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STRENGTH-BASED PHYSIOLOGICAL PROFILES OF NCAA DIVISION I

WOMEN'S BASKETBALL AND GYMNASTICS ATHLETES: IMPLICATIONS FOR

INJURY RISK ASSESSMENT

by

Curtis S. Cazier

A plan B project submitted in partial fulfillment of the

requirements for the degree

of

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in

Health and Human Movement

Approved:

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Abstract

The purpose of this study was to provide a comprehensive strength-based physiological profile of women's collegiate basketball and gymnastic athletes; and to make sport-specific comparisons for various isokinetic and maximal and rapid isometric strength characteristics of the knee flexor and extensor muscles. A focus on antagonist muscle balance (hamstrings to quadriceps ratios, H:Q) will help elucidate particular vulnerabilities in these at-risk female athletes. Fourteen Division I collegiate level women's basketball and 13 women's gymnastics athletes performed isokinetic and isometric strength testing of the knee extensors and flexors. Outcome measures included absolute and body mass normalized (relative) isokinetic and isometric peak torque (PT) values, rate of torque development at 50, 100, 200 ms (RTD50, RTD100, RTD200) and H:Q ratios of all variables. The basketball athletes had greater absolute strength for all variables except for isokinetic PT at $240°s^{-1}$ and isometric RTD50 for the knee extensors. The gymnasts showed ~20% weaker relative concentric PT for the knee flexors at 60 and $120°·s^{-1}$, and decreased conventional H:Q ratios at 60 and $240°·s^{-1}$ (~15%) compared to the basketball team. These findings suggest that collegiate level gymnastics athletes may be prone to increased ACL injury risk due to deficient relative knee flexor strength and the associated H:Q strength imbalance. Optimizing strength training programs for collegiate gymnastics with increased focus on strength improvements for the hamstrings may be a potentially effective strategy to help decrease the ACL injury risk.

Key Terms

Rate of force development, rate of torque development, peak torque, female sports, Hamstring-to-Quadriceps ratio, injury prevention

Introduction

Performance-related profiles of athletes can provide a basis for understanding key requirements necessary for sport success and injury risk management. For example, physiological attributes found to discriminate top levels of play in sport may be useful for improved planning, executing and managing training routines, both in- and off-season, as well as for talent identification and characterizing positional differences (Jenkins et al. 2013; Miller, Keiffer, Kemp, & Torres, 2011). Such information may also help the athlete and practitioner determine levels of risk for the athlete according to the particular demands of the sport when combined with knowledge of performance-based deficits matched to sport-specific demands.

Physiological profiles have been previously described for men's basketball, soccer (Metaxas, Koutlianos, Sendelides, & Mandroukas, 2009), football (Barker et al., 1993), and rugby (Baker & Newton, 2008); and women's soccer (Jenkins et al. 2013), volleyball, basketball, and softball (Rosene, Fogarty, & Mahaffey, 2001). These studies have provided valuable information describing key attributes for attaining sport success as a result of identifying fundamental performance contributors required for high performance, which are specific to the respective sport. One performance attribute that has been noted for a variety of the sports examined involves the strength-related capacities of the athlete. The ability to produce high levels of strength is an important contributor for explosive sports, which rely heavily on the capacity to move one's own body mass (i.e., acceleration, change of direction etc.) or that of an object (ball, discus, loaded barbell) or human (e.g., football, wrestling).

Although previous studies have investigated physiological profiles consisting of a variety of physiological measures such as maximal aerobic capacity, anaerobic capacity, vertical jump power, repeated sprint ability, agility, and body composition (Jenkins et al., 2013), more research is warranted examining strength, and in particular, explosive strength variables in women's athletics. Women's athletics is unfortunately plagued with high injury incidence rates, particularly of the lower extremities. For example, previous reports have shown women's soccer to have an ACL injury rate of 2.55 per 10,000 athlete-exposures (AE) (Stanley, Kerr, Dompier, & Padua, 2016) which is substantially higher than that of men's soccer at a rate of 0.63 per 10,000 AE, a trend which has also been found in the sport of basketball (1.95 vs. 0.70 per 10,000 AE for women and men, respectively) (Stanley, Kerr, Dompier, & Padua, 2016). Given the high occurrence and potential impact of these injuries, which are widespread across sports, levels, ages and geographic regions, future work is needed to help determine more comprehensive strength-related attributes of the lower body for multiple collegiate women's sports.

Two such sports which have received little attention in this regard include women's gymnastics and basketball, given these sports show relatively high ACL injury rates, with women's basketball showing a rate of 0.22 per 1,000 AE and gymnastics a rate of 0.24 per 1,000 AE in comparison to women's softball which demonstrated a rate of only 0.06 per 1,000 AE (Agel, Rockwood, & Klossner, 2016), a comprehensive strength-based profile involving the muscles of the knee would fill knowledge gaps regarding the physiological and performance requirements of these at risk women athletes.

