

Original Research

Comparing the Dominant and Non-Dominant Leg Strength of Division I Collegiate Female Cutting Athletes to Jumping Athletes: A Pilot Study

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Keywords: injury risk, limb symmetry, female athlete

<https://doi.org/10.26603/001c.137955>

International Journal of Sports Physical Therapy

Vol. 20, Issue 6, 2025

Background

Assessing lower extremity strength and performance is common practice in sports medicine. Sport-specific demands could impact the amount of leg strength asymmetry between the dominant and non-dominant leg present in athletes.

Hypothesis/Purpose

The purpose of this pilot study was to explore the amount of lower limb strength asymmetry between the dominant and non-dominant of female collegiate athletes across different sports.

Study Design

Case control study.

Methods

A total of 43 female Division I collegiate athletes from soccer, tennis, and volleyball teams participated in the study. Subjects were separated into groups based on participation in a jumping sport (volleyball) versus a cutting sport (soccer and tennis). Differences in concentric quadriceps peak torque between the dominant and non-dominant legs at 60 deg/sec, measured using the Biodex System 3 isokinetic dynamometer, were compared across groups. Athletes of each sport type were classified as “dominant stronger”, “equal”, or “non-dominant stronger” based on the differences between leg strength using a cut-off value of a difference of 10ft-lbs of torque. Odds ratios were calculated to determine the association between sport exposure and quadriceps strength on the dominant side.

Results

Jumping athletes were 30 times (OR=29.96 (CI 95%, 1.56 - 577.25) more likely than cutting athletes to have a stronger dominant quadriceps. In jumping athletes, the participants were distributed almost evenly across the “dominant stronger”, “non-dominant stronger”, and “equal” groups. In cutting athletes, 76.9% fell into the “equal” category, while the remaining 23.1% fell into the “non-dominant stronger” category.

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Conclusion

Female collegiate jumping athletes were much more likely to have a stronger quadriceps on the dominant vs non-dominant leg than were cutting athletes. This information can be used to help develop specific strength and conditioning and rehabilitative programs for female athletes.

Level of Evidence

Level 3

INTRODUCTION

The movement demands athletes are challenged with vary based on the sport. Sports, such as soccer and tennis, require a large volume of cutting and change in direction maneuvers. Volleyball, on the other hand, requires more jumping. The competitive athlete's movement can also be influenced by the use of the upper limbs during sport. Tennis and volleyball require unilateral and bilateral upper limb use, while soccer is a predominantly a lower limb sport. Lastly, the movement requirements between lower limbs may vary depending on the sport. In soccer, during ball handling, passing, and kicking, the non-dominant lower limb provides a unilateral stable base of support by accepting the players body weight and assisting the trunk in maintaining the body upright while the upper limbs abduct and to counterbalance the torque and decelerating velocity through non-dominant lower limb. In tennis, the use of the kinetic chain during the forehand stroke calls for the non-dominant lower limb to load and stabilize to counterbalance upper limb and trunk rotational movement and torque.^{1,2} In volleyball, the propulsive, eccentric preparation phase and explosive concentric phase of a jumping when blocking or spiking, require similar movements between lower limbs or between the dominant and non-dominant legs.³ An assumption in many athletes that perform these types of maneuvers, is that one limb is stronger than the other and is therefore described as the dominant lower limb.

A common assumption in competitive sport is that a healthy, non-injured athlete should demonstrate symmetry between their dominant and non-dominant legs. However, previous research has demonstrated lower limb strength asymmetry in athletes of different sports, but the amount of asymmetry is unknown.⁴⁻⁶ Recent work by Sullivan et al. found a mean 5-7% asymmetry between lower limbs in healthy male and female collegiate athletes had on a battery of tests that included jumping and strength measures.⁷ The test battery included single leg vertical jump, single leg hop for distance, and power testing using a leg press machine. Similar findings have been presented by Dai et al., demonstrating that less than 10% asymmetry exists in countermovement jumping and Y-Balance Test among 500 Division I collegiate athletes.⁸ In the population of collegiate athletes, a consensus on what normal asymmetry exists, including whether the dominant or non-dominant lower limb is stronger, in male and female athletes of different sports is lacking. More specifically, these recommendations should include the strength of isolated muscle groups

of the lower limb rather than just performance tests such as jumping or balance assessments.

