Published in final edited form as:

J Orthop Sports Phys Ther. 2018 April ; 48(4): 270–279. doi:10.2519/jospt.2018.7794.

Kinematic Differences During Single-Leg Step-Down Between Individuals With Femoroacetabular Impingement Syndrome and Individuals Without Hip Pain

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Abstract

STUDY DESIGN: Controlled laboratory study, case-control design.

BACKGROUND: Despite recognition that femoroacetabular impingement syndrome (FAIS) is a movement-related disorder, few studies have examined dynamic unilateral tasks in individuals with FAIS.

OBJECTIVES: To determine whether movements of the pelvis and lower extremities in individuals with FAIS differ from those in individuals without hip pain during a single-leg step-down, and to analyze kinematic differences between male and female participants within groups.

METHODS: Individuals with FAIS and individuals without hip pain performed a single-leg step-down while kinematic data were collected. Kinematics were evaluated at 60° of knee flexion. A linear regression analysis assessed the main effects of group, sex, and side, and the interaction of sex by group.

RESULTS: Twenty individuals with FAIS and 40 individuals without hip pain participated. Individuals with FAIS performed the step-down with greater hip flexion (4.9°; 95% confidence interval [CI]: 0.5°, 9.2°) and anterior pelvic tilt (4.1°; 95% CI: 0.9°, 7.3°) than individuals without hip pain. Across groups, female participants performed the task with more hip flexion (6.1°; 95% CI: 1.7°, 10.4°), hip adduction (4.8°; 95% CI: 2.2°, 7.4°), anterior pelvic tilt (5.8°; 95% CI: 2.6°, 9.0°), pelvic drop (1.4° 95% CI: 0.3°, 2.5°), and thigh adduction (2.7°; 95% CI: 1.3°, 4.2°) than male participants.

CONCLUSION: The results of this study suggest that individuals with FAIS have alterations in pelvic motion during a dynamic unilateral task. The noted altered movement patterns in the FAIS group may contribute to the development of hip pain and may be due to impairments that are modifiable through rehabilitation.

Keywords

FAIS; hip pain; impingement; step-down

Femoroacetabular impingement syndrome (FAIS) classifies individuals presenting with hip pain that, in combination with structural hip morphology, is thought to contribute to premature contact between the proximal femur and acetabulum.²² The abnormal morphology can either be of the femur (cam) or the acetabulum (pincer). When cam and pincer morphology coexist, the term *mixed* morphology is used. Impingement may occur during hip flexion alone or when combined with adduction and internal rotation, potentially leading to acetabular labral and chondral damage.^{20,30} Cam morphology has been linked to an increased risk for the development of hip osteoarthritis.^{2,54} The risk with pincer morphology, however, is still debated, with recent studies reporting no elevated risk of osteoarthritis.^{3,54}

Despite agreement that FAIS is a “motion-related” disorder,²² research on FAIS has primarily focused on the differences in bony morphology, with less attention given to altered movement in the presence of cam or pincer morphology and no attention given to the interaction between the type of morphology and the altered movement. The few published gait studies in individuals with FAIS have reported inconsistent results at the hip and pelvis. These results vary from no difference in kinematics³⁷ to decreased hip excursion in the sagittal plane^{15,35,53} and frontal plane^{35,53} in individuals with FAIS compared to individuals without hip pain. The decreased sagittal plane excursion may be from decreased hip extension²⁹ or decreased hip flexion.⁵³ The decreased frontal plane excursion likely is from decreased hip abduction,^{27,35,53} although 1 study reported decreased hip adduction.²⁹ It is unclear why these alterations during gait occur, as they would not affect theorized positions of impingement. Deep bilateral squat is a more demanding task than walking, yet with this movement, the only findings have been increased hip adduction,³⁷ decreased sagittal plane pelvic excursion,³⁹ and decreased posterior pelvic tilt.⁶ The limited differences between individuals with FAIS and individuals without hip pain suggest that these tasks may not be sufficiently challenging for detecting altered movement at the hip.

Dynamic unilateral activities that challenge the neuromuscular control of the hip in multiple planes of motion may be more appropriate for detecting deficits than bilateral tasks.⁴⁴ Stair climbing has been reported in 2 studies, with mixed results. Hammond et al²⁴ noted that individuals with FAIS ascended stairs more slowly and displayed more trunk flexion (measured relative to the pelvis) than individuals without FAIS. In contrast to the findings of no differences in hip motion by Hammond et al,²⁴ Rylander et al⁵³ reported reduced sagittal plane hip motion, primarily due to reduced extension, and reduced peak hip internal rotation in individuals with FAIS compared to healthy individuals. Additionally, they found increased transverse plane pelvic motion and increased peak anterior pelvic tilt in individuals with FAIS, and these alterations remained following arthroscopic osteochondroplasty to address hip morphology,⁵³ indicating that correcting the hip morphology was insufficient to normalize the movement pattern. These findings also highlight the importance of evaluating more challenging unilateral tasks than level walking.

A confounding factor to consider when evaluating movement is the substantial evidence of sex-specific movement-pattern differences during unilateral tasks such as single-leg landing,^{31,57} single-leg squat,^{21,46,61,63} and single-leg step-down.¹⁷ For example, during the single-leg step-down task, Earl et al¹⁷ noted that females performed the task with more hip

adduction and knee abduction than males. Given these noted movement-pattern differences in healthy individuals, it is important to assess sex-specific movement patterns when evaluating unilateral tasks in a patient population, such as those with FAIS, to determine a potential interaction between the condition and sex.

The purpose of this study was to determine whether pelvic and lower extremity movement patterns in individuals with FAIS are different from those in individuals without hip pain during a single-leg step-down task. The secondary purpose was to analyze differences in the kinematics between male and female participants in both the FAIS and comparison groups during this task. We hypothesized that individuals with FAIS would have different pelvic and hip movement patterns from those in individuals without hip pain, and that these differences would be sex specific.