In both basketball and gymnastics, the strength of the lower extremities provides the foundation for the capacity to achieve many of the primary athletic tasks required (i.e., accelerating, cutting, jumping, landing). Thus, a physiological profile of lower extremity strength can be a useful assessment tool for determining an athlete's ability to compete at an elite level, as well as determining the athlete's risk for injury. Important variables representing the strength profile include peak torque (PT) as well as the rate of torque development (RTD) (Thompson et al., 2013). The RTD represents explosive strength production, and provides information about the ability to express strength during the initial, and functionally important, stages of muscle action. Because maximal strength requires in excess of 300 ms to attain, and many sport movements are achieved in less than 200 ms (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen 2002; L.L. Andersen, J. L. Andersen, Zebis, & Aagaard, 2010), the rapid strength characteristics may be more functionally relevant and consequently more sensitive for identifying muscle performance deficits, which may in turn be key markers for sport performance and/or injury risk (Thompson et al., 2013; Palmer et al., 2015). Moreover, it has been reported that the time for injury to occur to the ACL is likely between 17 and 50 ms (Krosshaug et al., 2007). This would suggest that the RTD variable would be particularly applicable and potentially sensitive as an athlete strength-related profile tool because it specifically describes the ability to produce muscular force in the early periods of muscle action, which would correspond to the time sensitivity of injury responses and the demands of explosive sport performance activities.

Strength-related injury risk profiles for athletes often include a measurement of the hamstrings to quadriceps strength ratio (H:Q) (Crosier, Ganteaume, Binet, Gentry, &

Ferret, 2008; Jenkins et al., 2013; Knapik, Bauman, Jones, Harris, & Vaughan 1991; Rosene, Fogarty, & Mahaffey, 2001; Zebis, Andersen, Ellingsgaard, & Aagaard, 2011). The conventional H:Q ratio measures the PT for the concentric action of the hamstrings and the concentric action of the quadriceps. Aagaard et al. (1998) introduced the functional H:Q ratio as a means to measure the strength of the hamstrings using a more functional eccentric muscle action along with the quadriceps concentric action. They found that during knee extension, the functional H:Q was almost always 1.0 or higher, which was nearly double that of the conventional H:Q (Aagaard et al. 1998). It was also reported that a functional ratio of .96 to 1.01 exhibited a protective effect of the hamstrings to resist anterior translation of the tibia, because it equals the magnitude of the maximal quadriceps contraction (Aagaard et al. 1998). Functionally, if the hamstrings are not strong enough or are dominated by the quadriceps muscles, the risk of injury increases. Knapik et al. (1991) reported that a conventional H:Q ratio below 0.75 resulted in a 1.6 times higher likelihood of lower extremity injury in women's soccer, volleyball, and basketball; and previous authors (Dauty, Potiron-Josse, & Rochcongar, 2003; Heiser, Weber, Sullivan, Clare, & Jacobs, 1984) found that a functional H:Q ratio of less than 0.60 in male soccer players identified the presence of previous injury to the hamstrings which in turn points to a risk for ACL injury. Additionally, Malinzak et al. (2001) reported that female athletes have a tendency for increased quadriceps muscle activation and decreased hamstrings muscle activation when compared to male athletes in selected athletic tasks such as single leg jumping, running, cross-cutting, and side-cutting. Research findings have also shown that females with conventional H:Q ratios below 0.60 or functional H:Q ratios that are not greater than or approximately 1.0, are at an increased

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risk of ACL injury (Dedinsky, Baker, Imbus, Bowman, & Murray, 2017; Dorgo, Edupuganti, Smith, & Ortiz, 2012; Holcumb, Rubley, Lee, & Guadagnoli, 2007; Soderman, Alfredson, Pietila, & Werner, 2001; Wilkerson et al., 2004). Another potentially useful H:Q variable may include the rapid H:Q strength ratio, defined as the ratio of the hamstrings isometric RTD vs. the quadriceps RTD. This rapid H:Q ratio variable may be highly relevant for expressing any deficits between the two muscle groups given its time sensitive features and has been suggested to be relevant for clinical evaluations in athletes (Zebis et al., 2011). Given the usefulness of the H:Q ratio as a potential ACL injury assessment marker, and the tendency for female athletes to exhibit unfavorable H:Q ratios, more research is warranted examining the rapid H:Q ratio, particularly in the more research neglected women's sports such as gymnastics.

Lower extremity strength is of critical importance to the success and injury risk management of female basketball and gymnastic collegiate athletes. Providing a comprehensive strength-based physiological profile of the two types of athletes can offer insight into the strength and explosive strength requirements that are highly involved in the rigors of these explosive and high impact-sports. Such a profile may reveal insight into the strengths, weaknesses, and unique characteristics of the two different types of athletes which may help athletes and practitioners better manage and develop customized training routines. Therefore, the purpose of the present study was to provide a comprehensive strength-based physiological profile of women's collegiate basketball and gymnastic athletes for maximal and rapid strength capacities of the hamstrings and quadriceps muscles to help elucidate these particular characteristics in these at-risk female athletes. It was hypothesized that there would be sport-related differences in

absolute strength capacities favoring the basketball players given their larger body mass, but that these differences would be removed when expressing these characteristics relative to body mass; and that the results of the study would reveal similar deficiencies in H:Q as previous research has shown involving women's soccer players (Jenkins et al., 2013; Myer et al., 2009).

