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Comparison of Isokinetic Hip Abductor and Adductor Peak Torque and Ratio between Sexes.

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Abstract:	Objective: To evaluate hip abductor and adductor peak torque outputs and compare their ratios between sexes. Design: A cross-sectional laboratory controlled study. Setting: Participants visited a laboratory and performed an isokinetic hip abductor and adductor test. All participants performed two sets of five repetitions of concentric hip abduction and adduction in a standing position at 60°/second. Gravity was determined as a function of joint angle relative to the horizontal plane and was corrected by normalizing the weight of the limb on an individual basis. Participants: A total of 36 collegiate athletes. Independent Variable: Sex (20 females and 16 males). Main Outcome Measures: Bilateral peak hip abductor and adductor torque were measured. The three highest peak torque values were averaged for each subject. Results: Independent t-tests were used to compare sex differences in hip abductor and adductor peak torque, and the abductor: adductor peak torque ratios. Males demonstrated significantly greater hip abductor peak torque compared to females (Males,1.29±0.24 N-m/kg, Females,1.13±0.20 N-m/kg;, p = 0.03). Neither hip adductor peak torque nor their ratios differed between sexes. Conclusion: Sex differences in hip abductor strength were observed. The role of weaker hip abductors in females deserves further attention and may be a factor for higher risk of knee pathologies.

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RE: Revision to Manuscript CJSM-13-7R1

Dear Mr. Hughes,

Please find revised manuscript CJSM-13-7R1 titled "Comparison of Isokinetic Hip Abductor and Adductor Peak Torque and Ratio between Sexes." We would like to thank you and the reviewer for the excellent comments that have influenced a much better presentation for the current manuscript. We sincerely hope that we were able to address their critiques appropriately. Each of our specific **responses** to the reviewer's and ***text edits*** are outlined in the **bold** text below. Also, parts we made changes were highlighted yellow on the manuscript.

Cumulatively, our revisions based on the suggestions provided by the reviewers and editorial staff has significantly strengthened the current revised manuscript. We think that you will agree that the revised manuscript is acceptable for publication.

Thank you again for helping to significantly improve the manuscript for publication. Please do not hesitate to call us directly with any inquiries at (513)-636-3913 or email us at tim.hewett@cchmc.org

Sincerely,

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ABSTRACT

Objective: To evaluate hip abductor and adductor peak torque outputs and compare their ratios between sexes.

Design: A cross-sectional laboratory controlled study.

Setting: Participants visited a laboratory and performed an isokinetic hip abductor and adductor test. All participants performed two sets of five repetitions of concentric hip abduction and adduction in a standing position at 60°/second. Gravity was determined as a function of joint angle relative to the horizontal plane and was corrected by normalizing the weight of the limb on an individual basis.

Participants: A total of 36 collegiate athletes.

Independent Variable: Sex (20 females and 16 males).

Main Outcome Measures: Bilateral peak hip abductor and adductor torque were measured. The three highest peak torque values were averaged for each subject.

Results: Independent t-tests were used to compare sex differences in hip abductor and adductor peak torque, and the abductor: adductor peak torque ratios. Males demonstrated significantly greater hip abductor peak torque compared to females (Males,1.29±0.24 N-m/kg, Females,1.13±0.20 N-m/kg;, $p = 0.03$). Neither hip adductor peak torque nor their ratios differed between sexes.

Conclusion: Sex differences in hip abductor strength were observed. The role of weaker hip abductors in females deserves further attention and may be a factor for higher risk of knee pathologies.

Word count: 205/250

Key terms: gravity, correction, strength training, body position

INTRODUCTION

It has been documented that approximately 100,000 to 250,000 individuals suffer an anterior cruciate ligament (ACL) injury annually in the US alone[1], and females have two to four-fold higher risk to suffer ACL injury compared to the male counterparts in sports of soccer and basketball.[2] In addition to females' higher risk for ACL injuries, they are more likely to develop patellofemoral pain syndrome (PFPS).[3,4] In fact, one retrospective case-control study that analyzed running injuries reported female runners have 1.7 times more PFPS incidents compared to male runners.[4] A common biomechanical risk factor for the both ACL and PFPS was knee abduction motion and torque.[5,6] Via examination of a total of 205 young female athletes, a prospective cohort study concluded that knee abduction moment is a strong predictor for future ACL injury with high sensitivity (78%) and specificity (73%).[5] Similarly, another prospective study that investigated 240 young female athletes found that knee abduction moment is an indicator for future knee PFPS development.[6]

