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Discriminative Ability of Lower Limb Strength and Power Measures in Lacrosse Athletes

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ABSTRACT

The objective of this investigation was to compare isokinetic strength, countermovement jump and drop jump variables between high-contributors and low-contributors within NCAA Division I Men's and Women's lacrosse athletes. Men's (N = 36) and Women's (N = 30) NCAA Division I lacrosse athletes completed strength testing of the quadriceps and hamstring across three speeds ($60° \cdot s^{-1}$, $180° \cdot s^{-1}$, $300° \cdot s^{-1}$), countermovement and drop jumps. To determine the discriminative ability of select lower-limb strength and power characteristics participants were categorized as high-contributors (Males N = 18, age = 20.3 ± 0.4 yrs, height = 183.9 ± 5.5 cm, mass = 90.8 ± 5.8 kg; Females N = 15, age = 20.8 ± 0.8 yrs, height = 169.3 ± 6.7 cm, mass = 64.1 ± 7.2 kg) or low-contributors (Males N = 18, age = 19.5 ± 0.2 yrs, height = 184.1 ± 5.6 cm; mass = 87.9 ± 8.1 kg; Females N = 15, age = 19.7 ± 0.2 yrs, height = 169.8 ± 7.0 cm, mass = 62.9 ± 7.7 kg) based upon the number of games the participants competed in during the regular season. Within the male cohort, moderate significant ($p < 0.05$) differences were observed between high-contributors and low-contributors in isokinetic hamstring strength of the left leg at $300° \cdot s^{-1}$ ($d = 0.69$) and peak power in countermovement jump ($d = 0.68$). Within the women's cohort a large ($d = 0.87$) significant difference ($p < 0.05$) in isokinetic strength of the left hamstring was observed between high-contributors and low-contributors at $60° \cdot s^{-1}$. Hamstring strength and lower-limb power are important strength measures for lacrosse performance and should be prioritized in training prescription for lacrosse athletes.

Introduction

Lacrosse is a high intensity invasion sport that requires athletes to perform sprints, changes of direction and execute skills such as passing and shooting often while undertaking bodily contact [1, 2]. Lacrosse is considered the fastest growing sport in the United States and as such participation rates across all levels of competition are increasing substantially. In fact, in 2018 there were 43,228 participants combined among men's and women's collegiate lacrosse programs [3]. With the increase in participation rates, specifically at the collegiate level there is a need for additional evidence that can be used by sports medicine and sport science practitioners to enhance on-field performance and inform training and rehabilitation programs.

The ability to produce strength and power in the lower limbs underpins the successful performance of many movements common to lacrosse [1, 2, 4, 5]. It is common within research and practice to identify specific measures of force production that possess discriminative ability between higher and lower levels of performers [6, 7]. For example, previous research has reported that starting players in elite Australian Rules football possess greater speed, leg power and endurance compared to their non-starting counterparts [6]. More specific to lacrosse, Sell and colleagues [7] identified that starters in a collegiate men's team possessed greater maximal speed, change of direction ability, vertical jump height and body mass compared to non-starters. In turn, this valuable information is used by coaches to understand the physical needs of an athlete required to perform at a specific level of competition and inform training prescription.

Participation in the sport of lacrosse presents a substantial risk of soft-tissue injury to the knee and upper leg [8, 9]. Injuries to the knee are considered more severe than other lower-limb injuries because they have been found to result in substantial time loss from training and competition compared to other body regions [8, 9]. Low levels of muscular strength, inadequate agonist / antagonist strength ratios and bilateral strength deficits are commonly noted internal modifiable risk factors for non-contact lower-extremity injury [10, 11]. Therefore, Isokinetic strength testing is commonly used by clinicians and researchers to provide a robust and objective measurement of muscle strength as it relates to injury risk of injury to the knee [12, 13]. Currently there is a need to present isokinetic strength data for the quadriceps and hamstrings of collegiate lacrosse athletes to serve as a reference point to inform injury prevention and rehabilitation programs for this quickly expanding cohort of athletes.

Isokinetic strength, countermovement (CMJ) and drop jump (DJ) testing each measure different aspects of an athlete's force generating capacity, which is valuable for on-field performance and to inform the design of training programs. Owing to the need for lacrosse athletes to frequently accelerate, change directions and withstand physical contact, the ability to express lower-limb strength and power is important for successful performance [1, 2, 4, 5]. Moreover, a comparison of these strength and power qualities between higher and lower-level performers can help sports performance practitioners prioritize training methods to maximize on-field performance. To date, only one study has examined the differences in strength and power characteristics in Division I Men's lacrosse starters and non-starters [7]. Additionally, only one study has investigated these differences in Women's Division I lacrosse athletes [14]. However, the investigation conducted by Vescovi et al. [14] was completed 14 years ago and did not include a measure of lower limb strength. Therefore, the primary aim of this investigation is to compare isokinetic strength, CMJ and DJ variables between higher contributors and lower contributors within NCAA Division I Men's and Women's lacrosse athletes. A secondary aim is to compare the lower-limb force generating capabilities between male and female collegiate lacrosse athletes. With an overarching objective to provide a lower-limb isokinetic strength and power profile of collegiate lacrosse athletes. It was hypothesized that statistically significant differences in strength and power measures would be observed between high-contributing players and their lower-contributing counterparts. Additionally, it was hypothesized that statistically significant differences in lower-limb strength and power will be observed between male and female collegiate lacrosse athletes.