Many practitioners and researchers use the limb symmetry index (LSI), a bilateral comparison of a particular variable, as a way to quantify leg strength and power asymmetry of isolated or multiple muscle groups in both healthy athletes and those rehabilitating after injury.^{9,10} The LSI is often used to assess the performance of the quadriceps due to its' biomechanical implications. In soccer, volleyball, and tennis athletes, the quadriceps plays a significant role in executing the cutting and jumping maneuvers that are necessary for successful sport performance.

Testing for leg strength asymmetry is a common practice in sport used to profile athletes. Practitioners often use this information to identify athletes at risk of injury and create interventions to address asymmetries as needed. This type of testing has been well-studied and investigated in populations of both healthy and injured athletes to establish normative values and guidelines for return to sport, but is mostly limited to male athletes.^{4,9,11,12} As it pertains to female athletes, particularly at the collegiate level, literature on leg strength asymmetry is limited and minimal information exists on differences based on sport and lower limb dominance.⁴⁻⁷

The purpose of this pilot study was to explore the amount of lower limb strength asymmetry between the dominant and non-dominant of female collegiate athletes across different sports. The authors hypothesize that greater asymmetry in lower limb strength will exist between the athletes who perform primarily cutting and changing direction movements (soccer and tennis) compared to those who perform jumping movements.

METHODS

STUDY DESIGN

This study used a case control design to investigate the difference in isokinetic knee extensor strength in female cutting and jumping athletes. To do this, athletes were divided into groups based on the lower extremity demands of their sports. Cutting athletes consisted of soccer and tennis athletes, while jumping athletes consisted of volleyball athletes. Case status was designated as dominant stronger vs. dominant not stronger and exposure status was designated as being a jumping athlete vs. a cutting athlete.

PARTICIPANTS

The study recruited a convenience sample of athletes. An athlete was included in the study if they were participating in 20 hours of athletic exposures a week at the time of testing. Athletic exposure was defined as any practice or competition that could result in athletic injury. All participants gave informed consent to participate in the study. The study was approved by the University's Institutional Review Board (IRB #202110917).

PROCEDURES

Data were collected at the University's Department of Intercollegiate Athletics. Testing occurred on one visit prior to the start of the fall season.

MEASURES

Demographic and Anthropomorphic Characteristics: These characteristics were self-reported and included age, height (cm), weight (kg), and dominant (preferred) leg. Body mass index (BMI) was calculated based on height and weight. Dominant leg was determined by asking each participant "which leg do you prefer to kick with?". Determination of the dominant leg is typically done by the observation of the leg chosen for kicking.^{9,13}

Strength: The Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was selected to assess isokinetic strength. Bilateral strength was measured in the form of peak torque at various angular velocities (60 deg/sec, 180 deg/sec, and 300 deg/sec). Researchers selected these velocities to assess muscular performance and strength. Slower angular velocities have been found to produce higher torque outputs, while faster angular velocities have been found to be more representative of power.¹⁴ For this reason, only data obtained from the 60 deg/sec speed were analyzed to represent the measure of strength. The Biodex system has been shown to provide reliable and valid measures of torque, position, and velocity.¹⁵

TESTING

A 10-min warm-up consisting of five minutes on a stationary bike, two minutes of dynamic lower extremity stretching, and three minutes of calisthenics was completed by each participant. Each participant was optimally positioned on the Biodex seat with chest and waist straps applied. The seat was adjusted so that the fulcrum of the dynamometer was positioned along the lateral knee joint. The dynamometer was calibrated prior to each leg being tested. The non-dominant leg was tested first. Participants were allowed up to three practice repetitions at each speed prior to testing. Following warm-up and practice trials, subjects were tested for five repetitions at 60 deg/sec, 10 repetitions at 180 deg/sec, and 15 repetitions at 300 deg/sec. A rest break of 30 seconds was given in between sets. Testing was completed by one physical therapist. Peak torques were produced in foot-pounds (ft-lbs).