Methods

Participants

Twenty-seven female collegiate athletes were recruited from two different National Collegiate Athletic Association (NCAA) Division I teams to participate in the study during their pre-season workout schedule. Specifically, 14 athletes from the women's basketball team (mean ± SD: age = 19.5 ± 1.6 years, height = 180.6 ± 7.7 cm, mass 75.9 ± 10.6 kg) and 13 from the gymnastics team (age = 19.5 ± 1.3 years, height = 157.5 ± 6.6 cm, mass = 63.7 ± 7.0 kg) volunteered to participate in the study. All athletes were required to have at minimum one year of experience competing and training at a competitive (high school or collegiate) level. Participants were excluded from the study if they had sustained an injury requiring surgery to one or both knees within the previous year, or if any lower extremity neuromuscular pain and dysfunction were reported at the time of testing. The study was approved by the University Institutional Review Board, and all participants provided written informed consent prior to study participation.

Procedures

Participants reported to the laboratory where they completed the informed consent and health history questionnaire. Upon completion of the paperwork the participants were instructed and familiarized on the assessment protocol. Participants were asked to refrain

from caffeine consumption within 12-hours of testing, and were tested only when they had not performed vigorous lower body exercise within 48-hours of testing.

Strength Assessments

Following familiarization, strength assessments were performed on an isokinetic dynamometer (Biodex System 3, Biodex Inc., Shirley, NY), which was calibrated prior to the start of the study. Reliability for the Biodex has been shown to be high for isometric, concentric and eccentric peak torque values with intraclass correlations of 0.88 – 0.92 (Alvares et al., 2015). Participants were seated on the dynamometer, and adjustments to the seat length and seat position were made based on the size of each participant, so the axis of the knee joint was in direct alignment with the input axis of the dynamometer. Restraining straps were placed over the thigh, and the lower limb was secured to a padded lever arm at 5 cm above the lateral malleolus. Participants performed a warm-up involving 10 submaximal knee flexion and extension repetitions at $120°·s^{-1}$ followed by a 2-min rest period. Following the warm-up, participants performed three, 3-sec isometric maximal voluntary contractions (MVCs) of knee extension and knee flexion with 1-min of recovery between repetitions and a minimum of 2-min between muscle groups. Testing was performed at 60° and 30° below the horizontal plane for the knee extensions and flexions, respectively, and was measured manually using a goniometer (Conchola, Thompson, & Smith, 2013). Participants then performed three full range of motion concentric knee extension and flexion MVCs at $60°·s^{-1}$, $120°·s^{-1}$, and $240°·s^{-1}$ followed by two eccentric muscle actions at only the $60°·s^{-1}$ and $120°·s^{-1}$ velocities (Tourny-Chollet & Leroy, 2002) to limit risk of injury. One minute of rest was given between velocities and 2-minutes between the concentric and eccentric muscle actions. Velocities were

randomly assigned; however, the eccentric tests were always performed following all concentric testing to delay fatigue onset during testing. During all MVCs, strong verbal encouragement was provided along with instructions to "push" or "pull" "as hard and as fast as you possibly can."

Data Analyses

The raw torque (Nm) signal was sampled at 2 KHz with a Biopac data acquisition system (MP150WSW, Biopac Systems Inc., Santa Barbara, CA), stored on a personal computer, and subsequently processed offline with custom written software (LabVIEW 2016, National Instruments, Austin, TX). The torque signals were filtered using a fourth order, zero phase-shift, low-pass Butterworth filter with a 50 Hz cutoff frequency in accordance with the procedures of de Ruiter et al. (2004). For isometric MVCs, the passive baseline torque value was considered the limb weight and subtracted from the signal so the baseline value was set at 0 Nm. Isokinetic MVCs were corrected for the gravity effect of the lower limb according to the procedures of Aagaard et al. (1995).

Isometric peak torque (PT, Nm) was calculated as the highest 500 ms epoch along the entire MVC, and isokinetic PT as the highest 25 ms epoch during the MVC plateau (Thompson, Conchola, & Stock, 2015). The RTD ($Nm \cdot s^{-1}$) was quantified from the linear slope of the ascending portion of the torque-time curve at time intervals of $0 - 50$, $0 - 100$, and $0 - 200$ ms from the onset. These time intervals were selected to represent the early and late phases of rapid torque production, which may reveal unique physiological information (Thompson et al., 2014). In addition to the absolute values, all PT and RTD variables were divided by the participant's body mass in order to provide a body mass normalized comparison. Finally, the conventional H:Q strength ratio was

quantified by dividing each participant's highest leg flexion PT or RTD value by the highest respective leg extension value. The functional H:Q ratio was derived by dividing the eccentric hamstrings PT value by the concentric quadriceps PT value (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998).

