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Original Research

Normative Hamstrings and Quadriceps Isometric Strength Values and Hamstrings-Quadriceps Asymmetry in Healthy Collegiate Soccer and Basketball Players

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ABSTRACT

International Journal of Exercise Science 17(4): 768-778, 2024. The objectives of this study were to report weight-normalized, sex- and sport-stratified normative values for hamstrings and quadriceps isometric strength in collegiate soccer and basketball players using a low-cost hand-held dynamometer and assess the prevalence of "substantial" hamstrings-quadriceps (H/Q) ratio strength imbalance (<0.6) among players. Ninety-four healthy collegiate male and female soccer and basketball players (age range: 18–24 years) were examined for baseline isometric hamstrings and quadriceps strength using a handheld isometric dynamometer with standardized and valid protocols. For soccer, the mean (95%CI) weight-normalized peak isometric strength values (considering dominant limbs) were 3.29 (2.90 to 3.64) N/kg (hamstrings) and 5.48 (4.96 to 6.00) N/kg (quadriceps) in male players and 2.62 (2.39 to 2.85) N/kg (hamstrings) and 4.55 (4.14 to 4.96) N/kg (quadriceps) in female players. For basketball, the mean (95% CI) peak strength values were 2.97 (2.72 to 3.21) N/kg (hamstrings) and 4.89 (4.44 to 5.33) N/kg (quadriceps) in male players and 2.48 (2.15 to 2.80) N/kg (hamstrings) and 4.21 (3.54 to 4.87) N/kg (quadriceps) in female players. The prevalence of substantial H/Q strength imbalance was 37% (95%CI: 24% to 52%) in soccer and 44% (95%CI: 29% to 60%) in basketball players. This study is first to provide normative values for peak isometric hamstrings and quadriceps strength using a low-cost hand-held dynamometer. The normative database from this study is valuable to coaches, sports medicine professionals, exercise scientists and other stakeholders to inform injury prevention, rehabilitation progression, return to play decisions and performance goals in collegiate soccer and basketball players.

KEY WORDS: Reference values, risk mitigation, lower limb injuries, anterior cruciate ligament, return to sport

INTRODUCTION

Collegiate basketball in the United States is highly competitive with significant overall injury incident rates of up to 10 injuries per 1000 athletic exposures (21, 3). The incidence of injury is slightly lower in soccer with an upper range of 7 injuries per 1000 athletic exposures reported in National Collegiate Athletics Association soccer (7, 4). Majority of injuries in collegiate soccer and basketball affect the lower extremities, primarily in the ankle and knee (21, 4).

Numerous studies have reported the role of the hamstring muscles (biceps femoris, semimembranosus and semitendinosus) in maintaining the functional integrity of the anterior cruciate ligament (ACL) by opposing anterior tibial translation, produced by the anterior-directed shear forces generated by the pull of quadriceps muscle (rectus femoris, vastus medialis, lateralis and intermedius) on the proximal tibia, in relation to the femur, placing the ACL in danger of rupture, especially when combined with rotational and varus/valgus forces of the aforementioned movements (5). Furthermore, regaining muscle strength in the hamstrings and quadriceps are significant rehabilitation goals after lower limb musculoskeletal injuries. Hamstrings and quadriceps strength tests are important when evaluating rehabilitation progression and making return to play decisions (19). Biological sex has also been indicated as a risk factor for specific injuries like ACL and lower extremity tendon injuries, especially in sports such as soccer and basketball (14, 15). Female athletes have been shown to have a higher incidence of ACL tears than males by over 2 folds (14). Additionally, athletes with neuromuscular deficits including strength deficits in the hamstrings, quadriceps and profound imbalance in hamstring-quadriceps (H/Q) ratio <60% have been reported to have a heightened risk of lower limb injuries, especially hamstrings and ACL injuries (5, 8, 9, 10, 14). Moreover, due to the profound muscle imbalance between hamstrings and quadriceps following ACL reconstruction, H/Q is used to determine the stability of the knee joint (1).

Assessments of muscular strength including hamstrings and quadriceps has been used in numerous studies that compare normative values for athletes with and without ACL reconstruction (13). However, the gold standard equipment (isokinetic dynamometer) used to evaluate the strength of these muscles has a high cost (10). The hand-held dynamometer is the more feasible and accessible equipment (2). The validity of the hand-held dynamometer in relation to the isokinetic dynamometer and its reliability has been demonstrated and it is strongly recommended as a useful pragmatic tool in clinical practice (1, 2, 8, 10).