METHODS

Participants

INDIVIDUALS WITH FAIS WERE RECRUITED through area orthopaedic and rehabilitation clinics between January 2011 and December 2016. To be included in the FAIS group, individuals needed to have been diagnosed with unilateral or bilateral cam, pincer, or mixed morphology by a physician based on clinical presentation, physical examination, and imaging. Additionally, individuals had to report having pain for longer than 2 weeks and had to have their hip pain reproduced with at least 1 of 3 provocative tests: (1) flexion, adduction, internal rotation (FADIR) test; (2) flexion, abduction, external rotation (FABER) test; and (3) resisted straight leg raise (SLR). For the FADIR test, which is also called the anterior impingement test, the hip was passively flexed to 90° and then adducted and internally rotated.²⁰ For the FABER test, the hip was passively positioned in flexion, abduction, and external rotation, with the foot of the tested leg on top of the contralateral knee.⁶⁰ For the resisted SLR, the leg was passively positioned in 30° of hip flexion, with the knee extended.⁴³ The participant was then asked to keep the leg in that position without assistance and to continue to hold the position as resistance was applied at the distal leg. Each test was considered positive when the test reproduced the individual's pain. These 3 tests are sensitive for intra-articular hip pathology.^{43,50}

Individuals in the comparison group were recruited through flyers, postings, and word of mouth. Exclusion criteria included current or recent (within the last 2 months) lower extremity injury, history of substantial lower extremity injury/surgery, and history of hip pain. Additionally, potential participants in the comparison group were excluded if they reported any hip or groin pain during any of the provocative tests (FADIR, FABER, and resisted SLR) or during any of the movement tasks. Although we did not assess morphology in these individuals, the absence of pain during the provocative tests or movement tasks eliminates the diagnosis of FAIS, even in the presence of cam or pincer morphology.

General inclusion criteria for both groups included being between 14 and 50 years of age and being able to walk safely for 10 minutes without assistance. Exclusion criteria for both groups included history of neurological disorder, history of lower extremity or back surgery, or current back, knee, or ankle pain.

The study was approved by the Institutional Review Boards of Boston University and Boston Children's Hospital, and all individuals provided written informed consent prior to participation.

Instrumentation

Three-dimensional kinematic data of the trunk, pelvis, and lower extremities were collected using a 10-camera motion-capture system (Vicon; Oxford Metrics plc, Oxford, UK) sampling at 100 Hz. Forty-two spherical, retroreflective markers (14-mm diameter) were placed over bony landmarks on the trunk and pelvis and bilaterally on the lower extremities as previously described.⁴¹ Plastic shells that contained 4 noncollinear markers each were positioned laterally over the thighs and shanks and attached via neoprene wraps and hook-and-loop fasteners.¹⁰

Questionnaires

Participants completed self-report questionnaires consisting of the University of California at Los Angeles (UCLA) activity score,⁴ the modified Harris Hip Score (mHHS),⁹ and the Hip disability and Osteoarthritis Outcome Score (HOOS).³⁶ The mHHS scores can be interpreted as 90 to 100, excellent; 80 to 89, good; 70 to 79, fair; and below 70, poor.³⁶ The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) was scored from the HOOS, which contains all the WOMAC questions.⁴⁷ While the mHHS and the HOOS activities of daily living (ADL) subscale do have ceiling effects when used in this patient population,³⁴ they are both reliable and have acceptable construct validity.³⁴ Additionally, these self-report measures have been used extensively in the FAIS literature.^{24,25,29,35,38,39,55,56}

Experimental Protocol

Participants wore a tight-fitting shirt, spandex shorts, and their own comfortable exercise shoes. After placing the reflective markers on the participant, participants performed a static standing trial in a neutral posture. For this trial, the participant stood upright facing straight forward, with feet shoulder-width apart and shoulders in approximately 90° of abduction. A model that included joint centers for the hips and knees was created using this trial. The medial ankle and knee markers were removed after the static trial so that they did not affect the movement.

Movement Analysis

Participants were instructed to stand with both feet on a 16-cm box, with their arms by their sides. They were asked to shift their weight onto 1 limb and hold their nonstance limb out in front of the box, then to lower themselves in a controlled manner until the heel of the nonstance limb contacted the floor, then to return to the starting position. A metronome at 60 beats per minute was used to help standardize movement speed. Participants were instructed to move "down on a beat and up on a beat." While participants were given feedback if moving too slowly or too quickly, strict adherence to the metronome was not enforced. The step-down task was demonstrated and participants had an opportunity to practice prior to data collection. Five trials were collected of individual repetitions on each side. If the

participant experienced a loss of balance during a trial, as indicated by substantial arm, trunk, or leg movement, contacting the ground with the nonstance leg in an uncontrolled manner, or performing the task with a jerky, noncontinuous motion, then the trial was not included in the analysis. Following each individual repetition of the task, all participants rated any pain they had in the hip or groin region on an 11-point numeric rating scale, with 0 being no pain and 10 being the worst imaginable pain.¹⁶

Data Processing

Marker trajectories were low-pass filtered using a 6-Hz, fourth-order Butterworth filter.⁵¹ Commercially available software (Visual3D; C-Motion, Inc, Germantown, MD) calculated the joint kinematics from the marker trajectories using an 8-segment hybrid model. Instead of using the Visual3D pelvis, the CODA pelvis¹² model was used to define the pelvis,⁸ as palpation of the anterior superior iliac spine and posterior superior iliac spine was possible in this non-obese population. Pelvic, thigh, and shank segment angles were determined with respect to the global coordinate system. Knee and hip joint angles were defined as the angle between the distal segment and the proximal segment using a Cardan *x-y-z* (mediolateral, anteroposterior, vertical) rotation sequence.¹³

Hip and knee joint angles and pelvic, thigh, and shank segment angles in the sagittal and frontal planes were extracted at 60° of knee flexion during the descent phase for each trial and averaged for each participant to produce the dependent variables. As 60° of knee flexion has been proposed as the depth criterion for a “good” single-leg squat,¹⁴ we selected this same angle for our point of analysis. We have previously demonstrated that adjusting step height based on the individual’s leg length or height is not required when analyzing data at the same knee angle for all individuals.⁴¹

Statistical Analysis

A sample-size calculation was performed for group differences in hip flexion angle based on preliminary data from our laboratory, which suggested a group difference of 9° and standard deviation of 9° during a step-down task. The calculation indicated that for statistical power of 0.80 and an alpha of .05 for the primary aim a minimum of 16 participants per group were needed.