Recent studies have discussed a sex specific influence of the lumbo-pelvic-hip complex,[7] which includes trunk, pelvis and thigh segments, on the knee abduction and lower extremity pathologies. Reviewing previously published studies, Mendeigchia et al. summarized that females tend to have less trunk and hip flexion during dynamic movements compared to males, which may lead to a decreased energy absorption and consequently increased knee and ankle loads.[8] Another study that compared video images of professional female and male basketball players revealed that female athletes who suffered an ACL injury landed with greater lateral trunk flexion and knee abduction angles compared to male basketball players.[9] Similarly, a three year prospective study examining 277 college female and male athletes reported that trunk neuromuscular control deficits, especially lateral trunk flexion, were a predictive variable for future knee ligamentous injuries including ACL injuries for females, but not for males.[10] Finally, a cross-sectional study assessing knee kinematics in a drop landing task found that fatigued hip abductor musculature is associated with elevated knee abduction in females, but not in males.[11]

A few studies investigated the role of hip abductor strength in knee pathologies and found weak hip abductor strength in a PFPS population compared to non-PFPS population.[12, 13] However, little is known about the contribution of the hip adductors, especially in relation to knee abduction (Figure 1). The knee abduction position or "knee valgus" refer to an angle that can be influenced by voluntary motion of hip. As the position of the pelvis changes relative to the distal segments, a lack of adduction muscular control can result in the knee abduction or valgus positions that increase risk of knee injuries including ACL and PFPS in female population. Therefore, hip adductor strength may potentially play a critical role in knee abduction kinematics in dynamic movements. More precisely, the strength ratio between hip abductors and adductors may be an important factor for the determination of injury predisposition since hip abductor strength may be responsible for counterbalancing against the hip adduction strength in dynamic movements. In addition, hip adductor strength may be different between sexes, which may explain the higher rates of knee pathologies in female population compared to the male counterparts because if hip adductor strength differences exist between sexes, it may influence frontal plane knee biomechanics. Specifically, higher hip adductor strength may potentially contribute to excessive knee valgus.

Of interest methodologically, there are various methods to control for gravity correction when assessing hip strength. Specifically, documentation of the methodology for gravity correction has often not been reported. Thus, the primary purpose of the current study was to investigate isokinetic concentric hip abductor and adductor peak torque and abductor:adductor peak torque ratios between sexes. It was hypothesized that sex differences in isokinetic hip abductor and adductor peak torque and abductor:adductor peak torque ratios would be observed. More precisely, females demonstrate higher hip adductor peak torque in relation to hip abductor compared to that of males. The secondary purpose was to demonstrate the importance of gravity correction when assessing hip abduction and hip adduction, and to compare gravity correction methods in the literature.

METHODS

Participants

With institutional review board approval, thirty-six healthy college aged athletes signed an informed consent and voluntarily participated in this study (16 males, age = 20.5±1.6 years: height = 1.89±0.09 m: mass = 86.2±9.9 kg and 20 females, age = 19.4±1.1 years: height =

1.79±0.05 m: mass = 72.3±8.2 kg). Included subjects engaged with sports of volleyball, basketball, baseball, and tennis. The exclusion criteria were: 1) Any previous knee surgery within six months from testing date. 2) Any previous hip surgery that limited full hip abduction and adduction range of motion. 3) Any acute, sub-acute, and chronic hip injury and condition that caused pain and limited full hip abduction and adduction range of motion. 4) Current pregnancy in female subjects. Any subject with hip and pelvic dysfunction that would potentially influence the outcome of the current study were treated as a confounding variable and excluded from this study.

Instrumentation

Isokinetic concentric hip adductor and abductor strength were assessed using the Biodex System 3 Isokinetic dynamometer (Biodex Medical System, Shirley, New York). Gravity correction was performed prior to testing of each subject. Details of the gravity correction were described in last paragraph of the procedure section.

Testing Procedures

Subjects were tested while standing and the testing leg was placed in approximately 5° of hip flexion. The approximately 5° of hip flexion was selected because the gluteus medius functions primarily as a hip abductor when the hip was flexed below 30°. However, once the hip flexion passes greater than 30° flexion, gluteus medius starts acting as a hip internal rotator.[14] Additionally, when the hip was extended more than 15°, the line of pull is changed and it becomes an external rotator.[14] The subject stood facing the dynamometer with the hip joint axis of rotation aligned with the dynamometer axis of rotation at frontal plane. The hip joint axis of rotation was defined as the intersection of an imaginary line directed inferiorly from the anterior superior iliac spine down the midline of the thigh and a second imaginary line medially directed from the greater trochanter of the femur toward the midline of the body. An attachment arm was placed over the middle one-third of the lateral thigh and resistance pad was applied at the same level of the medial thigh. The hip was securely restrained by a supporting strap to stabilize hip and torso movements during testing. Leg testing order was counterbalanced throughout the study.