Studies reporting normative data on student-athletes are currently sparse. To our knowledge, there is currently no single study on sex-specific and weight-normalized normative reference values for hand-held dynamometer-measured isometric hamstrings and quadriceps strength among collegiate soccer and basketball players. Establishing sex- and sport-specific normative hamstring and quadriceps muscle strength values in these sports will be useful to sports medicine professionals to minimize injury or re-injury risk among student-athletes and will also provide them with data to make evidence-informed decisions relating to players' rehabilitation programs, safe return to play and athletic performance. The specific objectives of this study were to: (1) establish a weight-normalized, sex- and sport-stratified normative database for hamstrings and quadriceps isometric strength in collegiate soccer and basketball players using a low-cost hand-held dynamometer; (2) assess the prevalence of "substantial" hamstrings-quadriceps (H/Q) ratio strength imbalance (<0.6) in players.

METHODS

Participants

Using a total population sampling, a cohort of 145 apparently healthy male and female basketball and soccer players officially listed on the team rosters of the athletic departments of two universities in St. Louis, Missouri (D1 NCAA and NAIA) were eligible and invited to participate in a baseline preseason isometric hamstrings and quadriceps muscle testing prior to the 2021-2022 competitive collegiate season. Players with an ongoing time-loss injury were identified by team athletic trainers prior to baseline testing and they were asked not to participate in the study. Participants with any medical conditions, including musculoskeletal problems that preclude baseline testing and optimal participation in sport were excluded from the study. Collaborative agreements were made between the athletics departments of the participating universities and our research team prior to the commencement of this study. Informed consent was obtained from each participating student-athlete prior to enrollment. The study was approved by the Saint Louis University Institutional Review Board (#31489). This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (13).

Protocol

This cross-sectional study is part of the RICHLoad (Reducing Injuries in Collegiate athletes through Load management) Project, a larger prospective cohort study investigating load-injury relationships in soccer and basketball players within complex multivariable models. The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines were used in the reporting of this observational study (see Appendix) (20).

All participants completed a baseline screening questionnaire to collect demographic (including dominant leg, sex, age), injury, and medical history data. Following this, participants completed a battery of body composition and performance tests at a scheduled testing session in their respective sporting centers and prior to or within the first week of the 2021/2022 competitive season. Knee flexor and extensor isometric strength (N/kg, i.e., force metric normalized by body weight) were assessed using a hand-held isometric dynamometer (Model 01165; Lafayette Instruments Co, Lafayette, IN). The hand-held isometric dynamometer is a reliable (inter and intra-rater ICC: 0.70 to 0.97) and a valid muscle strength assessment tool when compared with the isokinetic dynamometer, the gold-standard measure of muscle strength (1, 6, 8, 10, 17). We adopted the previously validated belt-stabilized hand-held dynamometer testing protocol described by Hirano et al., 2020 (6). Strength measurements were conducted by four graduate professional year Doctor of Physical Therapy students. All students had an extensive hands-on training regarding the testing protocols prior to data collection.

Knee flexion and extension strength were tested with participants in sitting position on a plinth (high sitting), hips and knees in 90 degrees of flexion, ankle and toes in neutral positions. Each participant completed one test trial and two experimental trials of a maximum voluntary isometric contraction (MVIC) of the hamstring and quadriceps muscles for both dominant and non-dominant limbs. With the hand-held dynamometer placed at the distal calf (posterior for flexion and anterior for extension), two-finger breath away from the level of the medial and lateral malleoli, participants exerted a 5-second maximal effort into an immovable strap in both knee flexion and extension directions, interspersed by 10-15 seconds of rest. Consistent and loud verbal instructions (push, push, push for extensors and pull, pull, pull for flexors) were used to motivate players to exert the MVIC possible within the 5-second period. The higher of the two MVIC experimental values, which we called the isometric peak strength, was used for data analyses after normalizing by body weight (N/kg).

Statistical Analysis

Participants baseline characteristics were presented using mean and standard deviation, frequency, and proportions as relevant. Normalized peak strength values were described for male and female participants based on leg dominance, separately for soccer and basketball, using mean with 95% CI and percentile ranks. Finally, we classified players with a peak strength value of <0.6 as having “substantial” H/Q strength imbalance ratio. The proportion (with 95% CIs) of participants exhibiting a H/Q ratio <0.60 was calculated by sex and sport to determine their baseline potential risk for acute knee injury. To avoid multiple statistical hypothesis testing and subsequent Type 1 error in our analysis – given that we had numerous comparisons – we did not conduct statistical tests of significance using p values; instead, we reported the CIs for all variables of interest and based comparative differences on unstandardized effect sizes and whether the CIs of the values presented overlap (inferring no difference) or not (inferring a difference) at a 95% confidence level (6).