STATISTICAL ANALYSIS

Statistical analyses were performed using SAS OnDemand for Academics version 9.4 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics were used to characterize the sample. Student's t-tests were used to compare the characteristics of the cutting and jumping groups. Researchers calculated differences in quadriceps peak torque between the dominant and non-dominant legs for both groups at 60 deg/sec. This slower velocity was selected as it most closely aligns with strength. Peak torque differences were calculated by subtracting the peak torque for the non-dominant leg from that of the dominant leg. A paired t-test was used to compare the dominant and non-dominant quadriceps strength separately for the cutting and jumping athletes. Positive difference values indicated that the dominant leg was stronger, and negative values indicated the inverse. If the dominant leg quadriceps peak torque was greater than 10 ft-lbs more than the non-dominant leg, subjects were classified as "dominant stronger." If the non-dominant leg quadriceps peak torque was greater than 10 ft-lbs more than the dominant leg, subjects were classified as "non-dominant stronger." If the difference between legs was less than 10 ft-lbs, the subject was placed in an "equal" category. A cut-off of 10 ft-lbs was selected due to the distribution of the data as well as the clinical opinion of the research team. The team believed that a difference of 10 ft-lbs was negligible and unlikely to capture a clinically significant strength asymmetry. To examine the association between being a jumping athlete and having a stronger quadriceps muscle on the dominant leg, we calculated odds ratios and 95% confidence intervals to compare "dominant stronger" to "equal or non-dominant stronger."

RESULTS

A total of 43 collegiate female athletes participated in the study. On average, the jumping (volleyball) athletes were taller (180.3cm vs 168.2cm) and weighed more (72.3 kg vs 62.8 kg) than the cutting (soccer/tennis) athletes. Both groups had similar average BMI, between 22.1-22.2 kg/m². All participants in the study reported they were right leg dominant. Descriptive statistics for both groups can be found in [Table 1](#).

Quadriceps strength differences between the dominant and non-dominant legs differed between the two groups. The jumping athletes showed a slightly stronger dominant quadriceps compared to the non-dominant side of 2.5 foot-pounds, but this was not statistically significant ($p = 0.52$). However, in cutting athletes, the non-dominant quadriceps was found to be significantly stronger than the dominant side for a difference of -4.8 foot-pounds ($p = 0.008$). [Table 2](#) demonstrates a comparison of quadriceps strength between the dominant and non-dominant legs in cutting and jumping athletes using a paired t-test.

Using a cut-off value of 10 ft-lbs, differences between the dominant and non-dominant quadriceps were investigated. In jumping athletes, results showed that the participants were distributed almost evenly across the "dominant

Table 1. Comparing the Demographic and Anthropomorphic Characteristics of Jumping to Cutting Athletes

Variable	Jumping Athletes mean (SD) [range] (n = 17)	Cutting Athletes mean (SD) [range] (n = 26)	p-value
Age (years)	19.8 (1.3) [18-22]	19.7 (1.3) [18-23]	p = 0.8
Height (cm)	180.3 (9.0) [162.6-193]	168.2 (6.7) [152.4-185.4]	p < 0.001
Weight (kg)	72.3 (11.8) [52.6-99.8]	62.8 (7.3) [50.8-82.6]	p < 0.01
BMI (kg/m ²)	22.1 (2.3) [19.5-22.8]	22.2 (2.0) [17.5-26.0]	p = 0.95

cm = centimeters; kg = kilograms; SD = Standard Deviation; BMI = Body mass index.

Table 2. Difference in Dominant and Non-Dominant Quadriceps Strength by Sport Group

	Jumping Athletes mean (SD) n = 17	Cutting Athletes mean (SD) n = 26
Dominant Quadriceps Peak Torque 60 deg/sec,	122.81 (28.59)	117.74 (29.11)
Non-dominant Quadriceps Peak Torque 60 deg/sec	120.29 (26.16)	122.57 (25.97)
Difference Dominant – Non-Dominant deg/sec	2.5 (16.0)	-4.8 (8.5)
p-value Paired t-test	p=0.52	p=0.008

Table 3. Proportion of Dominant, Equal or Non-Dominant Stronger by Sport Group

	Jumping Athletes n (%)	Cutting Athletes n (%)	Chi-square p-value
Dominant stronger	6 (35.3%)	0 (0%)	p=0.001
Equal	6 (35.3%)	20 (76.9%)	
Non-dominant stronger	5 (29.4)	6 (23.1%)	
Total	17 (100%)	26 (100%)	

Dominant Stronger=dominant quadriceps more 10 foot-pounds of torque greater than non-dominant quadriceps. Equal= difference between dominant and non-dominant quadriceps less than 10 foot-pounds of torque. Non-dominant stronger= non-dominant quadriceps more 10 foot-pounds of torque greater than dominant quadriceps.

stronger”, “non-dominant stronger”, and “equal” groups. In cutting athletes, 76.9% fell into the “equal” category, while the remaining 23.1% fell into the “non-dominant stronger” category. None of the cutting athletes fell into the “dominant stronger” category. The frequency distribution of quadriceps strength differences between the dominant and non-dominant legs in both groups can be found in [Table 3](#).