Statistical Analysis

Independent samples *t*-tests were used to compare differences between the sports teams for each strength variable. Additionally, Cohen's *d* effect sizes were used to evaluate the group differences, with values of 0.20, 0.50, and 0.80 corresponding to small, moderate, and large differences, respectively. The proportion of athletes in each sport team that displayed a conventional H:Q ratio below 0.60 (Dorgo et al., 2012; Holcumb et al., 2007; Wilkerson et al., 2004) and a functional H:Q ratio below 1.0 (Dorgo et al., 2012; Holcumb et al., 2007) were also reported. An alpha level of 0.05 was used to determine statistical significance and IBM SPSS Statistics software (version 24, IBM Corporation, Armonk, NY) was used for statistical analyses.

Results

There were no differences between the women's basketball and gymnastics teams for age ($P = 0.94$), however, there were significant differences for height ($P < 0.01$), and body mass ($P < .01$). Post hoc power analysis using G*Power software for an effect size of 1.2 which was the observed effect size for both the knee extensors $120°·s^{-1}$ and knee flexors $60°·s^{-1}$ variables resulted in a power level of 0.85 for the current sample.

For the isometric variables, absolute PT for the knee extensors and flexors was greater for the basketball compared to the gymnastics team ($P < 0.01$). Both adjustments for mass and height for PT of the knee extensors and flexors were also greater for basketball compared to gymnastics ($P < 0.01$, for BM and HT knee extensors and HT knee flexors, and $= 0.02$, for BM knee flexors). For the absolute RTD variables, for both the knee extensors and flexors the basketball team exhibited greater values for RTD100 ($P = 0.01$ and 0.04), and RTD200 ($P < 0.01$) and for the knee flexors only for RTD50 ($P = 0.03$) compared to gymnastics; however, there was no difference for RTD50 for the knee extensors ($P = 0.12$). Body mass and height adjusted RTD, however, showed no significance for the knee extensors and flexors between the two teams for RTD50 ($P = 0.41$ for BM, and $P = 0.3$ for HT; and $P = 0.27$ for BM, and $P = 0.18$ for HT). At BM RTD100 ($P = 0.07$ and 0.45) no significance was found for the knee extensors and flexors, but for HT RTD100 ($P = 0.04$) the knee extensors were significantly greater for the basketball team. Again, no significance was found for the flexors at BM RTD200 ($P = 0.09$) while HT RTD200 ($P = 0.04$) resulted in basketball being significantly greater than gymnastics. The BM and HT knee extensors RTD200 were both significantly greater ($P = 0.04$, for BM and $P = 0.02$, for HT) for the basketball team. No significant

differences were shown between the teams for the isometric H:Q ratios for PT ($P = 0.80$), RTD50 ($P = 1.0$), RTD100 ($P = 0.15$), and RTD200 ($P = 0.60$). Table 1 presents all absolute and relative isometric PT, RTD, and H:Q ratio variables and effect size values for the knee extensors and flexors for the women's basketball and gymnastics teams.

Table 1. Mean (SD) in Nm and Cohen's *d* effect size values for the isometric knee extensors and flexors maximal and rapid torque characteristics for women's basketball and gymnastics.

	Variable	Basketball	Gymnastics	Cohen's *d*
Knee extensors	PT	193.7 (43.4) *	135 (23.8)	1.75
	RTD50	673.5 (419.6)	465.8 (189.7)	0.68
	RTD100	686.8 (334.6) *	407.5 (137.7)	1.18
	RTD200	507.5 (191.2) *	321.5 (89.6)	1.32
	BM PT	2.5 (0.42) *	2.1 (0.33)	1.07
	BM RTD50	8.9 (5.3)	7.4 (3.3)	0.35
	BM RTD100	9 (4.1)	6.5 (2.5)	0.76
	BM RTD200	6.7 (2.2) *	5.1 (1.4)	0.89
	HT PT	1.1 (0.22) *	0.86 (0.14)	1.2
	HT RTD50	3.7 (2.24)	2.96 (1.2)	0.44
	HT RTD100	3.8 (1.8) *	2.6 (0.9)	0.89
	HT RTD200	2.8 (0.99) *	2.0 (0.56)	0.97
Knee flexors	PT	108.7 (20.5) *	78 (16.0)	1.68
	RTD50	266.2 (98.8) *	194.8 (47.0)	0.98
	RTD100	328.7 (113.8) *	250.3 (67.8)	0.85
	RTD200	352.1 (82.1) *	248.3 (77.6)	1.30
	BM PT	1.4 (0.19) *	1.2 (0.23)	0.95
	BM RTD50	3.6 (1.4)	3.1 (0.75)	0.47
	BM RTD100	4.4 (1.7)	4 (1.2)	0.28
	BM RTD200	4.7 (1.0)	3.9 (1.2)	0.73
	HT PT	0.6 (0.11) *	0.5 (0.09)	1.16
	HT RTD50	1.5 (0.56)	1.2 (0.3)	0.7
	HT RTD100	1.8 (0.65)	1.7 (0.73)	0.14
	HT RTD200	1.9 (0.43) *	1.6 (0.46)	0.67
HQ Ratio	PT	0.58 (0.11)	0.59 (0.12)	0.09
	RTD50	0.45 (0.17)	0.46 (0.18)	0.06
	RTD100	0.53 (0.18)	0.65 (0.24)	0.57
	RTD200	0.74 (0.17)	0.79 (0.32)	0.20