Procedure

The investigator set the subject's range of motion by assigning 0° of adduction as the position when the hip was in a neutral alignment. The subject was instructed to abduct the hip to approximately 45° of abduction. (Figure 2) At that time, the subject was asked to be relaxed, and the subject's limb was weighed to calculate the gravitational factor. (Figure 2) The tested range of motion was approximately 45° of hip abduction to 0° of hip adduction motion. The subject was tested at 60°/sec for two sets of five repetitions per leg. This particular velocity was utilized because it has been reported that slower velocities can reproduce greater concentric forces in isokinetic testing.[15]

Each subject was given five minutes to warm-up and stretch. The subject was given several pre-trial submaximal repetitions before performing the actual trial. For each trial, subjects were asked to "push in" as hard and fast as possible to the end of the range of motion and then to "pull out" as hard and as fast as possible until they returned back to the hip neutral (starting) position. Subjects initiated testing following a verbal start command from the investigator, and verbal encouragement was given to the subjects throughout the testing session to employ maximal efforts. After one limb was tested, the subject received a few minutes of rest to prevent muscular fatigue of the contralateral hip, as pelvic stabilization during this activity results in bilateral co-contracture of the hip musculature. The same process was repeated with the opposite limb.

The dependent variables were hip abductor and adductor peak torque and hip abductor: adductor peak torque ratio. The independent variable was sex. A difference was not observed between right and left limb so that the bilateral peak torque values were combined to produce a single measure. Three highest peak torque values were obtained from five peak torque repetitions and were extracted for statistical analysis. The hip abductor:adductor peak torque ratio was defined as hip adductor peak toque divided by hip abductor peak torque. The three highest peak torque units were converted from Foot-pound (Ft-lbs) to Newton-meters (N-m), and the values were normalized by mass (kg). Although gravity correction was executed prior to each trial by the Biodex 3 system, potential contribution of upper body gravity, since the testing position was standing, was a concern. Thus, gravity correction was once removed and the data without gravity compensation was obtained (Figure 3). Segmental percents of mass and length of upper leg, lower leg, and foot were referenced from previous studies[16, 17] and applied to each subject's upper leg, lower leg, and foot based on their mass and height. Then, gravity compensation was recalculated solely for the lower extremities (Figure 3). A series of calculations was applied for the above gravity correction procedure (Table 1), and these values were used for statistical analysis.

Statistical Analysis

The concentric abductor and adductor peak torque, and the abductor:adductor peak torque ratios were analyzed by a series of independent t-tests to compare differences between male and female subjects. Alpha level (α) was set at <0.05 prior to the analysis.

RESULTS

Descriptive values [mean and standard deviation (SD)] for the concentric abductor and adductor peak toque, and the abductor:adductor peak torque ratios are displayed in Table 1.

There was a significant difference in hip abductor peak torque between male (1.29±0.24 N-m/kg) and female (1.13±0.20 N-m/kg) athletes. Males produced 0.16 N-m/kg higher concentric abductor peak torque than that of females ($p = 0.03$; Table 2).

In contrast, concentric hip adductor peak torque was not different between sexes ($p = 0.79$; Table 1). The concentric adductor peak torque was 0.75±0.32 (N-m/kg) and 0.72±0.27 (N-m/kg) for male and female. The concentric adductor peak torque difference between male and female athletes was only 0.03 N-m/kg (Table 2). There were no statistical differences in abductor:adductor peak torque ratios between sexes ($p = 0.32$; Table 2). The abductor:adductor peak torque ratios were 0.64±0.21 for male and 0.57±0.18 for female.

DISCUSSION

The primary purpose of this study was to compare isokinetic concentric hip abductor and adductor peak torque and the abductor:adductor peak torque ratios between males and females. The tested hypothesis was that there would be a sex difference in isokinetic concentric hip abductor and adductor peak torque, and abductor:adductor peak torque ratios. A difference in isokinetic concentric hip abductor peak torque was observed between male and female populations. (Table 2) However, no difference in concentric hip adductor peak torque and abductor:adductor peak torque ratios were observed. Therefore, one of the three variables in our hypothesis was supported, but the other two variables within our hypothesis were not supported.

Specific hypothesis was that females show higher hip adductor peak torque relative to hip abductor compared to that of the male counterparts. The hip adductor peak torque did not demonstrate a difference between the sexes; however, since greater hip abductor peak torque was noted in the males compared to the females, the abductor:adductor peak torque ratio demonstrated slight disparity, yet it was not statistically significant. (Table 2) The higher hip adductor peak torque in relation to hip abductor in female population was hypothesized because the imbalanced hip musculature strength may exist in the female population, which may potential link to higher ACL and PFPS rates in female population. However, this study did not find a difference in the hip abductor:adductor peak torque ratio between sexes.