Materials and Methods

Study design

A cross-sectional observational cohort study design was employed to compare the isokinetic strength of the hamstring and quadriceps muscle groups, CMJ and DJ variables between high-contributors and low in game contributors within NCAA Division I men's and women's lacrosse athletes and to compare the male and female athletes. For the first comparison the independent variables were the level of contribution from the players in competition. For the second comparison, the independent variable was the athlete's sex. For both comparisons the dependent variables from the isokinetic testing were: concentric isokinetic peak torque of the quadriceps and hamstring muscle groups across three speeds of $60° \cdot s^{-1}$, $180° \cdot s^{-1}$ and $300° \cdot s^{-1}$[13]. Dependent variables from the CMJ were jump height (JH) and relative peak power (RPP). Additionally, reactive strength index (RSI) was the dependent variable from the drop jump. The CMJ and DJ were performed first followed by the isokinetic strength testing to minimize the risk of fatigue or potentiation. All testing occurred over a single day in the pre-competition phase of the athlete's periodized training program and all athletes were free from injury at the time of data collection. Ethical approval was obtained by the research ethics committee from Southern Connecticut State University and Yale University.

Participants

A convenience sample was obtained from the University's men's (N = 36, age = 20.1 ± 0.6 yrs, height = 183.8 ± 5.5 cm, mass = 92.6 ± 15.8 kg) and women's (N = 30, age = 20.2 ± 0.8 yrs , height = 169.6 ± 6.7 cm, mass = 63.5 ± 7.3 kg) lacrosse programs. Retrospective from the data collection and following the competitive phase of the training program, the athletes were then sub-categorized as "higher contributors" (Men: N = 18; Women: N = 15) and "lower contributors" (Men: N = 18; Women: N = 15) based upon the number of games they competed in during the regular season. Specifically, higher contributors were defined as those players that played in more than eight games which was half of the team's sixteen regular season games. Higher contributors and lower contributors were chosen instead of the traditional "starters and non-starters" delineation to better align with the tactical decision making of the team's coaching staff. The coaching staff frequently alternated the starting players to suit in-game strategy. Additionally, rules within the sport of lacrosse allow for frequent in-game substitutions of players providing a clear delineation between higher and lower-level performers based upon the number of games played in. Please note that the conference the athletes competed within does not allow for red shirt players which is a player that trains with the team but is not eligible to compete in games. Therefore, all members of the team were eligible to compete in all games. The characteristics of participants is provided in ► **Table 1**.

Procedures

Isokinetic Strength

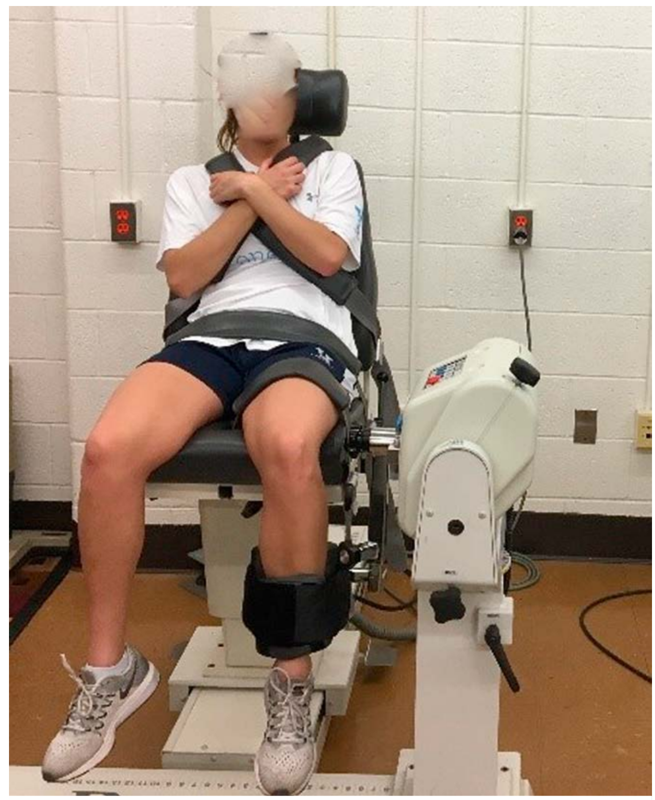
All testing occurred during the pre-competition phase of the athletes' periodized training program. All participants were familiar with the testing procedures as they are part of their routine moni-

▶ **Table 1** Characteristics of participants. No statistically significant difference in characteristics were observed.