PT= peak torque; RTD= rate of torque development; BM = body mass adjusted; ECC= eccentric; HQ= hamstrings to quadriceps. * denotes *P* < 0.05

For the isokinetic variables, the basketball team exhibited greater values for the eccentric knee flexors for absolute PT 60 ($P < 0.01$) and PT 120 ($P < 0.01$), and both the relative PT 60 ($P = 0.05$ for BM, and $P= 0.03$ for HT), but there was no difference found between the eccentric knee flexors of the two teams for both the relative PT 120 ($P = 0.11$ for BM, and $P= 0.06$ for HT). For the concentric knee extensors, the basketball team showed greater values for absolute PT 60 ($P = 0.01$) and PT 120 ($P < 0.01$), however, no significant difference was found between the two teams for absolute PT 240 ($P = 0.23$) and both the relative variables PT 60 ($P = 0.82$ for BM, and $P= 0.49$ for HT), PT 120 ($P = 0.27$ for BM, and $P= 0.19$ for HT), and PT 240 ($P = 0.25$ for BM, and $P= 0.63$ for HT). For the concentric knee flexors, the basketball team showed greater PT for the absolute variables PT 60 ($P < 0.01$), PT120 ($P < 0.01$), PT240 ($P < 0.01$), and both the relative variables PT 60 ($P = 0.01$ for BM, see Figure 1; and $P< 0.01$ for HT), and PT 120 ($P < 0.01$ for both BM and HT). No significant difference was shown between the two teams for both relative PT 240 ($P = 0.29$ for BM, and $P= 0.13$ for HT) for the concentric knee flexors.

The isokinetic H:Q ratio results revealed the basketball team exhibited greater conventional ratios than the gymnastics team for Con 60 ($P = 0.05$, Figure 1) and Con 240 ($P = 0.03$), however, there was no difference for the conventional Con 120 ($P = 0.70$). The functional H:Q ratios showed no significant difference between the two teams for Func 60 ($P = 0.36$) and Func 120 ($P = 0.55$). Table 2 presents all absolute and relative isokinetic PT, conventional H:Q, and functional H:Q ratio variables and effect size values for the knee extensors and flexors for the women's basketball and gymnastics teams.

Table 2. Mean (SD) in Nm and Cohen's *d* effect size values for the isokinetic knee extensors and flexors peak torque and hamstrings to quadriceps ratios for women's basketball and gymnastics.

	Variable	Basketball	Gymnastics	Cohen's *d*
Knee extensors	PT 60	143.9 (23.0) *	120 (23.0)	1.04
	PT 120	132 (23.5) *	105.4 (20.1)	1.22
	PT 240	85.7 (19.6)	77.4 (15.2)	0.48
	BM PT 60	1.9 (0.28)	1.9 (0.32)	0
	BM PT 120	1.7 (0.21)	1.6 (0.22)	0.47
	BM PT 240	1.1 (0.17)	1.2 (0.23)	0.50
	HT PT 60	0.8 (0.12)	0.76 (0.14)	0.31
	HT PT 120	0.73 (0.12)	0.67 (0.12)	0.50
	HT PT 240	0.47 (0.10)	0.49 (0.09)	0.21
Knee flexors	PT 60	88.7 (20.2) *	61 (10.1)	1.93
	PT 120	80.4 (15.0) *	56 (9.6)	1.98
	PT 240	56.7 (10.7) *	43.8 (11.7)	1.15
	BM PT 60	1.2 (0.20) *	0.97 (0.18)	1.21
	BM PT 120	1.1 (0.15) *	0.88 (0.14)	1.52
	BM PT 240	0.75 (.13)	0.69 (0.17)	0.40
	HT PT 60	0.49 (0.10) *	0.39 (0.06)	1.25
	HT PT 120	0.44 (0.07) *	0.35 (0.05)	1.50
	HT PT 240	0.31 (0.06)	0.28 (0.07)	0.46
ECC knee	PT 60	125.1 (27.0) *	91.4 (21.1)	1.40
	PT 120	123.4 (24.5) *	93.5 (17.9)	1.41
	BM PT 60	1.7 (0.29) *	1.4 (0.26)	1.09
	BM PT 120	1.6 (0.26)	1.5 (0.24)	0.40
	HT PT 60	0.69 (0.14) *	0.58 (0.12)	0.85
	HT PT 120	0.68 (0.13)	0.59 (0.1)	0.78
HQ Ratio	Con 60	0.62 (0.10) *	0.53 (0.13)	0.78
	Con 120	0.61 (0.10)	0.54 (0.10)	0.70
	Con 240	0.67 (0.11) *	0.57 (0.11)	0.91
	Func 60	0.88 (0.21)	0.8 (0.27)	0.33
	Func 120	0.94 (0.17)	0.9 (0.17)	0.24