Group composition was assessed using chi-square tests for categorical variables, independent-samples *t* tests for continuous variables, and Mann-Whitney *U* tests for ordinal variables to ensure that groups did not differ in terms of sex, age, body mass index, or activity level. We used linear regression analysis with 2 between-subject factors (group, sex) and 1 within-subject factor (side). For FAIS participants, the more painful side was defined as the side that the participant stated had worse symptoms. The contralateral side was then considered the less painful side, whether symptoms were bilateral or unilateral. For participants without hip pain, the more painful side was randomly assigned. As each side was included in the analysis, a generalized estimating equation (GEE) correction was applied to the model. The GEE approach is similar to the more commonly used repeated-measures analysis of variance, but has higher power and is more robust.⁴² We analyzed the main effects of group (FAIS versus comparison), sex, and side, a 2-way interaction of sex by

group, and a 3-way interaction of sex by group by side. A separate GEE was performed for each variable of interest. Least-significant-difference pairwise comparisons were performed if a significant effect was found. All analyses were run in IBM SPSS Statistics Version 20 (IBM Corporation, Armonk, NY), and an alpha level of .05 was used for all comparisons.

RESULTS

TWENTY INDIVIDUALS WITH FAIS AND 40 individuals without hip pain participated in the study (TABLE 1). The groups were not different in terms of sex, age, height, mass, body mass index, or UCLA activity score. The majority of the individuals with FAIS had cam morphology (80%; 10 of 11 males and 6 of 9 females), with 10% having pincer morphology (2 females) and 10% having mixed morphology (1 male and 1 female). Nine individuals had been diagnosed with FAIS bilaterally. Three individuals had FAIS on the right only, and 8 on the left only. Ninety-five percent of individuals with FAIS had a positive FADIR test (TABLE 2).

Individuals with FAIS scored lower on the mHHS, all subscales of the HOOS, and the WOMAC (TABLE 3) than individuals without hip pain. While the average mHHS score for the FAIS group for the more painful side was in the fair category,⁹ there was a wide range (34.1-95.7) of scores. Of the 19 participants with FAIS with an mHHS score, 3 had excellent, 7 good, 1 fair, and 8 poor (a score of below 70) function and pain ratings. During the step-down task, the average $\pm$ SD pain rating for the FAIS group was 1.7 ± 1.9 (range, 0-6.3) on the more painful side and 0.5 ± 1.0 (range, 0-4) on the less painful side.

Individuals in our study participated in a variety of sporting activities. Seventeen of the 20 individuals with FAIS reported participating in competitive sports in the past 12 months. The level of participation ranged from recreational to elite. Running and soccer were the 2 most frequently reported activities. Other activities included baseball, basketball, CrossFit, cycling, ice hockey, lacrosse, military service, rowing, rock climbing, rugby, skiing, softball, tennis, ultimate, volleyball, and yoga. Of the 40 individuals without hip pain, information about participation in competitive sports was available for 25 individuals. Ten of these 25 individuals in the comparison group reported participating in competitive sports at the recreational to college levels in the past 12 months. Running was the most commonly reported activity. Individuals also participated in the following sports: basketball, broomball, cycling, gymnastics, skiing, soccer, softball, tennis, track, triathlon, and weightlifting. Despite the differences in the proportions of individuals participating in competitive sports, the UCLA activity score, which was available for 19 of 20 individuals in the FAIS group and all 40 individuals in the comparison group, was not different between groups ($U = 376$, $P = .95$), and 58% of individuals in each group participated in impact sports either sometimes or regularly.

Group Comparison

The 3-way interaction of sex by group by side was significant for knee abduction angle (Wald $\chi^2 = 8.65$, $P = .034$) (TABLE 4). However, none of the follow-up comparisons between males and females within the FAIS group ($P = .098$), between groups within males ($P = .111$), or between groups within females ($P = .052$) were significant. No other significant

3-way interactions were found. No significant effects of side were detected for any variable, and therefore the following data represent the average of the 2 sides.

No significant interactions of sex by group were detected for any of the analyzed variables. Individuals with FAIS performed the step-down task with greater hip flexion (FIGURE 1) (Wald $X^2 = 4.85$, $P = .028$) and anterior pelvic tilt (FIGURE 2) (Wald $X^2 = 6.35$, $P = .012$) than individuals without hip pain (TABLE 4). At 60° of knee flexion, pairwise comparisons indicated that individuals with FAIS were in 4.9° (95% confidence interval [CI]: 5°, 9.2°) more hip flexion ($P = .028$) and 4.1° (95% CI: 0.9°, 7.3°) more anterior pelvic tilt ($P = .012$) than individuals without hip pain.

Sex Comparison

Females performed the step-down task with different hip flexion (Wald $X^2 = 7.52$, $P = .006$) and adduction (Wald $X^2 = 13.06$, $P < .001$), pelvic anterior tilt (Wald $X^2 = 12.60$, $P < .001$) and drop (Wald $X^2 = 6.32$, $P = .012$), and thigh adduction (Wald $X^2 = 13.25$, $P < .001$) from those of males (FIGURES 1 and 2). At 60° of knee flexion, pairwise comparisons indicated that females were in 6.1° (95% CI: 1.7°, 10.4°) more hip flexion ($P = .006$) and 4.8° (95% CI: 2.2°, 7.4°) more hip adduction ($P < .001$) than males. Females were also in 5.8° (95% CI: 2.6°, 9.0°) more anterior pelvic tilt ($P < .001$), 1.4° (95% CI: 0.3°, 2.5°) more pelvic drop ($P = .012$) to the nonstance side, and 2.7° (95% CI: 1.3°, 4.2°) more thigh adduction ($P < .001$) than males.