	Male			Female		
	Total (N = 36)	**Higher Contributors (N = 18)**	**Lower Contributors (N = 18)**	**Total (N = 30)**	**Higher Contributors (N = 15)**	**Lower Contributors (N = 15)**
Age (yrs)	20.2 ± 0.8	20.3 ± 0.4	19.5 ± 0.2	20.2 ± 0.5	20.8 ± 0.8	19.7 ± 0.2
Height (cm)	183.8 ± 5.5	183.4 ± 5.5	184.1 ± 5.6	169.6 ± 6.7	169.3 ± 6.7	169.8 ± 7.01
Mass (kg)	92.6 ± 15.8	90.8 ± 5.8	87.9 ± 8.1	63.5 ± 7.3	64.1 ± 7.2	62.9 ± 7.5
BMI (kg/m²)	26.9 ± 3.9	26.9 ± 1.3	27.5 ± 6.5	22.1 ± 1.7	22.3 ± 1.8	21.7 ± 1.7
Years in program	2.29 ± 1.0	2.38 ± 1.0	2.2 ± 1.0	2.3 ± 1.0	2.7 ± 1.1	1.9 ± 1.0

toring of physical capabilities. Each testing session commenced with the athletes completing a standardized warm-up consisting of three minutes of moderate intensity jogging followed by dynamic stretching over a 10 m distance targeting the musculature of the lower extremities. Following completion of the standardized warm-up athletes were provided with 2 minutes of self-directed preparation to target musculature that they did not feel were adequately addressed during the warm-up.

Isokinetic strength during a concentric muscle action of both the right and left quadriceps and hamstring muscle groups was assessed across three velocities: $60° \cdot s^{-1}$, $180° \cdot s^{-1}$ and $300° \cdot s^{-1}$ (Biodex System 3, Biodex Medical Systems, Shirley New York USA) [13]. The order of the velocities used in the isokinetic strength testing was not randomized and always started with $60° \cdot s^{-1}$ followed by $180° \cdot s^{-1}$ and concluding with $300° \cdot s^{-1}$. Athletes were comfortably secured using shin, thigh, pelvic and upper torso stabilization straps. To isolate force production to the lower extremities and limit the influence of the upper-body, athletes were instructed to cross their arms over their chest and not hold the testing chair during repetitions. The axis of rotation of the knee was aligned with the shaft of the dynamometer with the ankle resistance pad secured immediately superior to the medial malleolus. Prior to testing on both the right and left sides a gravity correction for limb weight was performed and the athlete's dominant leg was assessed first. Prior to testing at each velocity, the athlete completed three submaximal repetitions of increasing effort, followed by five maximal repetitions. One minute of rest was provided prior to increasing the testing velocity. Athletes were verbally encouraged throughout each repetition to ensure a maximal effort was provided. Peak torque (Nm/kg) was normalized to body mass, and values for both quadriceps and hamstring muscle groups for each limb at each speed were retained for analysis. Reliability of isokinetic strength testing on the Biodex System 3 at the velocities used in this investigation has been previously established [13]. ▶ **Figure 1** provides a visual representation of the setup for isokinetic strength testing.



▶ **Figure 1** Visual representation of setup for the isokinetic strength test.

Countermovement jump

Athletes completed a set of four submaximal CMJs with the instruction to increase the intensity of each jump so that the final jump was a "near maximal effort". After two minutes of rest the athlete performed a set of four maximal CMJs with 10–15 seconds between attempts on a force plate sampling at 500 Hz (Kistler Quattro Jump, Winterthur Switzerland). To isolate force production in the lower extremity, each jump was performed with hands placed on hips. The athletes were instructed to perform a countermovement to a self-selected depth and jump for maximal height [15]. The average of the two attempts that produced the greatest jump height were retained for analysis. ▶ **Figure 2** provides visual representation of the CMJ test.

Drop jump

Drop jumps were performed from a 30 cm box onto a force plate sampling at 500 Hz (Kistler Quattro Jump, Winterthur Switzerland). Although the athletes were familiar with the drop jump exercise because it is part of their normal training routine, they were provided with opportunities to practice until sufficient technique was observed by the tester (i. e. not jumping off, or stepping down from the box when initiating their jump). For each attempt the athlete placed their hands on their hips and were provided with the spe-

▶ **Figure 2** Visual representation of the countermovement jump.

▶ **Figure 3** Visual representation of the drop jump.

cific instructions to "jump for maximal height and minimal ground contact time" [16]. The athlete performed a minimum of four drop jumps with the attempt that produced the greatest reactive strength index (RSI) score as determined by jump height divided by contact time retained for analysis. ▶ **Figure 3** provides a visual representation of the DJ test.

