was also substantially older than the ≤ 5 -year group, and this marked age imbalance should be taken

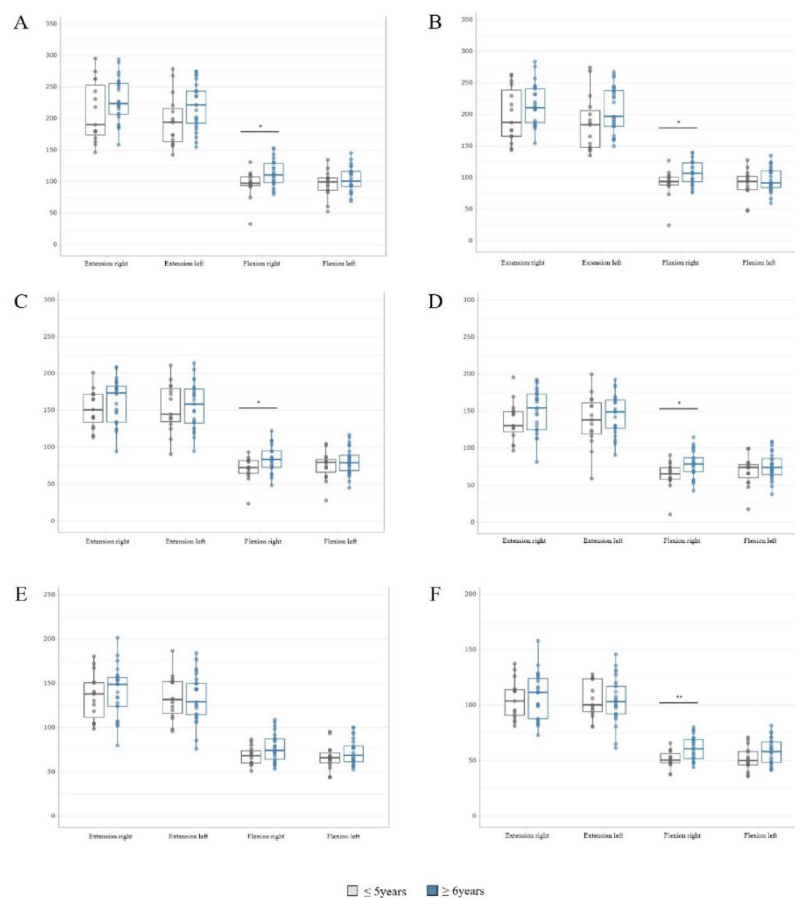


Fig. 1. Measurements of the left and right knees according to groups. **(A)** peak torque of isokinetic knee strength extension and flexion test at 60°/s; **(B)** average peak torque of isokinetic knee strength extension and flexion test at 60°/s; **(C)** peak torque of isokinetic knee strength extension and flexion test at 180°/s; **(D)** average peak torque of isokinetic knee strength extension and flexion test at 180°/s; **(E)** peak torque of isokinetic knee strength extension and flexion test at 240°/s; **(F)** average peak torque of isokinetic knee strength extension and flexion test at 240°/s.

into account when interpreting all career-based comparisons. Therefore, the observed career-group differences should be interpreted with caution, as they may reflect the combined influence of training exposure and age rather than career duration alone. This point is particularly relevant for explosive performance-related variables. The superior performance of the older, more experienced group may reflect not only greater training exposure but also differences in physiological maturation and peak-performance age. Accordingly, the higher strength values observed in the ≥ 6 -year group cannot be attributed solely to athletic career duration. Currently, few studies have established precise normative values for the explosive ratio. Nevertheless, they are associated with changes in the H/Q ratio and peak torque velocity and are commonly used as indirect indicators of explosive power^{28,29}.

In the present study, the reported H/Q values represent the conventional hamstring-to-quadriceps ratio rather than the functional ratio. An inadequate H/Q ratio, particularly values below 0.6, has been widely associated with an increased risk of ACL injuries due to the imbalance in anterior-posterior knee joint stabilization. The disproportionate strength of the quadriceps and hamstrings may result in excessive anterior tibial translation during high-velocity movements, thereby increasing the mechanical load on the ACL³⁰. While some studies report an H/Q ratio below 0.4–0.5 as a risk factor for ACL injury³¹, others indicate a cutoff point of 0.6³². A review of 22 studies involving 1,145 male participants revealed a significant positive correlation between the conventional H/Q ratio and angular velocity applied during isokinetic testing, indicating that higher speeds are associated with increased H/Q ratios.