RESULTS

Ninety-four male and female soccer (51) and basketball (43) players (55% female; mean age (SD): 20.1 (1.6) years; age range: 18 – 24 years) completed the baseline isometric muscle testing. One team (male soccer team) declined participation in this study based on the head-coach’s decision (n=31), 12 players were excluded because of ongoing injuries, and eight participants declined consent. Detailed participant characteristics are presented in Table 1.

Table 2 presents the mean (95% CI) and percentile ranks of weight-normalized peak strength values of players by sport, sex, and limb dominance. For soccer, the mean (95%CI) weight-normalized peak isometric strength values (considering dominant limbs) were 3.29 (2.90 to 3.64) N/kg (hamstrings) and 5.48 (4.96 to 6.00) N/kg (quadriceps) in male players and 2.62 (2.39 to 2.85) N/kg (hamstrings) and 4.55 (4.14 to 4.96) N/kg (quadriceps) in female players. For basketball, the mean (95% CI) peak strength values were 2.97 (2.72 to 3.21) N/kg (hamstrings) and 4.89 (4.44 to 5.33) N/kg (quadriceps) in male players and 2.48 (2.15 to 2.80) N/kg (hamstrings) and 4.21 (3.54 to 4.87) N/kg (quadriceps) in female players. Overall, peak strength values were higher in men compared with women, higher in quadriceps muscle compared with hamstrings, and higher in soccer compared with basketball players. Strength values were similar for dominant and non-dominant limbs across sports and sex.

Table 1. Participant characteristics.

	SOCCER		BASKETBALL	
	Male (n = 15)	Female (n = 36)	Male (n = 27)	Female (n = 16)
Age	20.8 (2.0)	19.4 (1.2)	20.9 (1.6)	19.8 (0.9)
Height, cm	176.9 (6.2)	162.2 (11.6)	189.4 (7.3)	175.9 (7.4)
Weight, kg	74.4 (9.7)	64.0 (8.5)	89.5 (11.3)	81.5 (17.2)
Body Mass Index, kg/m^2	23.7 (2.5)	23.7 (2.7)	24.9 (2.1)	26.3 (5.1)
Dominant Leg, Right, n (%)	11 (73.3)	31 (86.1)	21 (77.8)	12 (75.0)
Play Position, n (%)	Goalie: 3 (20.0) Defender: 3 (20.0) Midfielder: 6 (40) Striker: 3 (20)	Goalie: 3 (8.3) Defender: 8 (22.2) Midfielder: 17 (47.2) Striker: 8 (22.2)	Point Guard: 4 (14.8) Shooting Guard: 6 (22.2) Small Forward: 5 (18.5) Power Forward: 4(14.8) Center: 8 (29.6)	Point Guard: 3 (18.8) Shooting Guard: 6 (37.5) Small Forward: 0 (0) Power Forward: 4 (25.0) Center: 3 (18.8)

Table 2. Weight-Normalized Strength Values (N/kg) for the Hamstrings and Quadriceps Muscles for Soccer and Basketball Student-Athletes by Sex and Leg Dominance.

SOCCER	**Mean (95% CI)**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**
Hamstring Strength (N/kg)						
Males						
Dominant	3.29 (2.90 to 3.64)	2.43	2.69	3.21	3.95	4.08
Non-Dominant	3.27 (2.80 to 3.74)	1.92	2.79	3.24	3.94	4.07
Females						
Dominant	2.62 (2.39 to 2.85)	1.82	2.13	2.42	3.06	3.57
Non-Dominant	2.66 (2.36 to 2.96)	1.77	2.09	2.53	2.99	3.71
Quadriceps Strength (N/kg)						
Males						
Dominant	5.48 (4.96 to 6.00)	4.21	4.79	5.56	6.18	6.67
Non-Dominant	5.46 (4.79 to 6.13)	3.83	4.42	5.25	6.18	7.35
Females						
Dominant	4.55 (4.14 to 4.96)	3.34	3.65	4.39	5.24	6.07
Non-Dominant	4.42 (4.11 to 4.93)	3.18	3.57	4.38	5.26	5.99
BASKETBALL	**Mean (95% CI)**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**
Hamstring Strength (N/kg)						
Males						
Dominant	2.97 (2.72 to 3.21)	2.19	2.65	2.90	3.35	3.77
Non-Dominant	2.96 (2.70 to 3.21)	2.20	2.53	2.91	3.33	3.99
Females						
Dominant	2.48 (2.15 to 2.80)	1.57	2.01	2.53	2.98	3.13
Non-Dominant	2.45 (2.16 to 2.74)	1.86	2.02	2.32	2.85	3.02
Quadriceps Strength (N/kg)						
Males						