From previous testing using the same equipment from the same laboratory in a similar group of collegiate athletes all variables from the CMJ and DJ demonstrated excellent test-retest reliability. Specifically, the reliability of the CMJ derived variables were Jump Height (ICC = 0.972; CV = 4.2 %), Relative Peak Power (ICC = 0.983; CV = 3.2 %). Variables derived from the DJ were Jump Height (ICC = 0.991; CV = 2.5 %), Contact Time (ICC = 0.997; CV = 4.3 %), RSI (ICC = 0.975; CV = 4.3 %). These measurements are similar to other studies that have investigated the reliability of jump testing in NCAA Division I collegiate athletes [17, 18].

Statistical analysis

All statistical analyses were conducted using the Statistical Package for the Social Science (SPSS) version 26 (IBM, New York, NY, USA). A Shapiro-Wilk test was used to assess the normality of the data. All data were distributed normally; therefore, to compare the differences in isokinetic strength, CMJ and DJ measures one-way analysis of variance (ANOVA) were utilized with an alpha level of significance set at $p \leq 0.05$. Three separate comparisons were conducted (i) a comparison of higher and lower-level contributors within the male participants; (ii) a comparison of higher and lower-level contributors within the female participants; (iii) A comparison between the males and females. Cohen's *d* effect sizes were calculated to determine the magnitude of the differences between high contributors and low contributors with the following descriptors used to describe the effect sizes; very small = 0.01–0.19; small = 0.20–0.49; medium = 0.50–0.79; large = 0.80–1.19; very large = 1.20 + [19].

Results

Participant characteristics

There was no statistically significant difference in the height ($p = 0.718$; d = 0.09) or body mass ($p = 0.510$; d = 0.40) between the male higher contributors and lower contributors. Additionally, there was no statistically significant difference in the height ($p = 0.859$; d = 0.07) or mass ($p = 0.667$; d = 0.17) between the female higher contributors and lower contributors. Male players possessed significantly greater height ($p < 0.01$; $d = 2.31$) and mass ($p < 0.01$; $d = 3.7$).

High vs low contributor comparison

Isokinetic Strength The isokinetic strength data for both higher contributing and lower contributing male and female lacrosse athletes are presented in ▶ **Tables 2** and ▶ **3**, respectively. Isokinetic strength of the left hamstrings at 300 °·s^{-1} was significantly greater in the higher contributing male players compared to lower contributing ones ($p = 0.05$; $d = 0.69$).

Within the female athletes, a statistically significant difference between the higher contributors and lower contributors was observed for the relative peak torque of the left hamstrings at 60 °·s^{-1} ($p = 0.03$; $d = 0.87$), peak torque of the left quadriceps at 180 °·s^{-1} ($p = 0.04$; $d = 0.95$).

There were no statistically significant differences in the hamstring to quadriceps ratio (H:Q ratio) between higher and lower contributing players in either the male or female players.

Countermovement jump

The countermovement and drop jump data for both the higher contributing and lower contributing male and female players is presented in ▶ **Tables 2** & ▶ **3**. The relative peak power of male higher contributors was significantly greater compared to lower contributors ($p = 0.04$; $d = 0.68$). Within the females there were no statistically significant differences in the jump height or relative peak power between high contributing and low contributing athletes.

Drop jump

There were no statistically significant differences in the reactive strength index of male and female high contributing or low contributing athletes.

Male vs female comparison

Isokinetic strength The isokinetic strength data for the males and females is presented in ▶ **Table 4**. At 60 °·s^{-1} there were statistically significant differences in the hamstring strength of male players compared to female players in the right hamstrings ($p = 0.04$; $d = 0.54$), left hamstring ($p = 0.02$; $d = 0.10$) and left quadriceps ($p = 0.01$; $d = 0.84$). At 180 °·s^{-1} significant differences in isokinetic strength between males and females were found in the right hamstrings ($p = 0.01$; $d = 0.65$), the right quadriceps ($p = 0.01$; $d = 0.66$) and the left quadriceps ($p = 0.03$; $d = 0.56$). At 300 °·s^{-1} the only statistically significant difference between the males and

▶ **Table 2** Lower limb Isokinetic strength and power profile of men's higher contributors and lower contributors. Flex = Flexion; Ext = Extension; Dif = Difference; H:Q Ratio = Hamstring:Quadriceps ratio. * = Statistically different (P ≤ 0.05). VS = very small; S = small; M = medium; L = large; VL = Very Large; CMJ = Countermovement Jump; DJ = Drop Jump