Participants were classified as “Dominant Stronger” or “Dominant not Stronger” (equal or non-dominant stronger). Odds ratios examining the association between playing a jumping sport and having a stronger dominant leg were calculated. The odds ratio for having a stronger

dominant quadriceps muscle in jumping athletes was 29.96 (95% confidence interval: 1.56, 577.25). When compared to cutting athletes, jumping athletes were almost 30 times more likely to have their dominant quadriceps stronger than the non-dominant quadriceps. Odds ratios for quadriceps strength in jumping and cutting athletes can be found in [Table 4](#).

DISCUSSION

The results of this study demonstrate that sport-specific participation plays a role in generating a movement/functional asymmetry in quadriceps strength in female athletes.

Table 4. The Association between Sport Type and Having Greater Quadriceps Strength on the Dominant Side

Quadriceps Strength	Jumping Athletes (n = 17)	Cutting Athletes (n = 26)	Odds Ratio	95% CI
60 deg/sec	6 (35.3%)	0 (00.0%)	29.96	1.55, 577.25
Dominant Stronger	11 (64.5%)	26 (100%)		
Dominant Not stronger				

Dominant Stronger=dominant quad more 10 foot-pounds of torque greater than non-dominant quad. Dominant Not Stronger =difference between dominant and non-dominant quad less than 10 foot-pounds of torque or non-dominant quad more 10 foot-pounds of torque greater than dominant quad.

These asymmetries presented differently in the jumping and cutting athletes. Jumping athletes demonstrated a difference between the quadriceps strength of the dominant and non-dominant leg that favored the dominant leg. Results also demonstrated that jumping athletes are 29 times more likely than cutting athletes to have a stronger quadriceps in the dominant leg. Cutting athletes demonstrated a difference between the quadriceps strength of the dominant and non-dominant leg that favored the non-dominant leg. Interestingly, no cutting athletes were placed in the “dominant stronger” category.

In volleyball, vertical jumping is a crucial component of the sport. The athlete must be able to jump frequently and powerfully. In a population of male and female collegiate athletes, researchers discovered that 23% of the variance in jump height during a countermovement jump was explained by knee extension strength.¹⁶ Due to the bilateral nature of this sport, asymmetries and muscle imbalances can be detrimental to performance and increase risk for injury.¹ In the current study, the jumping athletes were distributed almost evenly among the “dominant stronger”, “equal”, and “non-dominant stronger” categories. This finding supports the research by Tillman et al. which demonstrates that there is some variability on which legs are responsible for take-off/landing during volleyball maneuvers. This study reported that most offensive jumps occur off both legs (84%), while almost half of offensive landings occur on one leg (45%) in elite female volleyball players. Unilateral landing in most right-handed athletes tends to occur on their left leg (35%).¹⁷ Considering that most female volleyball athletes tend jump off both legs, it is interesting that in our study an asymmetry strongly favoring the dominant leg was found. A study by Schons et al. investigated the relationship between quadriceps isokinetic strength and jump performance. These researchers were unable to find statistically significant differences between having asymmetry of isokinetic quadriceps strength and jump performance in professional athletes.¹⁸ This indicates that although asymmetry of leg strength may be present in volleyball athletes, jumping performance is not negatively impacted.

The current results showed that most cutting athletes (76.9%) demonstrated a difference of less than 10ft-lbs between the dominant and non-dominant quadriceps. The authors considered a difference of less than 10ft-lbs to be indicative of symmetry between sides. Despite the majority of cutting athletes demonstrating relative symmetry, the non-dominant quadriceps was found to be significantly stronger than the non-dominant quadriceps. This finding

supports the theoretical function of the quadriceps during a cutting maneuver, which requires a stronger quadriceps of the non-dominant side. This is further supported by the fact that none of the cutting athletes fell into the “dominant stronger” category.