Dominant	4.89 (4.44 to 5.33)	3.61	4.06	4.93	5.40	6.75
Non-Dominant	4.42 (4.09 to 4.76)	3.16	3.86	4.43	4.91	5.49
Females						
Dominant	4.21 (3.54 to 4.87)	2.97	3.34	3.99	5.00	6.13
Non-Dominant	3.81 (3.32 to 4.31)	2.52	3.24	3.68	4.54	5.03

Values are mean (95% CIs) unless otherwise indicated. Ham: Hamstring; Quads: Quadriceps; N: Newton.

Table 3 presents the median (25th, 75th percentile) weight-normalized peak strength values (N/kg) of players by sport and play position and stratified by sex and limb dominance. Strength values were mostly similar across play positions in male and female soccer and basketball players.

Table 3. Weight-Normalized Strength Values (N/kg) for the Hamstrings and Quadriceps Muscles for Soccer and Basketball Student-Athletes by Sex, Leg Dominance and Play Position.

	Hamstring				**Quadriceps**			
	Males		Females		Males		Females	
	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant	Non-Dominant
SOCCER								
Goalie	3.95 (3.21, 4.04)	3.72 (2.44, 3.94)	2.14 (1.61, 3.78)	2.11 (1.07, 4.99)	4.85 (4.68, 6.67)	5.25 (4.96, 7.61)	3.90 (2.62, 7.75)	3.50 (3.40, 7.55)
Defender	3.01 (2.98, 3.34)	2.98 (1.92, 4.86)	2.02 (1.80, 2.60)	2.51 (2.07, 2.75)	6.11 (4.21, 7.22)	4.36 (3.79, 7.35)	3.87 (3.48, 4.83)	4.12 (3.42, 5.45)
Midfielder	3.35 (2.45, 4.08)	3.40 (2.81, 4.04)	2.86 (2.27, 3.17)	2.58 (2.20, 2.90)	5.58 (5.12, 6.18)	5.73 (4.42, 5.75)	4.77 (4.05, 5.72)	4.53 (3.39, 5.06)
Striker	2.69 (2.43, 3.45)	2.89 (2.79, 3.88)	2.72 (2.24, 3.30)	2.62 (2.15, 3.19)	4.92 (4.78, 5.67)	4.92 (4.91, 7.16)	4.19 (3.62, 4.96)	4.66 (4.33, 5.29)
BASKETBALL								
Point Guard	2.92 (2.42, 3.48)	2.92 (2.37, 3.32)	2.83 (1.57, 3.00)	2.89 (2.26, 2.97)	4.55 (4.09, 5.45)	3.55 (3.23, 4.03)	3.96 (3.54, 6.13)	4.55 (2.52, 5.02)
Shooting Guard	2.78 (2.04, 3.03)	2.85 (2.54, 3.56)	2.77 (1.96, 3.13)	2.73 (2.38, 2.82)	4.55 (3.99, 5.12)	4.48 (4.41, 4.91)	4.55 (3.80, 5.12)	4.25 (3.48, 4.59)
Small Forward	2.90 (2.65, 3.17)	2.67 (2.44, 2.73)	-	-	4.95 (4.63, 5.21)	4.43 (4.17, 4.52)	-	-
Power Forward	3.07 (2.75, 3.47)	2.82 (2.28, 3.42)	2.27 (1.80, 2.63)	2.17 (1.88, 2.62)	3.88 (2.94, 4.92)	3.68 (3.09, 4.52)	4.03 (2.67, 5.09)	3.54 (2.74, 4.03)
Center	3.02 (2.66, 3.39)	3.10 (2.84, 3.93)	2.14 (2.06, 3.06)	1.92 (1.89, 2.12)	5.23 (4.73, 6.08)	4.98 (4.57, 5.45)	3.30 (3.0, 4.02)	3.49 (2.89, 3.60)

Values are median (25^{th}, 75^{th} percentile).