	Group				
Measurement (Mean ± SD)	**Higher Contributors (N = 18)**	**Lower Contributors (N = 18)**	**% Difference**	***P*- Value**	**Cohen's d**
Isokinetic Strength at 60 °·s^{-1}					
Right Flexion (Nm/kg)	1.49 ± 0.25	1.37 ± 0.32	− 8.05	0.22	*d* = 0.41 (S)
Right Extension (Nm/kg)	2.65 ± 0.49	2.41 ± 0.71	− 9.05	0.25	*d* = 0.39 (S)
Right H:Q Ratio (%)	57.09 ± 7.8	54.38 ± 9.3	− 4.74	0.35	*d* = 0.31 (S)
Left Flexion (Nm/kg)	1.46 ± 0.20	1.35 ± 0.28	− 7.53	0.20	*d* = 0.45 (S)
Left Extension (Nm/kg)	2.67 ± 0.48	2.50 ± 0.52	− 6.36	0.32	*d* = 0.33 (S)
Left H:Q Ratio (%)	55.88 ± 9.5	54.5 ± 7.27	− 2.47	0.63	*d* = 0.16 (S)
Isokinetic Strength at 180 °·s^{-1}					
Right Flexion (Nm/kg)	1.21 ± 0.24	1.06 ± 0.20	− 12.39	0.06	*d* = 0.67 (M)
Right Extension (Nm/kg)	1.86 ± 0.33	1.72 ± 0.40	− 7.52	0.28	*d* = 0.38 (S)
Right H:Q Ratio (%)	65.96 ± 14.00	59.63 ± 10.53	− 9.59	0.14	*d* = 0.51 (M)
Left Flexion (Nm/kg)	1.16 ± 0.23	1.01 ± 0.21	− 12.93	0.06	*d* = 0.68 (M)
Left Extension (Nm/kg)	1.85 ± 0.34	1.61 ± 0.51	− 12.97	0.11	*d* = 0.55 (M)
Left H:Q Ratio (%)	63.88 ± 13.09	59.82 ± 9.7	− 6.35	0.30	*d* = 0.35 (S)
Isokinetic Strength at 300 °·s^{-1}					
Right Flexion (Nm/kg)	0.99 ± 0.23	0.86 ± 0.16	− 13.13	0.06	*d* = 0.65 (M)
Right Extension (Nm/kg)	1.45 ± 0.32	1.35 ± 0.28	− 6.89	0.33	*d* = 0.33 (S)
Right H:Q Ratio (%)	69.68 ± 13.58	62.22 ± 12.44	− 10.70	0.10	*d* = 0.57 (M)
Left Flexion (Nm/kg)	**0.97 ± 0.24**	**0.82 ± 0.19**	**− 15.46**	***0.05****	***d* = 0.69 (M)**
Left Extension (Nm/kg)	1.47 ± 0.34	1.36 ± 0.29	− 7.48	0.29	*d* = 0.34 (S)
Left H:Q Ratio (%)	66.73 ± 13.25	60.40 ± 11.34	− 9.48	0.14	*d* = 0.51 (M)
CMJ & DJ Measures					
CMJ JH (CM)	38.1 ± 14.1	37.5 ± 5.7	1.5	0.86	*d* = 0.05 (VS)
CMJ Relative PP (W/Kg)	**60.4 ± 7.1**	**56.1 ± 5.3**	**5.6**	**0.04**	***d* = 0.68 (M)**
DJ RSI (cm/sec)	155.5 ± 28.8	161.7 ± 23.5	3.9	0.5	*d* = 0.23 (S)

▶ **Table 3** Lower limb Isokinetic strength and power profile of female higher contributors and lower contributors Flex = Flexion; Ext = Extension; H:Q Ratio = Hamstring:Quadriceps ratio. * = Statistically different (P ≤ 0.05). VS = very small; S = small; M = medium; L = large; VL = Very Large; CMJ = Countermovement jump; DJ = Drop Jump