PT= peak torque; BM = body mass adjusted; ECC= eccentric; HQ= hamstrings to quadriceps; Con= conventional ratio; Func= functional ratio. * denotes *P* < .05

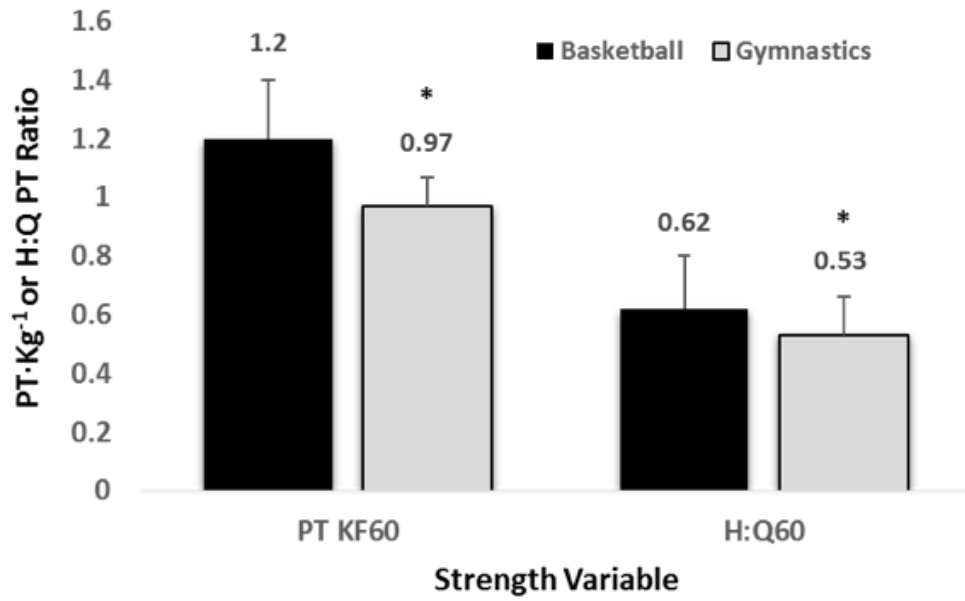**Figure 1.** Relative peak torque (PT) for the concentric knee flexion muscle action at $60°·s^{-1}$ (PT KF60) and concentric hamstrings to quadriceps strength ratios (Con H:Q 60) for the basketball and gymnastics teams. *denotes significantly lower than basketball, $P < 0.05$.

The proportion of athletes from the basketball team that failed to reach the conventional H:Q recommendation of ≥ 0.60 was 36% at $60°{\cdot}s^{-1}$ and 43% at $120°{\cdot}s^{-1}$. When the functional H:Q was examined, the proportion of athletes from the basketball team that failed to reach the recommendation of ≥ 1.0 was 71% at $60°{\cdot}s$ and 79% at $120°{\cdot}s^{-1}$. The gymnastics team showed relatively greater proportions of athletes that did not meet the recommendation of conventional H:Q with 69% below the cutoff at $60°{\cdot}s^{-1}$ and 77% at $120°{\cdot}s^{-1}$. The proportion of gymnastic athletes that failed to meet the cutoff for the functional H:Q was 85% at $60°{\cdot}s^{-1}$, and 77% at $120°{\cdot}s^{-1}$.

Discussion

The present study showed significantly greater absolute isokinetic strength of both the knee extensors and flexors for the basketball team versus the gymnastics team. However, adjusting for body mass and height removed the differences for the knee extensors between the teams, but interestingly, the knee flexors' strength (both concentric and eccentric) remained significantly lower for the gymnastics team for the slow and medium velocities (60 and $120°{\cdot}s^{-1}$, respectively).

The present values for the basketball team were similar to the values reported by Wilkerson et al. (2004) for absolute PT of the knee flexors at $60°{\cdot}s^{-1}$ (88.7 vs. 90.8 Nm for the present study and Wilkerson et al., respectively); however, the isokinetic PT for the present basketball team were somewhat lower than those reported by Wilkerson et al. (2004) for the knee extensors at $60°{\cdot}s^{-1}$ (143.9 vs. 169.8 Nm). The current basketball teams' isokinetic PT values were also markedly lower than those reported by Rouis et al. (2015) for $240°{\cdot}s^{-1}$ (85.7 vs. 133.9 Nm) of the knee extensors and (56.7 vs. 94.4 Nm) for the knee flexors. The strength-related discrepancies noted between these studies may be