The prevalence of H/Q strength imbalance (based on having at least a substantial imbalance on one side) was 37% (95%CI: 24% to 52%) among soccer players and 44% (95%CI: 29% to 60%) among basketball players. The distribution of substantial H/Q strength imbalance for the dominant lower limb was more than twice that of the non-dominant limb in men and women basketball. In contrast, the distribution of substantial H/Q strength imbalance was the same for both the dominant and non-dominant limbs in women's soccer and higher for non-dominant limb compared to dominant limb in men's soccer (Figure 1).

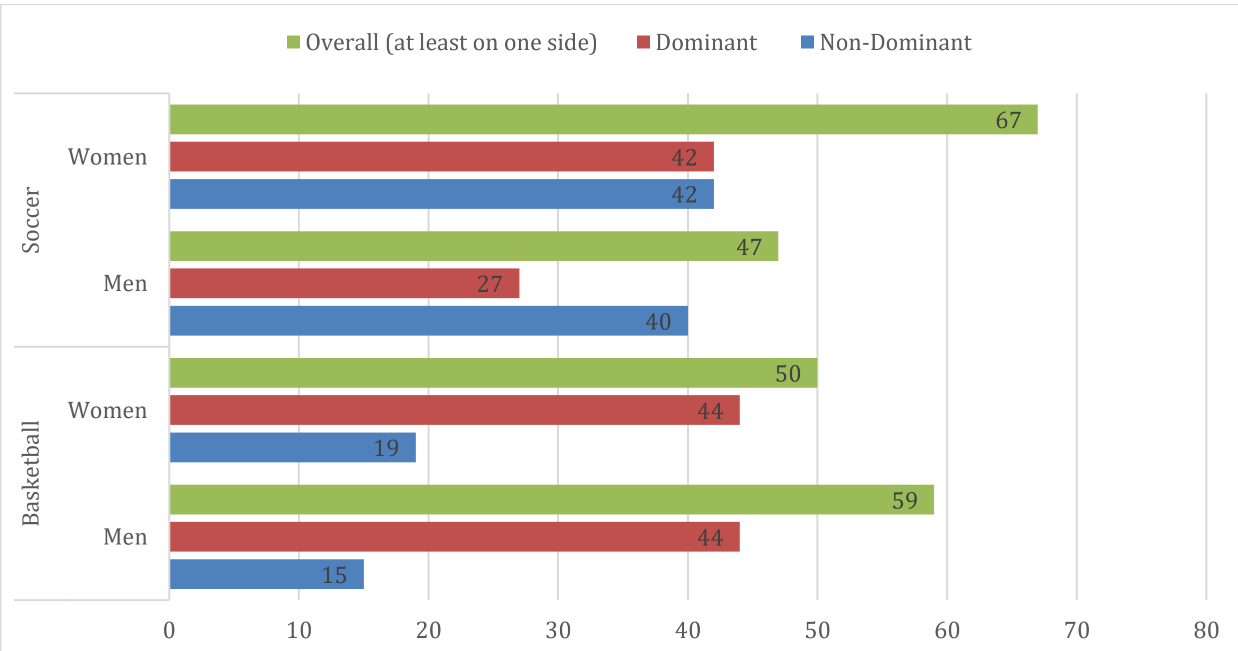

Figure 1. Distribution (%) of Student-Athletes with Substantial Hamstrings-Quadricep Strength Ratio (<0.6) Imbalance Based on Sport, Sex and Limb Dominance.

DISCUSSION

Our first objective was to provide a weight-normalized, sex and sport stratified normative database for hamstrings and quadriceps isometric strength and hamstrings-quadriceps ratio in collegiate soccer and basketball players. Overall, strength values were higher in men compared with women, higher in quadriceps muscle compared with hamstrings, and higher in soccer compared with basketball players. Strength values were similar for dominant and non-dominant limbs across sports and sex, and mostly similar across play positions in male and female soccer and basketball players. The findings of higher strength values in male vs. female players is consistent with other studies (7, 11). Muscle strength differences between sexes are attributed to several factors, including hormonal factors, muscle fiber composition, lean body mass and biomechanical differences (15). For example, higher levels of testosterone in males and estrogen impacts muscle development and strength, and males generally have a higher percentage of Type II muscle fibers which are associated with greater strength, while females have more Type I muscle fibers which are associated with muscular endurance (15, 11).