	Group				
Measurement (Mean±SD)	**Higher Contributors (N = 15)**	**Lower Contributors (N = 15)**	**% Difference**	**P- Value**	**Cohen's d**
Isokinetic Strength at 60°·s⁻¹					
Right Flexion (Nm/kg)	1.36 ± 0.15	1.26 ± 0.18	−7.63	0.13	*d* = 0.60 (M)
Right Extension (Nm/kg)	2.39 ± 0.41	2.26 ± 0.23	−5.59	0.26	*d* = 0.39 (S)
Right H:Q Ratio (%)	57.21 ± 7.49	56.09 ± 7.36	−1.97	0.68	*d* = 0.15 (S)
Left Flexion (Nm/kg)	**1.35 ± 0.16**	**1.21 ± 0.16**	**−10.93**	***0.03*** *	***d* = 0.87 (L)**
Left Extension (Nm/kg)	2.31 ± 0.31	2.12 ± 0.33	−8.57	0.12	*d* = 0.59 (M)
Left H:Q Ratio	59.2 ± 5.6	57.7 ± 7.83	−2.56	0.57	*d* = 0.22 (S)
Isokinetic Strength at 180°·s⁻¹					
Right Flexion (Nm/kg)	1.04 ± 0.07	0.98 ± 0.16	−5.94	0.24	*d* = 0.48 (S)
Right Extension (Nm/kg)	1.63 ± 0.23	1.55 ± 0.19	−5.03	0.30	*d* = 0.37 (S)
Right H:Q Ratio (%)	64.32 ± 7.61	63.32 ± 7.3	−1.56	0.71	*d* = 0.13 (S)
Left Flexion (Nm/kg)	1.04 ± 0.14	0.97 ± 0.17	−6.95	0.20	*d* = 0.44 (S)
Left Extension (Nm/kg)	**1.62 ± 0.14**	**1.46 ± 0.19**	**−10.38**	***0.01****	***d* = 0.95 (L)**
Left H:Q Ratio (%)	64.24 ± 6.96	66.22 ± 8.29	3.03	0.48	*d* = 0.22 (S)
Isokinetic Strength at 300°·s⁻¹					
Right Flexion (Nm/kg)	0.86 ± 0.09	0.85 ± 0.15	−1.16	0.59	*d* = 0.09 (VS)
Right Extension (Nm/kg)	1.29 ± 0.20	1.30 ± 0.17	0.77	0.80	*d* = 0.01 (VS)
Right H:Q Ratio (%)	67.4 ± 10.11	65.5 ± 9.96	−2.85	0.61	*d* = 0.18 (VS)
Left Flexion (Nm/kg)	0.87 ± 0.11	0.84 ± 0.13	−3.50	0.54	*d* = 0.24 (S)
Left Extension (Nm/kg)	**1.29 ± 0.20**	**1.30 ± 0.17**	**0.77**	**0.24**	***d* = 0.05 (VS)**
Left H:Q Ratio (%)	65.55 ± 7.65	69.30 ± 9.1	5.56	0.23	*d* = 0.45 (S)
CMJ and DJ Measures					
CMJ JH (CM)	28.4 ± 3.9	26.5 ± 5.1	6.6	0.26	*d* = 0.41 (S)
CMJ Relative PP (W/Kg)	43.3 ± 5.2	41.3 ± 5.5	4.9	0.31	*d* = 0.37 (S)
DJ RSI (cm/sec)	96.2 ± 28.3	87.5 ± 18.3	9.4	0.32	*d* = 0.36 (S)

females was found in the left quadriceps ($p = 0.02$; $d = 0.51$). Isokinetic strength testing results are provided in ▶ **Table 4**.

Countermovement jump

A large statistically significant difference was observed in countermovement jump height in males compared to females ($p < 0.01$; $d = 1.92$). A very large statistically significant difference ($p < 0.01$; $d = 2.81$) was found in relative peak power of male players compared to female.

Drop jump

A very large statistically significant difference ($p < 0.01$; $d = 2.44$) was found in reactive strength index between males and females.

Discussion

This study sought to determine if specific characteristics of lower limb force generating capacity could discriminate between higher and lower-level players within the team. Additionally, a secondary objective was to compare the force generating capacity between male and female collegiate lacrosse athletes. The overarching objective of the study was to provide sports medicine and science practitioners and researchers with an isokinetic strength profile of the lower limb for NCAA Division I Men's and Women's lacrosse athletes that can be used to inform rehabilitation and physical preparation programs.

The main findings from this study were that in the men's cohort the ability to produce strength in the left hamstrings at relatively high contraction speeds (300°·s⁻¹) was significantly greater in the higher contributing compared to the lower contributing athletes. Additionally, higher contributing athletes produced significantly greater relative peak power in the CMJ compared to their lower contributing counterparts. Within the women's cohort the ability to produce strength in the left hamstrings at slow contraction speeds (60°sec) and strength in the left quadriceps at moderate speeds (180°·s⁻¹) was significantly greater in the contributors compared to the non-contributors.

Amongst both the male and female athletes the ability of the higher contributing players to produce greater strength in the left hamstrings was a common trend that reached statistical significance at moderate speeds for the females and high speeds for the males. This finding may be linked to the important technical skill of overhand lacrosse shooting. During this skill when shooting right-handed the left leg is stepped forward then planted into the

▶ **Table 4** Lower limb Isokinetic strength and power comparison of male and female lacrosse players Flex = Flexion; Ext = Extension; H:Q Ratio = Hamstring:Quadriceps ratio. * = Statistically different (P ≤ 0.05). VS = very small; S = small; M = medium; L = large; VL = Very Large; CMJ = Countermovement jump; DJ = Drop Jump.

