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Males With Patellofemoral Pain Have Altered Movements During Step-Down and Single-Leg Squatting Tasks Compared to Asymptomatic Males: A Cross-Sectional Study

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Males with patellofemoral pain have altered movements during step-down and single-leg squatting tasks compared to asymptomatic males: A cross-sectional study

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Abstract

Background and Aims: Patellofemoral pain (PFP) is common in males, causing reduced physical activity and chronic pain. One proposed cause of PFP is aberrant biomechanics during tasks loading the patellofemoral joint. Consistent evidence exists for females with PFP, but it is uncertain if males with PFP have altered biomechanics. This study investigated the kinematics of males with PFP compared to pain-free males during forward step-down (StDn) and single-leg squat (SLSq).

Methods: A cross-sectional study including 40 males aged 20–39 years (28.28 ± 5.46) was conducted (20 PFP, 20 pain-free). Participants performed StDn and SLSq while motion was captured with a video-based motion capture system (Motion Analysis Corporation). Triplanar peak angles and angular ranges of motion (ROM) of the trunk, pelvis, and weight-bearing hip, knee, and ankle were dependent variables. Mixed-model ANOVA tests were used to determine the presence of significant interactions and main effects of group and task.

Results: Males with PFP had significantly lower peak knee adduction angles compared to pain-free males ($p = 0.01$). Significant group x task interactions were found for hip and pelvis ROM ($p < 0.05$). PFP participants had increased hip and pelvis ROM during StDn in the frontal and transverse planes but reduced or nearly equal ROM for these variables during SLSq. Peak hip adduction, hip internal rotation, contralateral pelvic drop and anterior tilt, trunk flexion, and ankle dorsiflexion were greater during StDn compared to SLSq ($p < 0.05$). ROM of the hip, pelvis, trunk, and ankle were greater during StDn compared to SLSq ($p < 0.05$).

Conclusion: Males with PFP had reduced peak knee adduction angles in StDn and SLSq. Males with PFP demonstrated increased hip and pelvis ROM during StDn versus SLSq, particularly in the frontal and transverse planes. Clinicians should consider StDn as a clinical test since aberrant movement may be easier to detect than in SLSq.

KEYWORDS
kinematics, male, observational study, patellofemoral pain syndrome

1 | INTRODUCTION

Patellofemoral pain (PFP) is characterized by the insidious onset of peripatellar or retropatellar pain produced by loading the patellofemoral joint, eg, squatting.[1] PFP is the most common musculoskeletal injury in male runners.[2] Reported prevalence of PFP for males includes 15.5% in the general population, 12.3% of male military recruits, and 35.7% of elite male cyclists.[3] Patients with PFP frequently have reduced physical activity, lower quality of life, and poor outcomes to rehabilitation.[4–6]

The etiology of PFP is multifactorial.[1] One theorized cause is increased patellofemoral joint stress from altered biomechanics.[7] There is consistent evidence for altered kinematics of females with PFP, but very limited evidence is available for males with PFP.[8,9] Males and females are reported to have different biomechanics during activities including squatting, stair descent, landing from a jump, running, and a forward step-down test.[10–15] During single-leg squatting, healthy males had less hip adduction and knee abduction of the weight-bearing limb as well as greater trunk flexion than healthy females.[10] Males rotated their pelvis towards the non-weight-bearing limb during the single-leg squat while females rotated their pelvis towards the weight-bearing limb.[10] During a forward step-down, males had less contralateral pelvic drop, greater hip adduction, and lower knee valgus angles than females.[14] Thus, faulty kinematics demonstrated by patients with PFP may be sex-specific and may impact the rehabilitation program accordingly.

The very few studies investigating the biomechanics of males with PFP have inconsistent results.[9,16] Increased knee adduction (KnADD) during single-leg squatting (SLSq) was reported in male recreational runners with PFP as well as increased KnADD and increased contralateral pelvic drop during running.[17] More recently, males with PFP were found to have reduced KnADD but increased knee internal rotation and increased hip internal rotation while running.[18] Altered kinematics during SLSq were also observed in a mixed-sex group of patients with PFP, with increased ipsilateral trunk lean, increased contralateral pelvic drop, increased hip adduction (HADD), and increased knee abduction angles; however, no comparison results for males with and without PFP were reported.[13] Sagittal plane trunk excursion during bipedal squatting was no different between males with PFP versus pain-free males.[19] Prospective studies found that male military recruits who developed PFP had greater knee valgus during SLSq and landing from a single-leg jump.[20,21] In contrast, a prospective study of military recruits found that only landing from a jump with <20° knee flexion and >5° hip external rotation were risk factors for males to develop PFP.[22] The forward step down (StDn) revealed increased ipsilateral trunk lean, increased contralateral pelvic drop, HADD, and increased knee abduction angles for a group of males and females with PFP versus pain-free controls; however, no single-sex comparison results were reported.[12]