This finding indicates a specific torque–velocity relationship between the knee extensors and flexors, wherein the hamstrings demonstrate a greater capacity to generate force relative to the quadriceps as the testing speed increases^{33,34}. In this study, the H/Q ratios ranged from 0.4 to 0.6. This range is broadly consistent with conventional concentric H/Q values reported in athletic populations and may reflect the torque–velocity relationship of the knee flexors and extensors, rather than imbalance alone²¹. Because this study used a cross-sectional design, the observed H/Q ratio pattern cannot be attributed to prolonged asymmetrical loading or

Variable		≤ 5-year (n, 15)	≥ 6-year (n, 25)	Cohen's d	p
60°/s	HQ Ratio (R)	0.48 ± 0.15	0.50 ± 0.09	0.2	0.646
	HQ Ratio (L)	0.50 ± 0.10	0.49 ± 0.08	0.1	0.675
	Rate of torque development (E.R)	442.00 ± 127.96	538.40 ± 144.56	0.7	0.040*
	Rate of torque development (E.L)	462.67 ± 186.64	588.40 ± 135.08	0.8	0.018
	Rate of torque development (F.R)	544.67 ± 270.16	464.00 ± 186.39	0.4	0.271
	Rate of torque development (F.L)	491.33 ± 255.23	445.36 ± 201.41	0.2	0.531
	Performance decrement % (E.R)	-5.87 ± 14.20	-3.32 ± 14.84	0.2	0.596
	Performance decrement % (E.L)	3.57 ± 14.89	-4.36 ± 14.32	0.5	0.103
	Performance decrement % (F.R)	29.36 ± 19.74	18.73 ± 19.22	0.5	0.102
	Performance decrement % (F.L)	24.56 ± 39.97	37.08 ± 103.91	0.2	0.593
180°/s	HQ Ratio (R)	0.49 ± 0.10	0.53 ± 0.11	0.4	0.291
	HQ Ratio (L)	0.49 ± 0.09	0.52 ± 0.10	0.3	0.386
	Rate of torque development (E.R)	239.33 ± 20.17	256.80 ± 39.97	0.5	0.075
	Rate of torque development (E.L)	239.33 ± 26.58	243.20 ± 36.14	0.1	0.721
	Rate of torque development (F.R)	318.67 ± 138.30	283.20 ± 64.14	0.3	0.363
	Rate of torque development (F.L)	254.67 ± 62.32	282.40 ± 67.72	0.4	0.205
	Performance decrement % (E.R)	7.60 ± 27.36	12.40 ± 14.31	0.2	0.536
	Performance decrement % (E.L)	8.33 ± 16.93	16.00 ± 11.86	0.5	0.101
	Performance decrement % (F.R)	28.56 ± 45.98	31.14 ± 18.86	0.1	0.839
	Performance decrement % (F.L)	32.50 ± 33.28	37.25 ± 17.49	0.2	0.615
240 °/s	HQ Ratio (R)	0.51 ± 0.07	0.57 ± 0.10	0.7	0.081
	HQ Ratio (L)	0.50 ± 0.07	0.55 ± 0.09	0.6	0.063
	Rate of torque development (E.R)	187.33 ± 27.12	191.20 ± 34.44	0.1	0.713
	Rate of torque development (E.L)	189.33 ± 32.62	194.41 ± 29.72	0.2	0.617
	Rate of torque development (F.R)	198.00 ± 65.16	208.40 ± 40.79	0.2	0.584
	Rate of torque development (F.L)	165.33 ± 40.68	216.00 ± 57.23	1.0	0.005**
	Performance decrement % (E.R)	35.71 ± 12.75	38.25 ± 9.63	0.2	0.480
	Performance decrement % (E.L)	31.99 ± 18.56	37.65 ± 9.58	0.4	0.287
	Performance decrement % (F.R)	44.92 ± 16.62	39.82 ± 17.96	0.3	0.378
	Performance decrement % (F.L)	41.09 ± 18.27	40.98 ± 13.32	0.0	0.981

Table 3. Analysis of the factors of isokinetic exercise test for knee by career. Values are expressed as mean ± SD, * $p < 0.05$, ** $p < 0.001$ by t-test; Rate of torque development ($\text{Nm}\cdot\text{s}^{-1}$); R, right; L, left; E, extension; F, flexion

cumulative training effects. Rather, these findings should be interpreted as associations that may reflect sport-specific and career-related neuromuscular characteristics.

Additionally, although wrestlers and individuals in the ≤ 5-year group tended to exhibit lower performance decrement %, these differences were not statistically significant. This pattern may suggest possible between-group differences in performance decrement-related characteristics; however, given the lack of statistical significance, these findings should be interpreted cautiously. Performance decrement has also been reported to reduce the H/Q ratio. Therefore, performance decrement-related indicators may hold clinical significance, and H/Q Ratio reduction and muscle stimulation strategies are required because hamstring performance decrement progresses more rapidly than quadriceps performance decrement during constant-velocity performance decrement tests²¹.

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design precludes any inference regarding causality. Second, and most importantly, the substantial age difference between the experience groups represents a major source of confounding, making it difficult to disentangle the potential influence of athletic career duration from that of age. Third, the relatively small sample size may have limited statistical power and reduced the generalizability of the findings. Fourth, the inclusion of athletes from two biomechanically distinct sports, together with their unequal distribution across the experience groups, may also have influenced the observed results. Finally, strength assessment was confined to the lower extremities and therefore does not provide a comprehensive evaluation of overall neuromuscular function. Despite these limitations, the present data provide clinically and practically relevant information on lower-extremity strength characteristics in athletes exposed to high mechanical loads and may serve as a useful basis for future hypothesis-driven and longitudinal investigations.