	Group				
Measurement (Mean ± SD)	**Males (N = 36)**	**Females (N = 30)**	**% Difference**	***P*- Value**	**Cohen's d**
Isokinetic Strength at 60°·s⁻¹					
Right Flexion (Nm/kg)	**1.44 ± 0.29**	**1.31 ± 0.17**	**−9.02**	**0.04***	***d* = 0.54 (M)**
Right Extension (Nm/kg)	2.54 ± 0.61	2.33 ± 0.33	−8.26	0.09	*d* = 0.42 (S)
Right H:Q Ratio (%)	55.77 ± 8.50	56.53 ± 7.32	1.36	0.19	*d* = 0.09 (VS)
Left Flexion (Nm/kg)	**1.41 ± 0.24**	**1.28 ± 1.77**	**−9.21**	**0.02***	***d* = 0.10 (VS)**
Left Extension (Nm/kg)	**2.58 ± 0.50**	**2.22 ± 0.33**	**−13.95**	**0.01***	***d* = 0.84 (L)**
Left H:Q Ratio (%)	55.22 ± 8.40	58.48 ± 6.74	−5.90	0.09	*d* = 0.42 (S)
Isokinetic Strength at 180°·s⁻¹					
Right Flexion (Nm/kg)	**1.13 ± 0.23**	**1.01 ± 0.12**	**−10.61**	**0.01***	***d* = 0.65 (M)**
Right Extension (Nm/kg)	**1.79 ± 0.37**	**1.59 ± 0.21**	**−11.17**	**0.01***	***d* = 0.66 (M)**
Right H:Q Ratio (%)	62.89 ± 12.67	63.82 ± 7.35	1.14	0.72	*d* = 0.08 (VS)
Left Flexion (Nm/kg)	1.09 ± 0.23	1.00 ± 0.16	−8.52	0.09	*d* = 0.45 (S)
Left Extension (Nm/kg)	**1.73 ± 0.44**	**1.54 ± 0.18**	**−10.98**	**0.03***	***d* = 0.56 (M)**
Left H:Q Ratio (%)	61.9 ± 11.5	65.2 ± 7.59	5.33	0.18	*d* = 0.33 (S)
Isokinetic Strength at 300°·s⁻¹					
Right Flexion (Nm/kg)	0.93 ± 0.21	0.86 ± 0.12	−7.52	0.10	*d* = 0.40 (S)
Right Extension (Nm/kg)	1.40 ± 0.30	1.29 ± 0.18	−7.85	0.10	*d* = 0.44 (S)
Right H:Q Ratio (%)	66.06 ± 13.39	66.47 ± 9.91	0.62	0.80	*d* = 0.03 (VS)
Left Flexion (Nm/kg)	0.90 ± 0.23	0.85 ± 0.12	−5.55	0.33	*d* = 0.27 (S)
Left Extension (Nm/kg)	**1.42 ± 0.31**	**1.26 ± 0.17**	**−11.26**	**0.02***	***d* = 0.51 (M)**
Left H:Q Ratio (%)	63.65 ± 12.59	67.43 ± 8.48	5.93	0.16	*d* = 0.35 (S)
CMJ & DJ Measures					
CMJ JH (CM)	**40.70 ± 8.65**	**27.40 ± 4.59**	**−32.67**	**<0.01***	***d* = 1.92 (L)**
CMJ Relative PP (W/Kg)	**58.86 ± 6.6**	**42.06 ± 5.27**	**−28.54**	**<0.01***	***d* = 2.81 (VL)**
DJ RSI (cm/sec)	**154.53 ± 27.48**	**92.21 ± 23.33**	**−40.32**	**<0.01***	***d* = 2.44 (VL)**

ground during the stick acceleration phase and contributes to force production through a powerful hip extension [20]. Previous research has demonstrated that the biceps femoris muscle significantly contributes to force production during execution of an overhand lacrosse shot and that the activation of the muscle increases concomitantly with shot speed [21]. Additionally, Talpey et al. [22] found that peak torque of the left hamstrings increased significantly over the course of a season, a finding that was not observed in the quadriceps indicating that exposure to high-speed overhand shooting typical in training and competition may potentially provide a stimulus to enhance force generating capacity of the hamstrings. This finding may provide impetus to further investigate the relationship between hamstring strength and overhand shooting in lacrosse.

Hamstring to quadriceps strength ratio is a valuable metric used to inform the rehabilitation process [12]. Therefore, an important finding from this investigation is that regardless of the contribution status of the athlete for both males and females, the hamstring to quadriceps ratio was within the typical range of 50–80 % presented in the literature for non-injured collegiate athletes [23]. Additionally, the relative peak torque values of both the hamstrings and quadriceps across all three speeds in the current investigation align closely with those reported by Tsuchiya and colleagues [24] in a cohort of collegiate-aged lacrosse players. These novel findings from the current investigation provide sports medicine practitioners within collegiate lacrosse with benchmark isokinetic strength data to inform their return to play programs.

Comparing physical qualities between higher and lower levels of competition and starters and non-starters is a commonly used approach to understand important physical qualities for performance in a particular sport. An important finding from the current investigation was the higher contributing male players were able to produce significantly greater relative peak power than non-contributing players. These findings can be compared to those of Sell et al. [7] who reported starting NCAA Division I lacrosse players had a significantly greater vertical jump than non-starters. However, within that study there was no statistically significant difference in one repetition maximum hang clean as a test of muscular power between starters and nonstarters. The findings from the current investigation add to those reported by Sell [7] because a countermovement jump performed on a force plate without an arm swing (as used in the current investigation) is a direct assessment of lower-limb power whereas performance in a vertical jump with an arm swing (as used in the study by Sell) is significantly influenced by the use of the arms and technical factors [25]. In the current investigation there was no-significant difference in the CMJ jump height between male high contributors and low contributors, even though there was significant difference in relative power output. Although it is plausible that other factors such as injury and illness may influence the discriminative ability of a physical quality, this finding indicates that physical preparation programs should specifically target the development of relative peak power. Meaning that any development in maximal power output achieved through training should also aim for a maintenance or reduction in body mass. Reactive strength assessed via a drop jump was not significantly different between male higher contributors and lesser contributors. Reactive strength is a specific power quality that is related to an athlete's ability to produce power in a short and fast stretch-shortening cycle [16]. Reactive strength underpins movements such as jumps from a run-up, sprinting at maximal speeds and changing directions while jumps from a run-up are not common in lacrosse sprinting and changing directions are common movements amongst specific position groups [1, 2]. Therefore, it is somewhat surprising that this specific power quality did not differ between groups of higher and lesser contributors. However, future research may consider a comparison between position groups which may yield different results.