StDn and SLSq are recommended clinical tests for patients with PFP.[1,23] Given the very limited and inconsistent evidence for the biomechanics of males with PFP, additional investigation is warranted. Use of a motion capture system with high accuracy to perform these investigations would yield the most accurate biomechanical results of such studies.[24] Currently laboratory video-based motion capture systems have high accuracy and are considered the "gold standard" for biomechanical studies.[24–26] We sought to examine triplanar knee, hip, pelvis, trunk, and ankle peak angles and ranges of motion (ROM) of the weight-bearing lower extremity (LE) during SLSq and forward StDn. It was hypothesized that males with PFP would have increased KnADD, HADD, contralateral pelvic drop, and ipsilateral trunk lean in one or both tasks. Secondary hypotheses were that 1) significant group by task interactions would be present for one or more kinematic variables, and 2) significant differences for peak angles and/or ROM would be present.

Key points

- Faulty kinematics are commonly reported in females with patellofemoral pain (PFP), but the kinematics of males with PFP are still uncertain.
- Males with PFP had reduced peak knee adduction angles during step-down and single-leg squatting. Compared to pain-free males, the PFP group had greater hip and pelvis ranges of motion (ROM) during step-down but reduced hip and pelvis ROM during squatting.
- The findings of this study indicate that males with PFP may have reduced knee adduction during weight-bearing tasks. Excessive hip and pelvis ROM during step-down may be present so may be a preferred clinical task to detect faulty kinematics.

2 | METHODS

2.1 | Study design

This cross-sectional study was conducted from September 2019 to January 2022 in a university research laboratory. Results are reported according to the requirements of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) and to the REPORTing of quantitative PatelloFemoral Pain (REPORT-PFP) checklist.[27,28] Dependent variables of interest included the tested LE triplanar peak angles and ROM of the knee, hip, pelvis, trunk, and ankle during SLSq and StDn. The study was approved by the Institutional Review Board of Thomas Jefferson University (Control # 19D.228). Informed consent was obtained from all participants before enrollment into the study.

2.2 | Participants

Participants were recruited from the community and referral from local sports medicine physicians and physical therapists. PFP group inclusion criteria were based on previous studies, the Academy of Orthopaedic Physical Therapy PFP clinical practice guideline, and diagnostic criteria from an international PFP consensus statement: male sex; age 18–40 years; anterior knee pain for ≥4 weeks; worst pain ≥3 on a numeric pain rating scale (NPRS) (0–10 points, 10 = worst pain imaginable); and knee pain provocation by ≥2 activities reported to increase pain in patients with PFP (eg, squatting and stair descent).[1,29,30] Inclusion criteria for the control group included males aged 18–40 years who had no knee pain at the time of enrollment.[30] Exclusion criteria for both groups included: current pain in the lower back, hip, or ankle/foot; a history of LE joint surgery or patellar dislocation or fracture; LE fracture within the previous year; and neurological, systemic, or other musculoskeletal conditions that may cause pain or weakness (eg, patellar tendinopathy).[30]

2.3 | Materials

A 12-camera motion analysis system (Motion Analysis Corporation) with retroreflective markers was used to capture data during biomechanical testing.[31] This optoelectronic motion capture system has a reported accuracy of less than one millimeter error for the wall-mounted Motion Analysis 1.3 MP cameras (0.435 mm mean, 0.213 mm standard deviation).[31] A modified 6 degree-of-freedom marker set was used to model the whole body.[32] Markers were placed on bilateral extremities and head-thorax-pelvis, as depicted in Figure 1, with a detailed list of marker placement locations found in Supporting Information S1: APPENDIX A1. The coefficient of multiple correlation (CMC) repeatability values for the 6 degree-of-freedom marker set were reported to be moderate-excellent for within- and between-session tests of the pelvis, hip, knee, and ankle (CMC mean[standard deviation]: within-session = 0.638[0.141] - 0.997[0.001]; between-session = 0.747[0.194] - 0.999[0.001]).[32]