There was no difference in hip adductor peak torque between male and female athletes. Instead, the normalized adductor peak torque values were actually fairly comparable between groups. The abductor:adductor peak torque ratios also did not differ between sexes. Comparing these results to previously published studies, the role of the hip abductor peak torque appears to be critical for distal segments, especially knee joint pathologies and kinematics.[12,13,18-23] For example, several cross-sectional studies identified that females with PFPS had lower hip abductor torque compared to females without PFPS.[12,13,20] Similarly, a laboratory controlled study that measured running kinematics between PFPS patients and uninjured controls found that PFPS patients had significantly lower isometric hip abductor peak torque and exhibited increased hip adduction angles during running, especially toward the end of the running.[21] Another laboratory controlled study demonstrated that knee abduction angles were increased in a running task in subjects with weak isometric hip abductors compared to the subjects who had stronger hip abductors.[23] A study that examined effects of knee kinematics in cutting, jumping, and running maneuvers after hip abductor fatigue protocol reported greater knee abduction angles as well.[22] Furthermore, females with greater eccentric hip abductor torque showed less femur adduction, medial rotation and greater knee adduction excursion compared to male population.[19] Because female’s pelvis is wider compared to their male counterparts, decreased hip abductor peak torque may lead to greater kinematic alteration in female population. In short, the previously published studies reported consistent evidence that decreased hip abductor peak torque may influence knee kinematics, resulting in an increase in knee abduction, especially in the coronal/frontal plane.[21-23] The application of an intervention to strengthen the hip abductors has been recently reported. A series of lumbo-pelvic-hip complex exercises were instituted to young female athletes for eight weeks and resulted in an increase in eccentric hip abductor peak torque, and a decrease in knee abduction angles performing a single leg squat when post-testing was compared to pre-testing values.[18] Therefore, the role of the hip abductors may be important for controlling the knee joint at coronal/frontal plane. Future studies to determine if differences exist between sexes for both strength and kinematics is warranted.

In our study, subjects generated higher isokinetic hip abductor torque (males 1.29±0.24 Nm/kg; females 1.13±0.20 Nm/kg, Table 2) than hip adductor torque (males 0.75±0.32 Nm/kg; females 0.72±0.27 Nm/kg, Table 2). In contrast, previous studies have reported higher isokinetic peak torque values in hip adductors rather than hip abductors.[24-26] For example, Donatelli et al. reported greater adductor values (males 152.6±54.1; females 108.2±24.5) than abductor (males 63.8±17.1; females 42.6±8.2; units were unrecorded, Table 3 and 4).[24] The reported abductor:adductor ratios for male and females were 1: 2.09 and 1: 2.46, which implied that the adductors are 2.09 and 2.46 stronger in males and females relative to abductors. Poulmedis et al. also reported higher isokinetic peak torque values for the hip adductors at three different speeds (160±17 Nm at 30°/sec, 137±24 Nm at 90°/sec, 109±22 Nm at 180°/sec) compared to the hip abductors (119±24 Nm at 30°/sec, 88±19 Nm at 90°/sec, 66±17 Nm at 180°/sec, Table 2 and 3) isometrically.[25] Similarly, isokinetic concentric peak torque values reported by Tippett et al. were higher in the hip adductors in two different speeds bilaterally (stance leg: 104±39.0 ft-lb at 30°/s and 96±38.6 ft-lb at 180°/sec, kicking leg: 107±32.8 ft-lb at 30°/sec and 97±33.4 ft-lb at

180°/sec) compared to the hip abductors (stance leg: 80±26.5 ft-lb at 30°/sec and 48±17.5 ft-lb at 180°/sec, kicking leg: 87±28.8 ft-lb at 30°/sec and 44±18.0 ft-lb at 180°/sec, Table 3 and 4).[26]

One likely reason for this discrepancy in the literature may be the inclusion or exclusion of gravity correction. Our comparison with and without gravity correction found 28% and 32% of differences in hip abductor and adductor peak torque values (Figure 3), and gravity compensation was not documented in the several studies.[24,26-28] In the studies performed by Donatelli et al. and Tippett et al., the side lying position was chosen for assessing hip abductors and adductors strength.[24,26] Since a gravity correction was not employed, the effect of gravity would artificially inflate the hip adduction values and artificially result in a depression of hip abduction values. In fact, our data displays the impact of gravity correction (Figure 2). Hip adductor peak torque showed higher values when gravity effects were not compensated. Conversely, hip abductor peak torque values appeared to be deflated when gravity compensation was not incorporated.