This was the second investigation and first in 14 years that has attempted to identify physical characteristics that can discriminate between higher and lower-level performers in Division I Women's lacrosse [14]. Interestingly, the findings from both the current investigation and the 2007 study by Vescovi [14] demonstrated homogeneity between higher and lower-level performers within Division I Women's lacrosse players. The lack of significant differences in physical qualities between starters and non-starters in Division I women's athletes has also been recently observed in soccer [26]. This result may be related to the resistance training habits of the team and indicates that technical, tactical or psychological aspects of performance rather than physical characteristics discriminate between higher and lower-level collegiate women's athletes [27]. Future research may focus on understanding aspects of performance in collegiate women's lacrosse other than physical qualities that are different between higher and lower levels of performance. Research in this area would provide valuable information to inform talent identification and talent development within this rapidly growing sport [27].

Sex differences in isokinetic strength were observed across the different speeds. The male athletes produced greater force in all measures of isokinetic strength with statistically significant differences achieved for the right hamstrings at $60\,°\cdot s^{-1}$ and $180\,°\cdot s^{-1}$, the left hamstring at $60\,°\cdot s^{-1}$, the right quadriceps at $180\,°\cdot s^{-1}$ and the left quadriceps at $60\,°\cdot s^{-1}$, $180\,°\cdot s^{-1}$ and $300\,°\cdot s^{-1}$. This finding is consistent with the results of previous research that has demonstrated that males produce approximately 45 % and 35 % greater values in peak torque in their hamstrings and quadriceps respectively compared to their female counterparts competing in the same sport [28]. There were "very small" to "small" non-significant differences in the hamstring to quadriceps ratio between the males and females. This isokinetic strength variable has received considerable attention in the literature owing to its diagnostic utility for the mitigation of risk associated with anterior cruciate ligament (ACL) injury [29]. These ratios for males and females are similar to those reported in the literature [28, 29]. However, the H:Q ratios in the present study are slightly greater than those previously reported [29]. This may be due to the specific strength training program for the female lacrosse athletes in this study in which hamstring strength training was a targeted priority.

Measures of lower body power were also significantly greater in the male players compared to their female counterparts. Specifically, a "large" statistically significant 27.4 % difference was observed in countermovement jump height, which was accompanied by a "very large" statistically significant 28.5 % difference in relative peak power and a 47 % difference in reactive strength. These findings are closely aligned with those reported by Abian et al. [30] who found a 27 % difference in relative peak power and 27.8 % difference in jump height between males and females. However, the current study only focused on the outcomes of the jump test (e. g. jump height and peak power output), future research comparing male and female athletes in jump based assessments should to investigate the differences in the phases of the jump through an in-depth force-time curve analysis [31]. This information would help researchers and practitioners understand the differing lower-limb force production strategies between males and females, which in turn can inform training to enhance performance and reduce the risk of injury.

Limitations

The results of this investigation need to be considered alongside its limitations. First, this investigation was focused on the Men's and Women's lacrosse teams from one university, and results may not be generalizable across all Division I lacrosse athletes. Second, testing of physical qualities occurred in the pre-competition phase of training and future research should incorporate the assessment of lower limb isokinetic strength and power across multiple time points within a periodized training plan. Third, a test of limb dominance was not conducted and may have impacted the results.

Conclusions

Owing to the finding that left hamstring strength was significantly different between contributing and non-contributing players within both the male and female cohort, it appears that strength in this muscle group may underpin an important aspect of lacrosse performance (e. g. overhand shooting). However, future research in this area is needed before a definitive conclusion can be made. Additionally, peak power was significantly greater in the contributing male players compared to their non-contributing counterparts highlighting power should be a targeted focus of training programs. Interestingly, this finding was not observed within the women's cohort indicating that aspects of performance not related to physical qualities may be more discriminative. The comparison of lower-limb force production between male and female lacrosse athletes aligns with findings from previous research. The isokinetic strength profile presented within this study can be used to provide benchmarks to inform the rehabilitation process for collegiate lacrosse athletes returning to play or for sports medicine practitioners screening athletes for injury risk.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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