2.4 | Procedure

After giving their consent, participants completed a questionnaire for demographics, health history, and LE dominance (LE used to kick a ball).[33] Participants completed an 11-point NPRS to rate current and worst pain. This tool has been found to be reliable and valid for measurement of pain in patients with PFP.[34] Function was measured using two patient-reported outcome measures that are valid and reliable for patients with PFP: The Knee injury and Osteoarthritis Outcome Score—Patellofemoral subscale (KOOS-PF) and the Anterior Knee Pain Scale (AKPS).[35,36] The KOOS-PF is an 11-item questionnaire scored from 0 to 100 (100 = best function/least pain).[35,37,38] The AKPS is a 13-item questionnaire scored

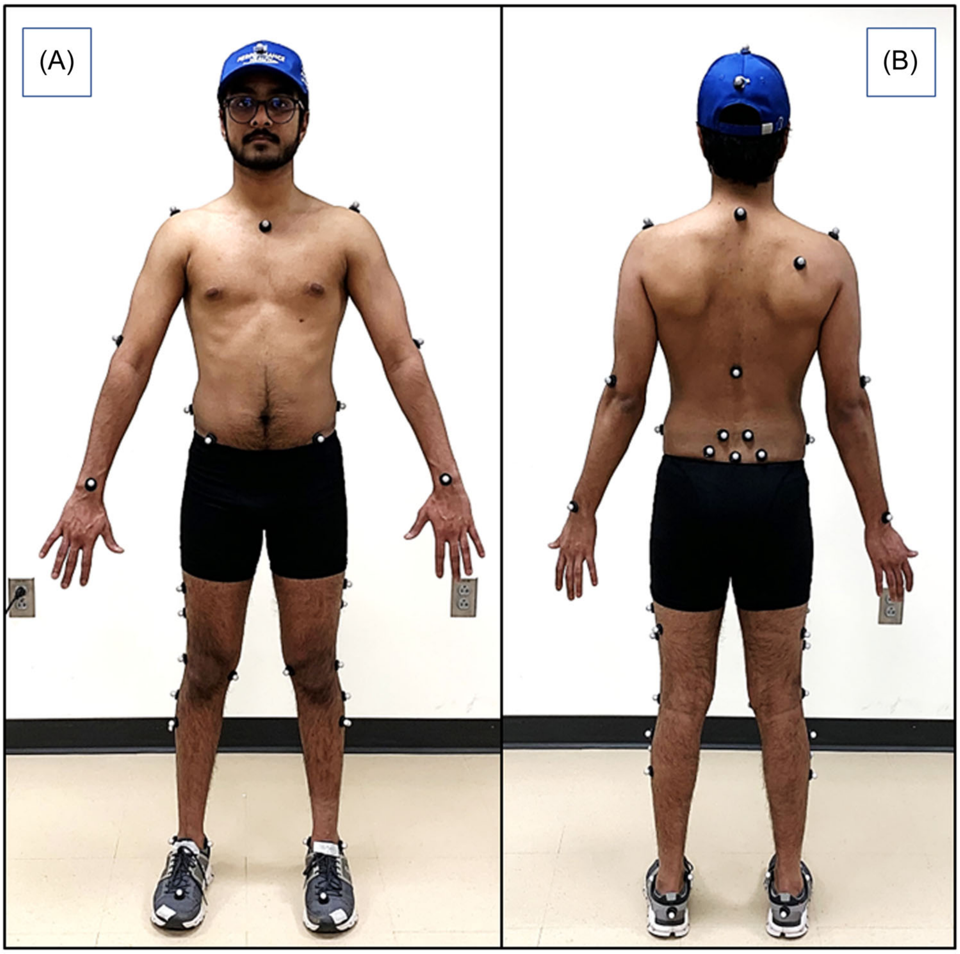

FIGURE 1 Motion capture marker set. (A): anterior view. (B): posterior view.

from 0 to 100 (100 = best function).[36–38] Physical activity was measured with the Tegner scale, a 10-point self-report scale that is reliable and valid for patients with knee injuries and has been used in previous studies of PFP.[4,30] Participants' height and weight were measured using a medical scale.