DISCUSSION

THE RESULTS OF THIS STUDY INDICATE that individuals with FAIS have different pelvic and lower extremity movement patterns during a single-leg step-down task than individuals without hip pain. While it is commonly believed that individuals with cam or pincer morphology would avoid motions contributing to impingement (ie, hip flexion), individuals with FAIS in this study demonstrated increased hip flexion. This increased hip flexion was primarily due to increased anterior pelvic tilt, as there was no difference in segmental thigh angle. The movement-pattern difference may be due to altered neuromuscular control and/or decreased hip strength, although there is no strong evidence of hip extensor weakness in this population.¹⁹ Altered neuromuscular control and strength are both impairments that are modifiable through rehabilitation.^{48,62}

Our finding of increased anterior pelvic tilt in individuals with FAIS is consistent with results of other studies. Rylander et al⁵³ noted increased peak anterior pelvic tilt during stair climbing in individuals with FAIS. During the bilateral deep squat, Lamontagne et al³⁹ reported decreased pelvic tilt excursion in individuals with FAIS compared to individuals without hip pain, and Bagwell et al⁶ noted decreased posterior pelvic tilt motion, resulting in 10.9° more anterior pelvic tilt at peak hip flexion. Similarly, Azevedo et al⁵ found decreased posterior pelvic tilt during active unilateral hip flexion in standing in individuals with FAIS compared to individuals without hip pain and individuals with other symptomatic hip conditions. However, in contrast to our results, none of these studies found differences in hip flexion angle. This could be due to differences in task or analysis point. In our study, a single-limb controlled-descent task may challenge the hip more than a bilateral task.^{17,44}

Additionally, in our study, as the step-down was performed from a single height (16 cm), the task had a predetermined end point and the analysis was conducted for a standard 60° knee flexion angle. This is in contrast to the bilateral squat used in other studies, where individuals without pain achieved a lower squat depth than individuals with FAIS.^{6,39}

Increased anterior pelvic tilt may contribute to the development of pain in the presence of cam or pincer morphology. A modeling study by Ross et al⁵² demonstrated that increased anterior pelvic tilt leads to simulated bony contact earlier in the flexion motion than when in a neutral pelvis position. Similarly, increased posterior pelvic tilt led to later simulated bony contact. The simulation study suggests that addressing increased anterior pelvic tilt could reduce impingement in individuals with the bony morphology of FAIS.

Sex Differences

Our data indicate that both females with FAIS and females without hip pain performed the step-down task with more hip flexion and hip adduction than males. The increased hip flexion was primarily due to increased anterior pelvic tilt, while the increased hip adduction was due to both increased pelvic drop and increased thigh adduction. Similar sex-specific differences in movement patterns during a single-leg step-down task were reported in a study by Earl et al,¹⁷ which found that females performed the task with greater hip adduction and knee abduction than males.

The sagittal plane sex differences, while present in both groups, were more pronounced in the FAIS group than in the comparison group, despite the interaction not being statistically significant. The difference between males and females in hip flexion was 9.3° in the FAIS group and only 2.9° in the comparison group. At the pelvis, the sex difference in the FAIS group was 7.8°, while the difference in the comparison group was 3.8°. This is in addition to the sex difference in the thigh segment of 1.8° in the FAIS group and -1.1° in the comparison group. This finding indicates that females with FAIS may have slightly different movement patterns than males with FAIS. This may also indicate that the females with FAIS were the primary contributors to the group differences detected.

The relationship between sex, type of FAIS morphology, and movement pattern is unknown. It was once thought that pincer morphology was more common in females and that cam morphology was more common in males.⁴⁹ The majority of our FAIS participants, however, had cam morphology, with only 2 females having isolated pincer morphology. This is more consistent with a recent multicenter study, which indicated that cam was the predominant morphology in both sexes.¹¹ Given our participant distribution, we were unable to test the interactions between sex, type of morphology, and movement pattern. We did, however, perform an analysis including only individuals with cam FAIS compared to individuals without hip pain. Although not powered to adequately investigate the question, this analysis indicated that at 60° of knee flexion during the step-down, females with cam FAIS were in more hip flexion and anterior pelvic tilt compared to males with cam FAIS and compared to males or females without hip pain. This preliminary finding highlights potential sex-specific movement-pattern differences within a single type of FAIS.

While sex-specific differences have not been assessed in movement studies of individuals with FAIS, they have been noted in other aspects of the syndrome.²³ Females have poorer presurgical self-reported function than males.³² Females with FAIS have smaller or less severe cam lesions than males with FAIS.^{7,26} This finding led Hetsroni et al²⁶ to comment, “In women, cam lesions may be more subtle.” In contrast, our findings suggest that the increased hip flexion in females with cam FAIS, combined with the increased hip adduction common to all females, may cause a smaller cam to be more symptomatic than in males with cam FAIS. These findings highlight the importance of conducting sex-specific analyses when investigating movement patterns in individuals with FAIS.

For the main effects of both group and sex, the differences at the hip, combined with the lack of differences at the knee, suggest that motion of the pelvis is the primary contributor to the noted differences. This assertion is further supported in that the pelvic segment angles are more disparate than the thigh segment angles. These findings highlight the need to closely examine pelvic motion in both research and rehabilitation.

The question of compensation versus causation is always of interest when a difference in movement pattern is noted; however, cross-sectional studies, such as the present one, cannot definitively answer that question. We can only theorize given our current understanding of the clinical diagnosis of FAIS. It seems unlikely that increased hip flexion and anterior pelvic tilt are beneficial in the presence of altered bony morphology that impinges with hip flexion. Instead, it is more plausible that the altered movement pattern is a modifiable contributor to the symptoms. Based on the pain theory by Hodges and Tucker,²⁸ it is plausible that the altered movement was once beneficial, but now has negative consequences. Regardless of its origin, this movement pattern may be a modifiable clinical target. Thus, improved control of the pelvis and hip during single-leg dynamic activities should be a focus of intervention for individuals with FAIS.

The present study does have limitations. Specific measurements of the alpha angle and the center-edge angle used to determine bony morphology of the participants with FAIS were not available to us. Instead, we were given the morphological classification (cam, pincer, or mixed) by the orthopaedic surgery group or, in 1 case, by the participant. We also did not conduct imaging studies on our comparison group to determine hip morphology. Some of these individuals without hip pain may have had cam or pincer morphology, as this morphology is often present in asymptomatic individuals, especially athletes.¹⁸ However, to be classified as having FAIS, the individual must also have symptoms and clinical signs,²² which were absent in our participants in the comparison group. An additional limitation of our group selection was the use of the UCLA activity score, a questionnaire originally intended for patients following total hip arthroplasty. The Hip Sports Activity Scale may be a more appropriate measure for individuals with FAIS.⁴⁵ In addition, as type of sporting activity appears to influence hip morphology,^{1,33,40,58,59} matching groups on type of sporting activity, not just activity level, may provide a more appropriate comparison group. As discussed earlier, it is unknown whether the increased hip flexion and anterior pelvic tilt detected in the FAIS group may be contributing to the pathology or may represent an attempt at compensation, but mechanically it is reasonable to suggest that they should be considered modifiable altered movement patterns.