The importance of correction for the influence of gravity has also been identified by several authors.[29-31] Winter et al. reported 26-43% and 55-510% of mechanical work errors associated with gravity in isokinetic knee extension and flexion tests in three different speeds (20°/sec, 40°/sec, and 60°/sec).[31] Using knee flexion as an example, the author explained that if subjects' efforts to engage with the knee flexion were low, gravity significantly assisted the knee flexion motion, which increased the mechanical errors. The author also pointed out that this may account for the greater mechanical work error margins in knee flexion compared to knee extension. Another study performed by Edouard et al. examined 33 healthy volunteers' dominant shoulder internal and external rotations concentrically and found 12-15% and 24-28% peak torque differences in shoulder internal and external rotation with and without gravity correction.[30] Greater influences of gravity were observed on internal and external shoulder rotation ratio calculation, and 39-42% of the ratio differences were documented with and without gravity correction. The author concluded that gravity correction has a significant impact on isokinetic peak torque measurements.

Limitations

Several limitations to this study should be stated. Although absence of gravity correction was suspected as a potential reason of inflated isokinetic peak torque values in the hip adductor muscle group, two studies[20,25] that actually compensated for gravity in the isokinetic testing reported higher isokinetic peak torque values in hip adduction compared to hip abduction. One study that used a side lying position for isokinetic peak torque measurement for eccentric hip abductor and adductor demonstrated higher isokinetic peak torque values in hip adductor (10 adults: 197.4±12.1 Nm/kg at 30°/s, 10 adults with PFPS: 171.0±13.4 Nm/kg at 30°/sec) compared to hip abductor (10 adults: 123.4±5.9 Nm/kg at 30°/s, 10 adults with PFPS: 88.9±10.3 Nm/kg at 30°/sec, Table 3 and 4).[20] Therefore, it is difficult to conclude that the gravity compensation is the only potential cause of higher peak toque values in the hip abductors.

A few studies employed a side-lying position to measure hip abduction peak torque.[12, 13, 15, 20-22] However, the current study chose a standing position in order to measure hip abductor and adductor peak torque simultaneously. Application of gravity correction for the standing testing position for hip abductors potentially involves upper body segments. As it was explained above, gravity correction gives a substantial influence on the torque values. Thus, although there is no gold standard for hip peak torque measurement, testing position and gravity correction method might have influenced the current results.

When the tested leg was transitioning from abduction to adduction directions, the torque values demonstrated counter directional values. (Figure 3) It was suspected that when the attachment arm, which was securely placed over the middle one-third of the lateral thigh, hit pre-programed hip abduction range of motion (approximately 45°), the force transition was not smooth, which in turn, generated counter directional values prior to actual transition to hip adduction direction. However, peak torque values of hip abductor and adductor were used for the data reduction; thus, it does not alter results of this study.

Both hip abductor and adductor peak torque were measured concentrically. From the suggested ACL and PFPS mechanisms, measuring eccentric hip abductor peak torque would have been ideal. Recently published studies[15, 18-20] measured eccentric hip abductor peak torque, which may be more applicable from functional stand point. Also, due to the concentric contraction, slight hip internal rotation might have contributed to the peak torque values although hip and distal thigh were securely stabilized. Additionally, since we eliminated subjects with previous hip surgery and any acute, sub-acute, and chronic hip injury, this study results are only applicable for athletic population without low back dysfunction. Those limitations are warranted for future studies.

CONCLUSION

In summary, the current cross-sectional study demonstrated reduced isokinetic concentric hip abductor peak torque in college aged females compared to college aged males. Another finding from the current project, which is contradictory to previous studies, is higher peak torque values in hip abduction compared to hip adduction values in both male and female subjects. Possible explanations for this finding is a status of gravity correction. Absence of gravity correction may result in inflated adductor and decreased abductor peak values and is important to consider when reviewing studies that did employ a gravity correction procedure. For future isokinetic research, implementation of gravity correction is warranted for accurate isokinetic hip abductor and adductor measurements.

Word count: 3377/3000

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A LIST OF FIGURE CAPTIONS

Figure 1. Knee abduction in the frontal plane (Left knee).

Figure 2. Positioning for standing hip abduction and adduction testing.

Figure 3. Example of a torque of five repetitions of hip abduction and adduction motions at 60°/sec.

A LIST OF TABLE

<u>Requests from Editorial Chief</u>:

1. Title Page: Fellowship information is not to be included as part of the academic and/or clinical degree information in the author list. Fellowship information can and should be included as part of the degree information provided for the corresponding author. This was revised on behalf of the authors by the Editorial office.