attributed to differences in playing level; the team investigated by Rouis et al. was comprised of top-level female basketball players at their national institute of sport while the present basketball players represented a mid-major Division I collegiate level. In another study, Xaverova et al. (2015) examined the isokinetic strength of female junior national handball players from Czech-Slovak, who's mean age (20.1) was similar to the age of the present study's participants (19.5). The trend persisted of the current collegiate basketball team exhibiting lower absolute strength in isokinetic knee extensor PT at $60°·s^{-1}$ (143.9 vs. 160.7 Nm) and $240°·s^{-1}$ (85.7 vs. 112.3 Nm), as well as in knee flexor PT at $60°·s^{-1}$ (88.7 vs. 93.5 Nm) and $240°·s^{-1}$ (56.7 vs. 78.2 Nm) in comparison to the junior national handball team. These differences may also be attributed to level of play (national vs. collegiate) as well as differences pertaining to sport-specific strength requirements that may reflect variations in training programming as well as sport-specific characteristics. While it appears that the present study's basketball team is relatively weaker in isokinetic PT than previously studied women's teams (Rouis et al., 2015; Wilkerson et al., 2004; Xaverova et al., 2015), it should be noted that limited previous research has examined isokinetic PT variables in Division I women's basketball.

The gymnastics team was found to be notably weaker in absolute isokinetic strength when compared to the present basketball players (11 – 25% lower for knee extensors and 29 – 45% lower for knee flexors). These discrepancies are consistent with previous studies examining isokinetic PT values of Division I collegiate women's soccer players for the concentric knee extensors at $60°·s^{-1}$ (120.0 vs. 154.1 Nm) and $240°·s^{-1}$ (77.4 vs. 88.8 Nm) and eccentric knee flexors at $60°·s^{-1}$ (91.4 vs. 127.6 Nm) (Jenkins et al., 2013), as well as when compared to international soccer players for concentric knee

extensors at $60°·s^{-1}$ (120 vs. 169 Nm) and concentric knee flexors at $60°·s^{-1}$ (61 vs. 91 Nm) (Andrade et al., 2012). These differences are largely a function of differences in body mass and height between the sports teams, as the gymnasts are by necessity smaller in size. Although these strength comparisons relative to body size may be more relevant for examining strength capacities across sports, few previous studies in women's collegiate sports have reported values normalized for body size, and we are aware of no studies examining these particular isokinetic strength values in collegiate level gymnasts. Nevertheless, the present findings highlighted the disparity in strength capabilities between sports teams not only in absolute terms but also for a few key relative strength variables.

While the basketball and gymnastics teams in the present study displayed significant differences in absolute strength, the adjustment for body mass shed a different light on the comparison. Although the two teams showed no significant difference in both the relative knee extensor PT variables, the two relative knee flexors variables revealed some key differences. Specifically, for concentric BM and HT PT the basketball team demonstrated ~20% greater strength at the $60°·s^{-1}$ and $120°·s^{-1}$ velocities for the knee flexors. There were no team differences for both relative eccentric knee flexor PT at the faster $120°·s^{-1}$ velocity, but at the slower $60°·s^{-1}$ the basketball players exhibited significantly greater (18% for BM and 16% for HT) PT than the gymnasts. Future research on women's sport profiles should consider reporting relative strength variables in addition to absolute strength as a means to provide a more comprehensive profile of strength capacities in collegiate women's sports that vary markedly in body size.

For isometric maximal (PT) and rapid strength (RTD) characteristics the basketball team showed greater absolute values compared to gymnastics for all knee extensor (30 – 41%) and flexor (24 - 29%) variables. The only exception was RTD50 for the knee extensors. For BM adjusted isometric variables, traditional hypothesis testing results (p values) revealed the basketball players had greater values for PT of both muscle groups and the RTD200 of the knee extensors. However, caution should be used regarding exclusive reliance on these interpretations as the effect sizes offer additional insight concerning the comparisons for which the effect sizes approached a "large effect" for the leg extensors' RTD100 (ES = 0.76) and leg flexors' RTD200 (ES = 0.73). When adjustments were made for height, knee extensors were stronger in basketball by 20 – 27% in HT PT, and HT RTD200, and be 32% in HT RTD100 when there was no significant difference between groups for BM RTD100. As with BW PT, HT PT was significantly greater in basketball than gymnastics for the knee flexors, however the adjustment for height also revealed the basketball team to be significantly stronger at HT RTD200 (19%) when BM RTD200 showed no significant differences between groups. This collective interpretation suggests that both relative PT as well as the later RTD time intervals (RTD100 – RTD200) tended to be deficient in the gymnasts when compared to the basketball players, and because they have been normalized to body mass and height, these deficiencies cannot be explained by the smaller size of the gymnasts. Moreover, this trend continues to show an under-performance of relative strength values for the gymnastics team when compared to elite female soccer players examined by Zebis et al. (2011) who reported higher relative PT of the knee extensors (2.1 vs. 3.7 Nm/kg for the present gymnasts vs. the Zebis et al. soccer athletes, respectively) and knee flexors (1.2

vs. 1.6 Nm/kg) than the current gymnasts. These differences could be attributed to age

dissimilarities (19.5 vs. 22.0 years) between the teams and level of competition

(collegiate vs. elite national) as well as sport specific training and sport performance

characteristics. Collectively, it appears that the present collegiate gymnastic athletes

exhibited deficiencies (compared to other collegiate female sports/athletes) regarding the

isokinetic strength of the knee flexor muscles, in both the concentric and eccentric muscle

actions, as well as with isometric PT of both the extensors and flexors when expressed

relative to their body size.