CONCLUSION

THE RESULTS OF THIS STUDY SUGGEST that individuals with FAIS have alterations in pelvic motion during a dynamic unilateral task. The increased anterior pelvic tilt may contribute to symptom development in the presence of cam or pincer morphology. In the FAIS group, the sex-specific differences in motion of the hip, pelvis, and thigh may indicate that movement impairments are more pronounced in females than in males.

ACKNOWLEDGMENTS:

The authors thank the members of the Human Adaptation Laboratory for assistance with data collection and processing, and the research coordinators at Boston Children's Hospital for assistance with participant recruitment.

The protocol for this study was approved by the Institutional Review Boards of Boston University and Boston Children's Hospital. Research reported in this article was supported by the Peter Paul Career Development Professorship and the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health under award numbers R21 AR061690, K23 AR063235, and P60 AR047785. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

REFERENCES

1. Agricola R, Bessems JH, Ginai AZ, et al. The development of cam-type deformity in adolescent and young male soccer players. *Am J Sports Med.* 2012;40:1099–1106. 10.1177/0363546512438381 [PubMed: 22415206]
2. Agricola R, Heijboer MP, Bierma-Zeinstra SM, Verhaar JA, Weinans H, Waarsing JH. Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). *Ann Rheum Dis.* 2013;72:918–923. 10.1136/annrheumdis-2012-201643 [PubMed: 22730371]
3. Agricola R, Heijboer MP, Roze RH, et al. Pincer deformity does not lead to osteoarthritis of the hip whereas acetabular dysplasia does: acetabular coverage and development of osteoarthritis in a nationwide prospective cohort study (CHECK). *Osteoarthritis Cartilage.* 2013;21:1514–1521. 10.1016/j.joca.2013.07.004 [PubMed: 23850552]
4. Amstutz HC, Thomas BJ, Jinnah R, Kim W, Grogan T, Yale C. Treatment of primary osteoarthritis of the hip. A comparison of total joint and surface replacement arthroplasty. *J Bone Joint Surg Am.* 1984;66:228–241. [PubMed: 6693450]
5. Azevedo DC, Paiva EB, Lopes AM, et al. Pelvic rotation in femoroacetabular impingement is decreased compared to other symptomatic hip conditions. *J Orthop Sports Phys Ther.* 2016;46:957–964. 10.2519/jospt.2016.6713 [PubMed: 27686413]
6. Bagwell JJ, Snibbe J, Gerhardt M, Powers CM. Hip kinematics and kinetics in persons with and without cam femoroacetabular impingement during a deep squat task. *Clin Biomech (Bristol, Avon).* 2016;31:87–92. 10.1016/j.clinbiomech.2015.09.016
7. Beaulé PE, Zaragoza E, Motamedi K, Copelan N, Dorey FJ. Three-dimensional computed tomography of the hip in the assessment of femoroacetabular impingement. *J Orthop Res.* 2005;23:1286–1292. 10.1016/j.orthres.2005.03.011.1100230608 [PubMed: 15921872]
8. Bell AL, Brand RA, Pedersen DR. Prediction of hip joint centre location from external landmarks. *Hum Mov Sci.* 1989;8:3–16. 10.1016/0167-9457(89)90020-1
9. Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 2-year follow-up. *Arthroscopy.* 2000;16:578–587. 10.1053/jars.2000.7683 [PubMed: 10976117]
10. Cappozzo A, Cappello A, Della Croce U, Pensalfini F. Surface-marker cluster design criteria for 3-D bone movement reconstruction. *IEEE Trans Biomed Eng.* 1997;44:1165–1174. 10.1109/10.649988 [PubMed: 9401217]
11. Clohisy JC, Baca G, Beaulé PE, et al. Descriptive epidemiology of femoroacetabular impingement: a North American cohort of patients undergoing surgery. *Am J Sports Med.* 2013;41:1348–1356. 10.1177/0363546513488861 [PubMed: 23669751]