Affiliations of all authors including fellowship site of primary author were incorporated. Thank you for your input.

2. Figures: Figures should not be uploaded as part of the manuscript (i.e., they should not appear in the body of the text portion nor as an attachment at the end of the manuscript), nor should the figures be uploaded as an individual "Figure" document, i.e., all figures saved in one document. The 3 figures included as part of your submission were uploaded as individual "Figure" items to the Editorial Manager system by the Editorial office.

Each figure will be removed from body of the manuscript and will be uploaded separately during the submission process.

3. Figure Captions: Figure captions should only be set out on the Figure Captions page that is inserted following the References section and not on the figures themselves. This was amended by the Editorial office.

"A LIST OF FIGURE CAPTIONS" was added following reference section. Thank you for identifying an error.

4. Copyright Transfer Agreement Form: Thank you for providing a revised, corrected Copyright Transfer Agreement form for author Palmer. Please note, however, that the Copyright Transfer Agreement forms for the remaining authors were not carried forward from the previous version of the submission. This was attended to by the Editorial office for this revision; however, please ensure all items to be included with the submission are carried over in the next revision.

All authors' signed Copyright Transfer Agreement Form will be uploaded with this submission.

5. Upload Order: Please note the order in which items are to be uploaded to the Editorial Manager system. This information is set out in the text box on the page where files are added. The upload order was revised by the Editorial office for this revision; however, please ensure the proper upload order is adhered to when preparing your revised submission.

We will upload our documents, figures, and tables in organized manner.

<u>Requests from Reviewer</u>:

I have just a few additional issues for you to consider:

Regarding the previous review comments item #3:

Reviewer's comments:

Line 137-140: Potential study limitation - No exclusion of past year of pelvic dysfunction / pain or low back dysfunction / pain (mechanical as well as neurological connection to the abductor and adductor muscles) as these factors could influence the participants muscle strength.

Author's response:

The term "low back dysfunction" was not specifically used; however, subjects with chronic pelvic dysfunction and pain that would potentially influence the outcome of the current study were treated as a confounding variable and excluded from this study. (Line 138-139)

Reviewer's new comments regarding this issue:

Thank you for clarifying. I have two further points:

1. Presently the revised lines read:

138 and adduction range of motion. 3) Any acute, sub-acute, and chronic hip injury and condition

139 that caused pain and limited full hip abduction and adduction range of motion.

There is no mention of chronic pelvic dysfunction and pain that would potentially influence the outcome of the current study were treated as a confounding variable and excluded from this study. This should be somehow reported.

The statement was incorporated at the end of the participants' description. Thank you for your input (Page 6, line 144 – 146). The texts now read to:

"Any subject with hip and pelvic dysfunction that would potentially influence the outcome of the current study were treated as a confounding variable and excluded from this study."

2. Not including low back dysfunction as a confounding variable is a potential study limitation and should be discussed, i.e., L2-S1 spinal levels nerve roots directly innervate the hip region (skin, ligaments, muscles, etc.) thereby affecting muscle recruitment and thereby strength of adductors and abductors as well as other hip muscles. These muscles also attach from the back to the femur and beyond and by this way also further affect leg alignment.

One sentence was inserted in the limitation (Line 333 – 336). The texts now read to:

"Additionally, since we eliminated subjects with previous hip surgery and any acute, sub-acute, and chronic hip injury, this study results are only applicable for athletic population without low back dysfunction."

3. Additionally: Table 3 and 4 still have formatting issues that should be addressed.

The format of the table 3 and 4 will be modified based on editorial office's request.

Figure 1. Knee abduction in the frontal plane (Left knee).