Regarding the H:Q ratios, two isokinetic conventional variables showed

significant differences between the basketball and gymnastics teams. The conventional

ratios at $60°·s^{-1}$ and $240°·s^{-1}$ were 15% higher in the basketball than in the gymnastic

athletes (62% vs. 53% and 67% vs. 57%, for basketball and gymnastics at 60 and $240°·s^{-1}$, respectively). When comparing the two teams to Wilkerson et al. (2004), the current

basketball team showed greater conventional H:Q balance at $60°·s^{-1}$ (62 vs. 54%

hamstrings to quadriceps strength, for the present study and Wilkerson et al.,

respectively), however, the gymnastics team had a similar ratio to Wilkerson's study (53

vs. 54%). In a different study conducted by Rosene et al. (2001), conventional H:Q ratios

were recorded at $60°·s^{-1}$ for female collegiate basketball (55%) and female collegiate

soccer (53%) players, which reveals that the basketball team from the present study

presents higher conventional H:Q values than those reported by these authors for their

collegiate basketball and soccer female athletes. However, the present gymnastics team

showed similar values to the previous reports. On the other hand, no significance was

found between teams in the present study for functional H:Q nor isometric H:Q ratios.

When compared to a Division I female collegiate soccer team studied by Jenkins et al. (2013) the functional H:Q at $60°·s^{-1}$ were relatively similar between the current basketball (88%) and gymnastics (80%) athletes, and Jenkin's et al. soccer (84%) players. Thus, the basketball team from the present study showed relatively greater H:Q values compared to previous reports for female collegiate athletics, and the gymnastics team was comparable to other reports when referring to overall H:Q strength ratios. However, caution should be used when interpreting these conclusions as not to suggest that the level of H:Q balance in these gymnasts was at an optimal level, but rather, that these as well as the previous female athletes in the aforementioned studies appear to be altogether insufficient regarding the meeting the proposed H:Q balance cutoff values.

Regarding injury risk assessment, as discussed previously, athletes that fall below the 60% mark for the conventional H:Q and 100% for the functional H:Q strength ratios may be at a higher risk of ACL injury (Dedinsky et al., 2017; Dorgo et al., 2012; Holcumb et al., 2007; Soderman et al., 2001; Wilkerson et al., 2004). When examining the proportion of athletes for each team that did not meet these predetermined cutoff values, it was found that for the conventional H:Q at $60°·s^{-1}$ that 36% of the basketball team did not meet the established criteria while gymnastics had a much higher proportion at 69% of the athletes below the 60% mark. In contrast, Devan, Pescatello, Faghri, & Anderson (2004) reported that 45% of a group of female collegiate athletes (including field hockey, soccer, and basketball) did not meet the same criteria. Based on this criterion, the majority of the current collegiate basketball team exhibited a more appropriate strength ratio between the knee flexors and extensors, while a larger portion

of the gymnasts demonstrated to have a more severe imbalance of strength between the two muscle groups.

In conclusion, this study presents a comprehensive strength-based physiological profile for Division I female basketball and gymnastics athletes, which includes multiple measures other than the traditionally investigated PT (RTD, isometric H:Q ratios and all body mass relative variables). Comparative analyses revealed that the basketball team displayed significantly greater absolute isometric and isokinetic strength in both the knee extensors and flexors than did the gymnastics team. After adjusting for body mass, several of the strength differences between teams declined with the exception of a few isokinetic variables which remained significantly lower in the gymnasts, principally for PT of the knee flexors at 60 and $120°\cdot s^{-1}$ as well as eccentric PT at $60°\cdot s^{-1}$. A key finding was the observed differences between the teams for the isokinetic H:Q ratios such that the gymnastics team demonstrated significant differences and/or large effect sizes for the conventional isokinetic H:Q ratios. Overall, the current study found the gymnastics team had a tendency to exhibit deficiencies in strength for the knee flexors per Kg of body size, which was the primary driver of the observed reductions in several H:Q ratio variables. The associated outcome of these assessments revealed that on an individualized analysis basis, a large majority of the gymnastics team (69%) failed to reach the designated ACL injury risk H:Q ratio cutoff value of 60%. In practice, these findings highlight the potential benefit that may be realized by optimizing strength training programming for female collegiate gymnastic athletes as a means to improve the overall hamstrings strength levels, which would have a direct impact on enhancing the H:Q ratios as a result of improved muscle group imbalances with plausible implications

for diminishing lower body injury risks. Specifically, a principle focus of such interventions should be targeted at strengthening the knee flexors to reduce relative strength deficiencies and to better counterbalance the overly dominant knee extensors in these particular female athletes.

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