12. CODA pelvis. Available at: https://www.c-motion.com/v3dwiki/index.php?title=Coda_Pelvis. Accessed September 23, 2017
13. Cole GK, Nigg BM, Ronsky JL, Yeadon MR. Application of the joint coordinate system to three-dimensional joint attitude and movement representation: a standardization proposal. *J Biomech Eng*. 1993;115:344–349. 10.1115/1.2895496 [PubMed: 8309227]
14. Crossley KM, Zhang WJ, Schache AG, Bryant A, Cowan SM. Performance on the single-leg squat task indicates hip abductor muscle function. *Am J Sports Med*. 2011;39:866–873. 10.1177/0363546510395456 [PubMed: 21335344]
15. Diamond LE, Wrigley TV, Bennell KL, Hinman RS, O'Donnell J, Hodges PW. Hip joint biomechanics during gait in people with and without symptomatic femoroacetabular impingement. *Gait Posture*. 2016;43:198–203. 10.1016/j.gaitpost.2015.09.023 [PubMed: 26475761]
16. Downie WW, Leatham PA, Rhind VM, Wright V, Branco JA, Anderson JA. Studies with pain rating scales. *Ann Rheum Dis*. 1978;37:378–381. 10.1136/ard.37.4.378 [PubMed: 686873]
17. Earl JE, Monteiro SK, Snyder KR. Differences in lower extremity kinematics between a bilateral drop-vertical jump and a single-leg step-down. *J Orthop Sports Phys Ther*. 2007;37:245–252. 10.2519/jospt.2007.2202 [PubMed: 17549953]
18. Frank JM, Harris JD, Erickson BJ, et al. Prevalence of femoroacetabular impingement imaging findings in asymptomatic volunteers: a systematic review. *Arthroscopy*. 2015;31:1199–1204. 10.1016/j.arthro.2014.11.042 [PubMed: 25636988]
19. Freke MD, Kemp J, Svege I, Risberg MA, Semciw A, Crossley KM. Physical impairments in symptomatic femoroacetabular impingement: a systematic review of the evidence. *Br J Sports Med*. 2016;50:1180. 10.1136/bjsports-2016-096152 [PubMed: 27301577]
20. Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res*. 2003;112–120.
21. Graci V, Van Dillen LR, Salsich GB. Gender differences in trunk, pelvis and lower limb kinematics during a single leg squat. *Gait Posture*. 2012;36:461–466. 10.1016/j.gaitpost.2012.04.006 [PubMed: 22591790]
22. Griffin DR, Dickenson EJ, O'Donnell J, et al. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. *Br J Sports Med*. 2016;50:1169–1176. 10.1136/bjsports-2016-096743 [PubMed: 27629403]
23. Halim A, Badrinath R, Carter CW. The importance of sex of patient in the management of femoroacetabular impingement. *Am J Orthop (Belle Mead NJ)*. 2015;44:172–175. [PubMed: 25844587]
24. Hammond CA, Hatfield GL, Gilbert MK, Garland SJ, Hunt MA. Trunk and lower limb biomechanics during stair climbing in people with and without symptomatic femoroacetabular impingement. *Clin Biomech (Bristol, Avon)*. 2017;42:108–114. 10.1016/j.clinbiomech.2017.01.015
25. Harris-Hayes M, McDonough CM, Leunig M, Lee CB, Callaghan JJ, Roos EM. Clinical outcomes assessment in clinical trials to assess treatment of femoroacetabular impingement: use of patient-reported outcome measures. *J Am Acad Orthop Surg*. 2013;21 suppl 1:S39–S46. 10.5435/JAAOS-21-07-S39 [PubMed: 23818190]
26. Hetsroni I, Dela Torre K, Duke G, Lyman S, Kelly BT. Sex differences of hip morphology in young adults with hip pain and labral tears. *Arthroscopy*. 2013;29:54–63. 10.1016/j.arthro.2012.07.008 [PubMed: 23200844]
27. Hetsroni I, Funk S, Ben-Sira D, Nyska M, Palmanovich E, Ayalon M. Femoroacetabular impingement syndrome is associated with alterations in hindfoot mechanics: a three-dimensional gait analysis study. *Clin Biomech (Bristol, Avon)*. 2015;30:1189–1193. 10.1016/j.clinbiomech.2015.08.005
28. Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. *Pain*. 2011;152:S90–S98. 10.1016/j.pain.2010.10.020 [PubMed: 21087823]
29. Hunt MA, Guenther JR, Gilbert MK. Kinematic and kinetic differences during walking in patients with and without symptomatic femoroacetabular impingement. *Clin Biomech (Bristol, Avon)*. 2013;28:519–523. 10.1016/j.clinbiomech.2013.05.002

30. Ito K, Minka MA 2nd, Leunig M, Werlen S, Ganz R. Femoroacetabular impingement and the cam-effect. A MRI-based quantitative anatomical study of the femoral head-neck offset. *J Bone Joint Surg Br.* 2001;83:171–176. 10.1302/0301-620X.83B2.0830171 [PubMed: 11284559]
31. Jacobs CA, Uhl TL, Mattacola CG, Shapiro R, Rayens WS. Hip abductor function and lower extremity landing kinematics: sex differences. *J Athl Train.* 2007;42:76–83. [PubMed: 17597947]
32. Joseph R, Pan X, Cenkus K, Brown L, Ellis T, Di Stasi S. Sex differences in self-reported hip function up to 2 years after arthroscopic surgery for femoroacetabular impingement. *Am J Sports Med.* 2016;44:54–59. 10.1177/0363546515610535 [PubMed: 26546302]
33. Kapron AL, Anderson AE, Aoki SK, et al. Radiographic prevalence of femoroacetabular impingement in collegiate football players: AAOS Exhibit Selection. *J Bone Joint Surg Am.* 2011;93:e111 10.2106/JBJS.J.01197 [PubMed: 22005872]
34. Kemp JL, Collins NJ, Roos EM, Crossley KM. Psychometric properties of patient-reported outcome measures for hip arthroscopic surgery. *Am J Sports Med.* 2013;41:2065–2073. 10.1177/0363546513494173 [PubMed: 23835268]
35. Kennedy MJ, Lamontagne M, Beaulé PE. Femoroacetabular impingement alters hip and pelvic biomechanics during gait: walking biomechanics of FAI. *Gait Posture.* 2009;30:41–44. 10.1016/j.gaitpost.2009.02.008 [PubMed: 19307121]
36. Klässbo M, Larsson E, Mannevik E. Hip disability and osteoarthritis outcome score. An extension of the Western Ontario and McMaster Universities Osteoarthritis Index. *Scand J Rheumatol.* 2003;32:46–51. 10.1080/03009740310000409 [PubMed: 12635946]
37. Kumar D, Dillon A, Nardo L, Link TM, Majumdar S, Souza RB. Differences in the association of hip cartilage lesions and cam-type femoroacetabular impingement with movement patterns: a preliminary study. *PM R.* 2014;6:681–689. 10.1016/j.pmrj.2014.02.002 [PubMed: 24534097]
38. Lamontagne M, Brisson N, Kennedy MJ, Beaulé PE. Preoperative and postoperative lower-extremity joint and pelvic kinematics during maximal squatting of patients with cam femoroacetabular impingement. *J Bone Joint Surg Am.* 2011;93 suppl 2:40–45. 10.2106/JBJS.J.01809
39. Lamontagne M, Kennedy MJ, Beaulé PE. The effect of cam FAI on hip and pelvic motion during maximum squat. *Clin Orthop Relat Res.* 2009;467:645–650. 10.1007/s11999-008-0620-x [PubMed: 19034598]
40. Lerebours F, Robertson W, Neri B, Schulz B, Youm T, Limpisvasti O. Prevalence of cam-type morphology in elite ice hockey players. *Am J Sports Med.* 2016;44:1024–1030. 10.1177/0363546515624671 [PubMed: 26823452]
41. Lewis CL, Foch E, Luko MM, Loverro KL, Khuu A. Differences in lower extremity and trunk kinematics between single leg squat and step down tasks. *PLoS One.* 2015;10:e0126258 10.1371/journal.pone.0126258 [PubMed: 25955321]
42. Ma Y, Mazumdar M, Memtsoudis SG. Beyond repeated-measures analysis of variance: advanced statistical methods for the analysis of longitudinal data in anesthesia research. *Reg Anesth Pain Med.* 2012;37:99–105. 10.1097/AAP.0b013e31823ebc74 [PubMed: 22189576]
43. Maslowski E, Sullivan W, Forster Harwood J, et al. The diagnostic validity of hip provocation maneuvers to detect intra-articular hip pathology. *PM R.* 2010;2:174–181. 10.1016/j.pmrj.2010.01.014 [PubMed: 20359681]
44. Myer GD, Schmitt LC, Brent JL, et al. Utilization of modified NFL combine testing to identify functional deficits in athletes following ACL reconstruction. *J Orthop Sports Phys Ther.* 2011;41:377–387. 10.2519/jospt.2011.3547 [PubMed: 21289456]
45. Naal FD, Miozzari HH, Kelly BT, Magennis EM, Leunig M, Noetzi HP. The Hip Sports Activity Scale (HSAS) for patients with femoroacetabular impingement. *Hip Int.* 2013;23:204–211. 10.5301/hipint.5000006 [PubMed: 23543465]
46. Nakagawa TH, Moriya ET, Maciel CD, Serrão FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 2012;42:491–501. 10.2519/jospt.2012.3987 [PubMed: 22402604]