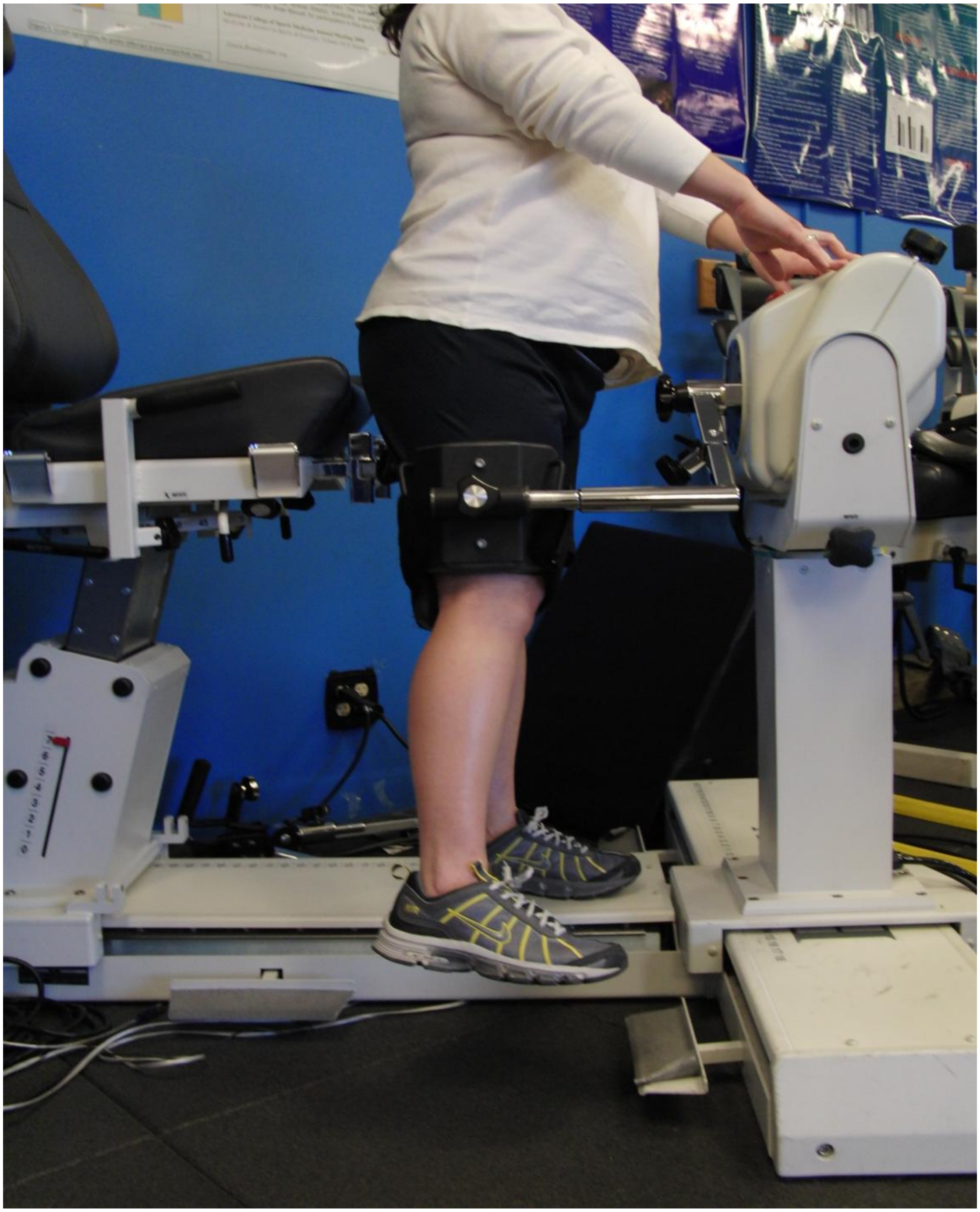

Figure 2. Positioning for standing hip abduction and adduction testing.