2.5 | Single-Leg squat and Step-Down motion capture

Participants were prepared for motion analysis as follows: retroreflective markers were applied to their extremities and trunk at the locations shown in Figure 1, and listed in Supporting Information S1: APPENDIX A1. A static standing trial was collected for calibration and used as participants' neutral alignment. Purely anatomical markers were removed (anterior superior iliac spines, medial knees, medial malleoli) during dynamic trials. Participants performed SLSq and StDn in a random order, as determined with a random number generator. The LE examined for PFP participants was the painful LE or the most painful LE for those with bilateral symptoms. The LE examined for control participants was randomly matched to PFP participants. Standardized scripts were used for participant instruction in tasks. Participants were given practice trials and a 30 s rest between trials. Participants wore their own footwear during testing. Three successful trials were captured for each task based on the recommended number of trials to ensure excellent within-session reliability of LE kinematic and kinetic variables during biomechanical testing.[39–41]

Participants performed SLSq by placing their hands on their lateral pelvis then raising the non-tested LE by flexing the hip and knee, while keeping the raised foot behind them (Figure 2).[42,43] Instructions were to "squat down as far as you can" for a total of 3 consecutive squats before lowering the raised foot to the floor. A metronome was used for pacing at 15 squats per minute.[13] Participants were verbally cued to squat "down" then "up." Data were collected during 3 trials, which were considered successful if participants maintained the raised LE off the floor and away from contact with the tested LE.

Participants performed StDn while standing on a 23-cm-high step stool. Participants placed their hands on their lateral pelvis, and raised the non-tested LE from the stool by flexing the hip with the knee in full extension (Figure 3).[12] Instructions were to lower their body towards the floor "as if you are walking down steps" and then raise back up for 3 consecutive StDn before placing the raised LE onto the step stool. Participants performed

FIGURE 2 Study participant position during single-leg squat task. (A): anterior view. (B): side view.

the StDn task at a pace of 15 StDn per minute, using the metronome and verbal cuing in similar fashion to the SLSq task.[12] Data were collected during 3 trials, considered successful if participants performed 3 StDn without losing their balance or stepping to the floor.

2.6 | Data processing

Three-dimensional marker coordinates were collected at a sampling frequency of 120 Hz. Marker data were identified using Cortex (Motion Analysis Corporation) and exported to Visual3D (C-Motion) to calculate kinematics. Marker data were low-pass Butterworth filtered with a cut-off frequency of 6 Hz.[13] Kinematic variables were averaged across trials for each participant and these data were used to determine group averages. The StDn and SLSq cycles analyzed were from 200 frames (1.66 s) before the sacral marker vertical position local minima to 200 frames subsequent to the local minima. Data from each of the three consecutive StDn and SLSq cycles for all three trials were used in data analysis, for a total of nine cycles analyzed for each task. Joint angles were calculated using the anatomic markers in the static trial to create local coordinate systems for each body segment (foot, shank, thigh, pelvis, and trunk). Joint centers were determined for the knee and ankle as the mid-point between the femoral epicondyles and malleoli, respectively. The hip joint centers were determined using the Bell method of creating an offset from the respective anterior superior iliac spine (ASIS) locations, as a function of the medial-lateral distance between the ASIS markers.[44] These segments were tracked throughout the dynamic trials and the angles between each local coordinate system can be determined at each frame of data, which provides the joint angles.[45] Most joint angles were calculated as the distal segment relative to the proximal segment. However, the pelvis angles were determined relative to the lab (global) coordinate system and the trunk angle was calculated relative to the pelvis.

FIGURE 3 Study participant position during forward step-down task. (A): anterior view. (B): side view.

2.7 | Statistical analysis

A power analysis using data from a previous study revealed adequate power with 18 participants per group (variables of hip adduction and knee abduction peak angles during SLSq, alpha = 0.05, power = 0.80).[13] Descriptive statistics were calculated for demographics, anthropometrics, pain ratings, reported function, and physical activity. Data were tested for normality and groups were compared using 2-tailed independent t-tests or Mann-Whitney U tests for non-normally distributed data. Descriptive data were reported as mean and standard deviation (SD) or median and interquartile range for non-normally distributed data. Mixed-model analyses of variance (ANOVA), 2-tailed [group (2) by task (2)] were used to examine kinematic variables. Significant interactions were examined using simple main effects and a Bonferroni correction for multiple comparisons. Statistical analyses were performed with SPSS version 28 statistical software (SPSS Inc). The significance level was set a priori at $p = 0.05$ for all comparisons.