47. Nilsdotter AK, Lohmander LS, Klässbo M, Roos EM. Hip disability and osteoarthritis outcome score (HOOS) – validity and responsiveness in total hip replacement. *BMC Musculoskelet Disord.* 2003;4:10 10.1186/1471-2474-4-10 [PubMed: 12777182]
48. Noehren B, Scholz J, Davis I. The effect of realtime gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome. *Br J Sports Med.* 2011;45:691–696. 10.1136/bjsm.2009.069112 [PubMed: 20584755]
49. Reid GD, Reid CG, Widmer N, Munk PL. Femoroacetabular impingement syndrome: an underrecognized cause of hip pain and premature osteoarthritis? *J Rheumatol.* 2010;37:1395–1404. 10.3899/jrheum.091186 [PubMed: 20516017]
50. Reiman MP, Goode AP, Cook CE, Hölmich P, Thorborg K. Diagnostic accuracy of clinical tests for the diagnosis of hip femoroacetabular impingement/labral tear: a systematic review with meta-analysis. *Br J Sports Med.* 2015;49:811 10.1136/bjsports-2014-094302 [PubMed: 25515771]
51. Robertson DG, Dowling JJ. Design and responses of Butterworth and critically damped digital filters. *J Electromyogr Kinesiol.* 2003;13:569–573. 10.1016/S1050-6411(03)00080-4 [PubMed: 14573371]
52. Ross JR, Nepple JJ, Philippon MJ, Kelly BT, Larson CM, Bedi A. Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. *Am J Sports Med.* 2014;42:2402–2409. 10.1177/0363546514541229 [PubMed: 25060073]
53. Rylander J, Shu B, Favre J, Safran M, Andriacchi T. Functional testing provides unique insights into the pathomechanics of femoroacetabular impingement and an objective basis for evaluating treatment outcome. *J Orthop Res.* 2013;31:1461–1468. 10.1002/jor.22375 [PubMed: 23625839]
54. Saberi Hosniji F, Zuiderwijk ME, Versteeg M, et al. Cam deformity and acetabular dysplasia as risk factors for hip osteoarthritis. *Arthritis Rheumatol.* 2017;69:86–93. 10.1002/art.39929 [PubMed: 27696746]
55. Samaan MA, Schwaiger BJ, Gallo MC, et al. Abnormal joint moment distributions and functional performance during sit-to-stand in femoroacetabular impingement patients. *PM R.* 2017;9:563–570. 10.1016/j.pmrj.2016.10.002 [PubMed: 27729286]
56. Samaan MA, Schwaiger BJ, Gallo MC, et al. Joint loading in the sagittal plane during gait is associated with hip joint abnormalities in patients with femoroacetabular impingement. *Am J Sports Med.* 2017;45:810–818. 10.1177/0363546516677727 [PubMed: 28006109]
57. Schmitz RJ, Kulas AS, Perrin DH, Riemann BL, Shultz SJ. Sex differences in lower extremity biomechanics during single leg landings. *Clin Biomech (Bristol, Avon).* 2007;22:681–688. 10.1016/j.clinbiomech.2007.03.001
58. Siebenrock KA, Behning A, Mamisch TC, Schwab JM. Growth plate alteration precedes cam-type deformity in elite basketball players. *Clin Orthop Relat Res.* 2013;471:1084–1091. 10.1007/s11999-012-2740-6 [PubMed: 23247816]
59. Siebenrock KA, Ferner F, Noble PC, Santore RF, Werlen S, Mamisch TC. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. *Clin Orthop Relat Res.* 2011;469:3229–3240. 10.1007/s11999-011-1945-4 [PubMed: 21761254]
60. Troelsen A, Mechlenburg I, Gelineck J, Bolvig L, Jacobsen S, Søballe K. What is the role of clinical tests and ultrasound in acetabular labral tear diagnostics? *Acta Orthop.* 2009;80:314–318. 10.3109/17453670902988402 [PubMed: 19421915]
61. Weeks BK, Carty CP, Horan SA. Effect of sex and fatigue on single leg squat kinematics in healthy young adults. *BMC Musculoskelet Disord.* 2015;16:271 10.1186/s12891-015-0739-3 [PubMed: 26423154]
62. Willy RW, Davis IS. The effect of a hipstrengthening program on mechanics during running and during a single-leg squat. *J Orthop Sports Phys Ther.* 2011;41:625–632. 10.2519/jospt.2011.3470 [PubMed: 21765220]
63. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med.* 2003;31:449–456. 10.1177/03635465030310032101 [PubMed: 12750142]

KEY POINTS

FINDINGS: Individuals with femoroacetabular impingement syndrome (FAIS) performed a single-leg step-down task with greater hip flexion and anterior pelvic tilt than individuals without hip pain. Across both groups, females exhibited more hip flexion and hip and thigh adduction, as well as more anterior pelvic tilt and pelvic drop, than males during the step-down task; however, these sex differences were more pronounced in the FAIS group than in the comparison group.