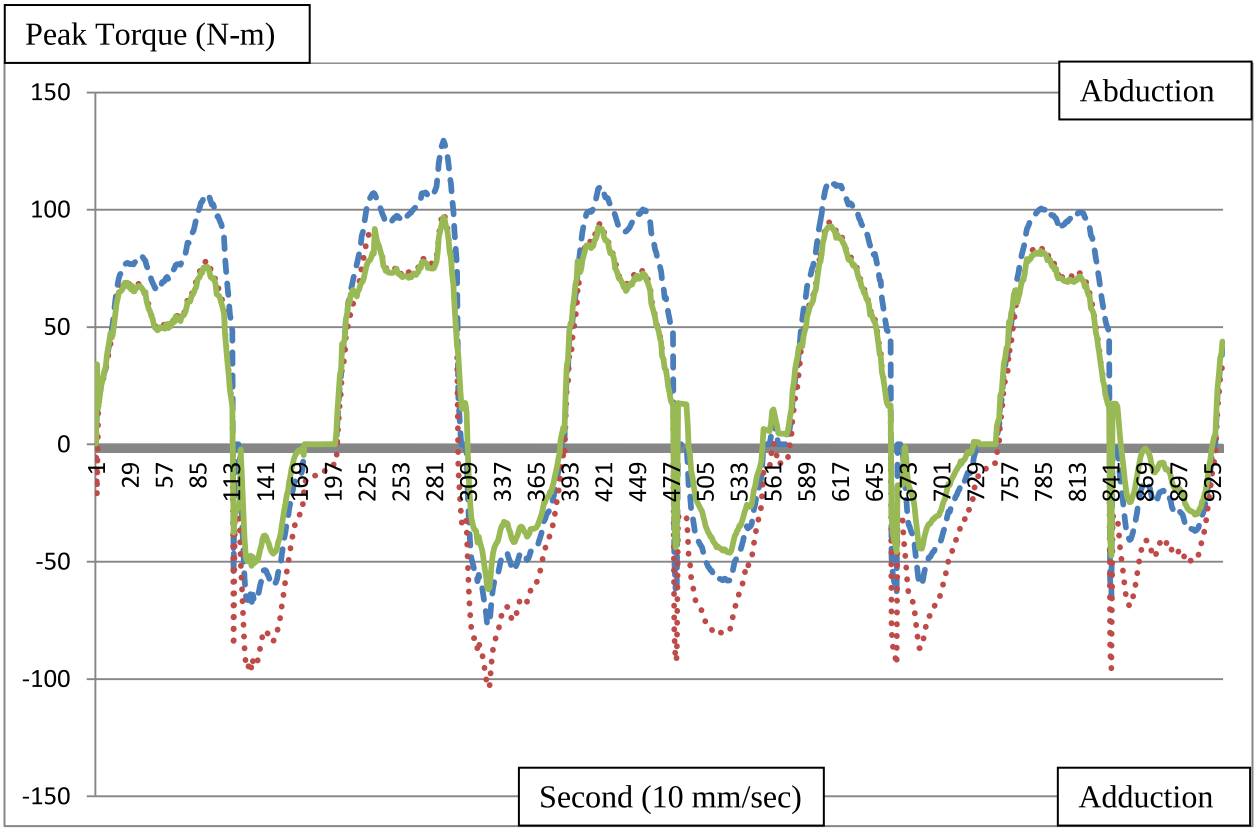

Figure 3. Example of a torque of five repetitions of hip abduction and adduction motions at 60°/sec. The blue dot line indicates an original torque with gravity correction from the Biodex. The red dash line displays a torque when gravity was removed from the Biodex. The green solid line illustrates a torque with gravity correction based on recalculation of lower extremities.

Table 1. A series of equations were applied to calculate the gravity correction.

Equations	Equation content	Purpose
Equation 1	Gravity compensated by the Biodex / Sin (radian(starting position) - 90°)	Gravity removal from the Biodex machine
Equation 2	-Cos (radian (moving angles)) x Sin	Adjustment of gravity direction with hip abduction and adduction motions for equation 5
Equation 3	Subject’s mass x Relative mass (Upper leg, Shank, and Foot)	Calculation for the application of equation 5
Equation 4	Subject’s upper leg length x Relative length (Shank and Foot)	Calculation for the application of equation 5
Equation 5	(Upper leg + Shank + Foot) x Sin + (Equation 2) x (Gravity compensated by the Biodex / Radian (starting position / 90°))	Gravity adjustment with calculated body segments throughout performed ROM

For equation 3 and 4, references[22, 29] were used for the relative mass and length calculations.

Table 2. Mean (± SD) Peak Torque of Hip Abductor, Adductor, and Abductor : Adductor Peak Torque Ratios for 36 subjects (20 females and 16 males).

Isokinetic Strength	Male	Female	Significance (p-value)
Abductor Peak Torque (N-m/kg)	1.29 ± 0.24	1.13 ± 0.20	0.03*
Adductor Peak Torque (N-m/kg)	0.75 ± 0.32	0.72 ± 0.27	0.79
Abductor : Adductor Peak Torque Ratios	0.64 ± 0.21	0.57 ± 0.18	0.32

*Significant $P < .05$

Table 3. Comparisons of isokinetic peak torque of the hip abductor at varying velocities and several previous studies.

Study	Subjects	Units		Abduction		
			30°/sec	60°/sec	90°/sec	180°/sec
Poulmedis et al.	18 males	Nm	119±24		88±19	66±17
Tippett et al.*	16 males Stance leg	Nm	109±35.9			65±23.7
	16 males Kicking leg	Nm	118±39.1			60±24.4
Cahalan et al.*	18 younger males	Nm	103±26		79±20	
	21 younger females	Nm	66±19		54±20	
	17	Nm	75±18		63±19	

	elderly males				
	16 elderly females	Nm	48±14		38±13
Donatelli et al.*	28 males	-**		63.8±17.1	
	56 females	-**		42.6±8.2	
Johnson et al.*	38 young	Nm		96.4±18.8	
	38 elderly	Nm		53.6±16.2	
Baldon et al.***	10 adults	Nm/kg	123.4±5.9		
	10 adults with PFPS	Nm/kg	88.9±10.3		

Values were expressed with mean ± SD. PFPS stands for patellofemoral pain syndrome.

*No gravity compensation stated.

**No units stated.

***The vales were multiplied by 100 in the original study.

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