Having a stronger non-dominant quadriceps muscle in cutting sports appears to be common based on the biomechanics of the sports. This theory was supported by our findings. Tennis is characterized by a combination of lower extremity acceleration, deceleration, and change in direction.¹⁹ Tennis athletes rely on their ability to effectively move in all directions to execute a variety of backhand and forehand strokes. Studies have shown the forehand stroke to be more powerful and efficient than the backhand stroke.^{19,20} This means the athlete is likely spending more time loading the non-dominant leg to power the forehand stroke. The non-dominant leg is also essential to the kinetic chain to create optimal power and stability during the serve.¹ The non-dominant leg functions to support the body during the initial portions of the serve. Both legs then work to push-off and propel the body into the air, but once again the non-dominant leg supports the body during landing as the athlete will typically land on one leg. Based on the frequency of serves and forehand strokes for most athletes, a need for a stronger non-dominant quadriceps is warranted.

In soccer, the use of both legs for different skills such as kicking, receiving, and cutting is seldomly done symmetrically.²¹ Vertical ground reaction forces in the non-dominant leg during a soccer kick are approximately 2.5-3.0 times body weight, a load considerably larger than that placed on the dominant leg.^{3,22} In a 90-minute soccer game, an athlete will kick the ball an average of 26 times.²¹ This results in a high level of activity from the supporting or non-dominant leg. A study by Brophy et al. investigated the role of leg dominance in non-contact ACL injuries in male and female soccer athletes at the professional, college, and high-school level. Results showed that 67% of non-contact ACL injuries in female soccer athletes occurred in the non-dominant leg.⁹ This is an interesting finding, considering that the current results showed that soccer athletes have a stronger quadriceps in the non-dominant leg than the dominant leg. While it may seem counterintuitive that the stronger non-dominant leg is more predisposed to non-contact ACL injury in female soccer athletes, the reason for this finding could be due to other factors such as poor lateral hip control, poor biomechanics, hamstring weakness, and anterior shear force on the tibia caused by the quadriceps.⁹

Clinically, the findings of this study will allow stakeholders to create optimal injury prevention and rehabilitative programs for female athletes. In the case of post-operative rehabilitation, clinicians can use these normative asymmetry values to create discharge goals that are specific to sport. More specifically, clinicians should work towards athletes having greater quadriceps strength in non-dominant leg if they play cutting sports such as soccer or tennis, or in the dominant leg if the athlete plays a jumping sport, like volleyball. Using these principles may require an athlete to achieve more than 100% of the strength of the non-surgical leg. If pre-injury baseline measures of quadriceps strength in an injured athlete are available, these measures should also be used to guide strength goals. The results of this study can also be applied to create injury prevention and/or strength and conditioning programs for non-injured athletes. For example, cutting athletes can be given specific exercises to promote proper biomechanics during planting or cutting on the non-dominant leg. In contrast, jumping athletes can work on plyometric activities to enhance push-off and landing of the dominant leg during jumping.

Limitations: There are several limitations to this study. To determine whether there was leg strength asymmetry between the dominant and non-dominant legs, a cut point of more than 10ft-lbs was created. This cut point was determined based on the clinical expertise of the research team and the distribution of data. Having a smaller cut point could have impacted the odds ratios that were calculated. Another limitation of this pilot study is sample size. To achieve sufficient statistical power, tennis and soccer athletes were grouped together. The researchers acknowledge that while both type of athletes are required to predominantly execute cutting maneuvers in their sports,

these movements can be quite different. Having more participants in both groups would lead to higher statistical power. Also, only concentric contractions were used to assess strength of the quadriceps in this study. Further studies should also include assessment of leg strength during an eccentric contraction to mimic the function of the quadriceps during sporting activities. Finally, data collection occurred at the pre-season time point. It is possible that more asymmetry between legs would be observed if the data were collected in the post-season.

CONCLUSION

Female collegiate jumping athletes demonstrated a stronger quadriceps on the dominant leg, while female collegiate cutting athletes demonstrated a stronger quadriceps on the non-dominant leg. Jumping athletes are 30 times more likely than cutting athletes to have a stronger quadriceps in the dominant leg. Sports medicine clinicians should consider using this information when assessing injury risk and functional performance in athletes. Furthermore, clinicians can apply these concepts to rehabilitation and return-to-sport planning. The findings of this pilot study are preliminary. Increasing sample size in future studies will help to produce more robust data as it pertains to sport-specific asymmetries of the lower extremity in female athletes of multiple sports.

Submitted: August 27, 2024 CDT. Accepted: April 23, 2025 CDT. Published: June 01, 2025 CDT.

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