IMPLICATIONS: The noted altered movement patterns in the FAIS group may contribute to the development of hip pain and may be due to impairments that are modifiable through rehabilitation.

CAUTION: This cross-sectional study design cannot definitively answer the question of cause versus compensation. Future studies are warranted to determine the effect that modifying these movement patterns has on symptoms.

FIGURE 1.

Joint angles of both sides averaged at 60° of knee flexion during the step-down task. (A) Hip flexion, (B) hip adduction, and (C) knee abduction. *Significant ($P < .05$) main effects of sex. †Significant ($P < .05$) main effects of group. Abbreviation: FAIS, femoroacetabular impingement syndrome.

FIGURE 2.

Segment angles of both sides averaged at 60° of knee flexion during the step-down task. Pelvic drop is positive and pelvic hike is negative. (A) Pelvic anterior tilt, (B) pelvic drop, (C) thigh flexion, (D) thigh adduction, (E) shank flexion, (F) shank abduction. *Significant ($P < .05$) main effects of sex. †Significant ($P < .05$) main effects of group. Abbreviation: FAIS, femoroacetabular impingement syndrome.

Table 1**Demographic Data^{*}**

Characteristic	FAIS	Comparison	P Value
Sex, n			.715 [‡]
Male	11	20	
Female	9	20	
Age, y	25.3 ± 8.9	24.1 ± 5.1	.583 [‡]
Height, m	1.74 ± 0.10	1.71 ± 0.11	.385 [‡]
Mass, kg	72.7 ± 13.2	68.6 ± 13.7	.276 [‡]
Body mass index, kg/m ²	23.9 ± 2.4	23.2 ± 3.0	.403 [‡]
Median (range) UCLA activity score	10 (4-10)	9 (4-10)	.945 [§]

Abbreviations: FAIS, femoracetabular impingement syndrome; UCLA, University of California at Los Angeles.

^{*} Values are mean ± SD unless otherwise indicated.

[‡] Chi-square test performed.

[‡] Independent-samples t test performed.

[§] Mann-Whitney U test performed.

TABLE 2

Number of Individuals With FAIS Who Had Pain With Provocative Tests*

Provocative Test	More Painful Side	Less Painful Side
FADIR	19 (95)	11 (55)
FABER	8 (40)	1 (5)
SLR	11 (55)	4 (20)

Abbreviations: FABER, flexion, abduction, external rotation test; FADIR, flexion, adduction, internal rotation test; FAIS, femoroacetabular impingement syndrome; SLR, straight leg raise resisted at 30°.

* Values are n (%). Individuals in the comparison group did not have any positive (painful) tests.

TABLE 3

Data From Self-Report Questionnaires*

Questionnaire	n	FAIS		Comparison	
		More Painful Side	Less Painful Side	n	All
mHHS	19	73.5 ± 17.3	90.8 ± 14.2	40	100.0 ± 0.2
HOOS subscales					
Pain	19	68.0 ± 16.9	93.4 ± 11.4	40	100.0 ± 0.0
Symptoms	19	66.6 ± 14.9	89.2 ± 12.0	40	98.0 ± 3.7
Functional activities	18	83.0 ± 11.9	97.2 ± 6.5	40	100.0 ± 0.2
Recreation/sport activities	17	61.4 ± 20.8	89.1 ± 14.7	40	99.8 ± 1.0
Quality of life	19	45.1 ± 22.1	84.8 ± 17.8	40	99.8 ± 1.0
WOMAC	18	80.6 ± 12.1	96.6 ± 7.2	40	100.0 ± 0.2

Abbreviations: FAIS, femoroacetabular impingement syndrome; HOOS, Hip disability and Osteoarthritis Outcome Score; mHHS, modified Harris Hip Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

* Values are mean ± SD. Data were missing for 1 individual with FAIS, and 2 other individuals with FAIS had incomplete data.

TABLE 4
Kinematic Data of Both Sides Averaged at 60° of Knee Flexion During the Step-Down Task

Variable	FAIS*		Comparison*		Group	Sex	Side	P Value [†]	
	Female	Male	Female	Male				Sex by Group	Sex by Group by Side
Joint angles									
Hip flexion	40.2 ± 8.9	30.9 ± 5.9	32.1 ± 9.4	29.2 ± 9.9	.03	.01	.81	.15	.64
Hip adduction	12.0 ± 6.0	7.2 ± 5.1	10.8 ± 5.7	6.0 ± 6.0	.37	<.01	.39	.98	.45
Knee abduction	6.1 ± 8.7	4.6 ± 7.3	4.4 ± 6.9	4.1 ± 6.2	.56	.63	.84	.76	.03
Segment angles									
Pelvic anterior tilt	13.9 ± 6.1	6.1 ± 4.4	7.8 ± 7.4	4.1 ± 7.5	.01	<.01	.98	.22	.73
Pelvic drop	1.1 ± 2.4	-0.5 ± 3.1	1.1 ± 3.0	-0.2 ± 2.7	.81	.01	.70	.72	.84
Thigh flexion	26.9 ± 4.8	25.1 ± 3.4	25.0 ± 3.3	26.0 ± 4.4	.61	.74	.81	.18	.34
Thigh adduction	8.0 ± 3.2	5.4 ± 2.7	7.3 ± 3.4	4.5 ± 4.2	.28	<.01	.90	.90	.84
Shank flexion	34.4 ± 4.7	35.8 ± 3.6	36.2 ± 3.3	34.6 ± 4.1	.80	.95	.89	.15	.46
Shank abduction	6.6 ± 1.9	7.5 ± 2.1	7.0 ± 2.4	6.8 ± 3.3	.82	.55	1.00	.29	.87

Abbreviation: FAIS, femoroacetabular impingement syndrome.

* Values are mean ± SD degrees.

[†] Main effects of group, sex, and side, and interactions of sex by group and sex by group by side.