Significant differences in MVIC strength normative values have been noted across different sports in different studies (7). Our finding of higher isometric peak strength values in soccer compared with basketball players could be a result of differences in movement maneuvers in the different sports. Basketball involves a lot more jumping compared to soccer, which consists of more running; however, both sports require speed and change of direction (12). Further, our study demonstrates similar strength values for dominant and non-dominant legs across the two sports. Considering the biomechanics of movement, soccer involves frequent planting of one leg and kicking using the other, and basketball involves frequent jumping mostly from one leg and landing on the other or both legs. It is possible that the dynamics in these movements allow for a similar distribution of load on both limbs at this level of play. Other studies in youth sports (8-15 years) have shown higher strength values in dominant legs compared to non-dominant legs (7). This could be attributed to the fact that most high-level youth soccer players possess strength dominance towards one leg (7).

The prevalence of substantial H/Q strength imbalance was slightly higher (by 7%) in soccer vs basketball. The distribution of substantial H/Q strength imbalance for the dominant lower limb was more than twice that of the non-dominant limb in male and female basketball players. However, the distribution of substantial H/Q strength imbalance was the same for both dominant and non-dominant limbs in female soccer players and higher for non-dominant limb compared to dominant limb in male soccer players. Neuromuscular deficits, particularly those related to hamstrings and quadriceps strength and an H/Q ratio <0.6% are associated with an increased risk of lower extremity injuries (5, 9, 10, 14). A greater risk of knee injury is associated with knee muscle strength characteristics (14) and this can also include the H/Q ratio (7). In this study, an average of 2 in 5 players had a substant H/Q ratio. Furthermore, we found a higher substantial H/Q strength imbalance in basketball (44%) vs. soccer (37%), and substantial H/Q strength imbalance was more than twice prevalent in men than women in collegiate basketball. Focused strength training is indicated as an effective intervention for injury prevention in soccer (14). The normative data presented in the current study provides reference values that would be useful to collegiate coaches, sports physical therapists, athletic trainers, and other sports medicine professionals in preventing lower limb injuries in soccer and basketball student-athletes and in making an informed return to sport decisions after time-loss knee and other lower extremity injuries. For example, the physical therapist or athletic trainer working with a team may initiate a routine preparticipation hamstring/quadriceps screening program early in the preseason to help mitigate lower limb injury risk in their team. Athletes found to have MVIC strength values lower than a set percentile rank threshold e.g., the 50th percentile rank of the normative values on Table 2, especially those with a recent 12-month history of time-loss injury may be referred to the team's strength and conditioning coach for a focused strength training regimen prior to the start of the competitive season.

Additionally, the data provides comparative standards for performance goals in student-athletes towards optimizing team performance. For example, a strength and conditioning coach may target a minimum isometric peak strength value at the 75th percentile rank for all their athletes at the beginning of the season for resilience and readiness in the competitive season.

Finally, our finding of 2 in 5 apparently healthy players having a substantial H/Q strength imbalance is concerning and demands attention. We recommend that sports medicine professionals and strength and conditioning coaches working with soccer and basketball teams routinely assess H/Q ratio values in their athletes and provide appropriate interventions to athletes with hamstring strength deficits to mitigate injury risk and optimize performance.

There are some strengths in this study. This study is the first to report a weight-normalized, sex and sport stratified normative database for hamstring and quadriceps isometric strength and H/Q ratios in a relatively large sample of collegiate soccer and basketball student-athletes. Our final sample size of 94 student-athletes appears to be a fair one given that the CIs in the reported mean estimates are not substantially wide, suggesting that the strength values reported are within statistically acceptable limits. Another strength in this study is the practicality of its methodology e.g., use of a cheap hand-held dynamometer, which makes its potential application by clinicians, trainers and coaches in practice more feasible.

The applicability of the findings from this study are limited to Division I in the NCAA and NAIA collegiate soccer and basketball players in the United States and may not be generalized for the larger population of soccer and basketball players or lower-level divisions. Future research should consider using a larger and diverse settings and across several collegiate sports to provide a more extensive dataset.

This study provides a weight-normalized, sex- and sport-specific normative database for hamstring and quadriceps peak isometric strength values in soccer and basketball players. About two out of every five players had a substantial H/Q ratio strength imbalance. The reference values and findings from this study will be useful to collegiate coaches, sports medicine professionals and other stakeholders to inform injury prevention, rehabilitation progression, return to play decisions and performance goals.

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