Conclusions

In this cross-sectional study, isokinetic knee strength-related characteristics differed according to sport type and athletic career-duration group in weightlifting and wrestling athletes. However, because of the cross-sectional design and the imbalance in age and sport distribution between groups, these findings should be interpreted as associations rather than as evidence of causal effects on muscle strength symmetry, performance decrement-

Variable		<i>p</i> (Sport)	<i>p</i> (Career)	<i>p</i> (Interaction)
60°/s	HQ Ratio (R)	0.009**	0.286	0.075
	HQ Ratio (L)	0.008**	0.959	0.177
	Rate of torque development (E.R)	0.003**	0.067	0.484
	Rate of torque development (E.L)	0.674	0.028*	0.864
	Rate of torque development (F.R)	0.009**	0.086	0.019*
	Rate of torque development (F.L)	0.064	0.334	0.372
	Performance decrement % (E.R)	0.457	0.490	0.210
	Performance decrement % (E.L)	0.222	0.076	0.755
	Performance decrement % (F.R)	0.559	0.140	0.806
	Performance decrement % (F.L)	0.600	0.694	0.289
180°/s	HQ Ratio (R)	0.285	0.217	0.388
	HQ Ratio (L)	0.642	0.363	0.954
	Rate of torque development (E.R)	0.070	0.189	0.462
	Rate of torque development (E.L)	0.335	0.630	0.570
	Rate of torque development (F.R)	0.027*	0.123	0.132
	Rate of torque development (F.L)	0.437	0.282	0.167
	Performance decrement % (E.R)	0.731	0.466	0.529
	Performance decrement % (E.L)	0.051	0.186	0.421
	Performance decrement % (F.R)	0.367	0.693	0.792
	Performance decrement % (F.L)	0.023*	0.233	<0.001***
240°/s	HQ Ratio (R)	0.520	0.117	0.689
	HQ Ratio (L)	0.232	0.107	0.433
	Rate of torque development (E.R)	0.987	0.685	0.267
	Rate of torque development (E.L)	0.374	0.507	0.387
	Rate of torque development (F.R)	0.304	0.691	0.272
	Rate of torque development (F.L)	0.206	0.003**	0.451
	Performance decrement % (E.R)	0.161	0.666	0.266
	Performance decrement % (E.L)	0.715	0.250	0.939
	Performance decrement % (F.R)	0.224	0.532	0.105
	Performance decrement % (F.L)	0.441	0.884	0.271

Table 4. Two-way ANOVA of knee isokinetic variables by sport type and career duration. Values are expressed as mean ± SD, * *p* < 0.05, ** *p* < 0.01, *** *p* < 0.001 by t-test; Rate of torque development (Nm·s⁻¹); R, right; L, left; E, extension; F, flexion

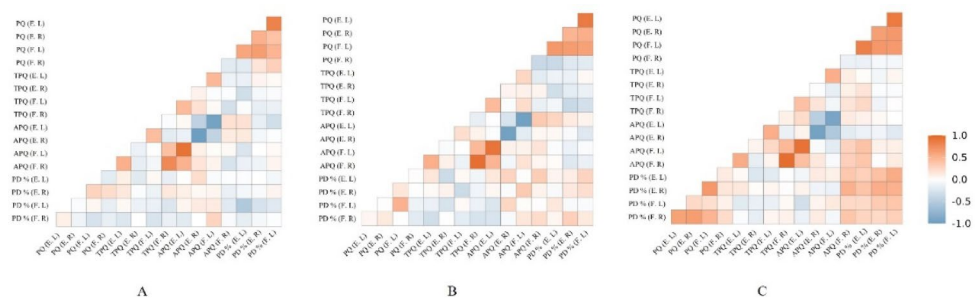


Fig. 2. Association of career and isokinetic knee strength extension and flexion tests. **(A)** Association of career and constant acceleration knee test at 60°/s; **(B)** Association of career and constant acceleration knee test at 180°/s; **(C)** Association of career and constant acceleration knee test at 240°/s; PTQ, peak torque; TPTQ, time to Peak torque; APTQ, angle of peak torque; PD, performance decrement; R, right; L, left; E, extension; F, flexion.

related characteristics, or conventional H/Q balance. The observed patterns may reflect sport-specific and career-related neuromuscular characteristics, but they cannot be attributed solely to training history. Future studies should use larger and more balanced samples, examine more homogeneous sport groups, and apply longitudinal designs to clarify the independent effects of training exposure, age, and sport-specific demands. In addition, further research should extend beyond the lower limbs and incorporate broader neuromuscular

and biomechanical assessments to provide a more comprehensive understanding of musculoskeletal health and performance in athletes.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

Overall planning of the research, data acquisition, creation of key results, analysis and interpretation, and major drafting and revision of manuscript submission was done by J.-Y. S.; and K.-K. L.; data acquisition, analysis and interpretation, and major drafting and revision of manuscript submission, K.-W. N.; Overall organization and direct supervision of the research was undertaken by S. P.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

All study procedures were approved by the Ethics Committee of Gachon University (approval date: November 28, 2024; approval number: 1044396-202410-HR-169-01), and the study was conducted according to the principles of the Declaration of Helsinki.

Additional information

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