3 | RESULTS

3.1 | Demographic and anthropometric parameters

Study participants included 20 males with PFP and 20 pain-free males as a control group. There were no significant differences between groups for height, mass, body mass index, and physical activity level; however, the PFP group was significantly older than the control group (Table 1). As expected, the PFP group had significantly worse pain than controls (Table 1). The PFP group NPRS-current pain mean (SD) was 1.45 (1.40), and NPRS-worst pain was 5.05 (1.64). Control group NPRS mean (SD) was 0.0 (0.0) for both current and worst pain. The PFP group had significantly lower reported function than controls (Table 1). Mean (SD) KOOS-PF scores for the PFP group were 66.48 (10.83) (control = 99.89 [0.51]) and AKPS mean scores for the PFP group were 81.90 (8.08) (control = 100.0 [0.0]). The PFP group mean (SD) knee pain duration was 68.0 (68.7) months. Nine PFP participants had unilateral knee pain and 11 PFP participants had bilateral knee pain. The most painful knee was the right for 14 and the left for 6 PFP participants. LE dominance was right for 37 participants and left for 3 participants.

3.2 | Peak angles

Kinematic analysis was performed using data from 39 participants; one control participant's data was excluded due to technical problems during motion capture. No significant interactions were found for any peak angle ($p > 0.05$) (Table 2). There was a significant main effect of group for peak KnADD with PFP group participants having significantly less peak KnADD compared to the control group ($p = 0.01$). No other main effects of group were found ($p > 0.05$). Significant main effects for task were found at the knee, hip, pelvis, trunk, and ankle. Peak angles during StDn were increased compared to SLSq for HADD, hip internal rotation, pelvic anterior tilt, pelvic contralateral drop, trunk flexion, and ankle dorsiflexion; StDn peak angles were less than SLSq peak angles for KnADD, knee external rotation, hip flexion, trunk ipsilateral lean, and ankle external rotation ($p < 0.05$) (Table 2).

3.3 | Range of motion measurements

Significant group by task interactions were found at the hip and pelvis for ROM measurements ($p < 0.05$) (Table 3). The PFP group had greater hip frontal and transverse plane ROM than the control group during StDn but less hip frontal and transverse plane ROM than controls during SLSq. At the pelvis, the PFP group had greater frontal and transverse plane ROM than controls during StDn but less than or nearly equal frontal and transverse plane ROM as controls during SLSq (Table 3). There were no main effects for group for ROM ($p > 0.05$). Significant main effects for task were found at the hip, pelvis, trunk, and ankle. ROM during StDn was greater than during SLSq for frontal and transverse planes at the hip, frontal and transverse planes at the pelvis, the transverse plane at the trunk, and the sagittal and frontal planes at the ankle ($p < 0.05$). Participants had less sagittal plane ROM during StDn than SLSq at the hip and pelvis ($p < 0.05$) (Table 3).

TABLE 1 Participant demographic and clinical characteristics.

Characteristics	PFP group	Control group	*p* value
Age (y)	30.25 (5.96)	26.30 (4.18)	0.02
Mass (kg)	82.60 (11.96)	79.32 (20.72)	0.54
Height (m)	1.79 (0.08)	1.79 (0.08)	0.99
Body mass index	25.63 (2.56)	24.55 (5.45)	0.43
NPRS, current (0–10)[a]	1 (3)	0 (0)	<0.001[b]
NPRS, worst (0–10)[a]	6 (2)	0 (0)	<0.001[b]
Pain duration (months)[a]	48 (99)	0 (0)	<0.001[b]
KOOS-PF score (0–100)[a]	65.91 (34.09)	100.00 (0)	<0.001[b]
AKPS score (0–100)[a]	80 (14)	100 (0)	<0.001[b]
Tegner score (0–10)[a]	5 (1)	6 (2)	0.06[b]

Note: Values are expressed as mean (SD) and *p* values are for independent *t* tests, 2 tailed, unless otherwise indicated.

Abbreviations: AKPS, Anterior Knee Pain Scale; kg, kilograms; KOOS-PF, Knee injury and Osteoarthritis Outcome Score—Patellofemoral subscale; m, meters; NPRS, numeric pain rating scale; PFP, patellofemoral pain; Tegner, Tegner Activity Level Scale; y, years.

[a]Median (interquartile range).

[b]Mann-Whitney *U* test, 2-tailed.

TABLE 2 Peak joint angles during tasks, comparison using mixed model ANOVA, 2-tailed to examine interaction of group x task and main effects of group and task.

		Mean (SD)		Mixed model ANOVA results *p* value (η_p^2)		
Peak kinematic variable	**Group**	**StDn (deg)**	**SLSq (deg)**	**Group x Task**	**Group**	**Task**
Knee flexion	PFP	−68.83 (11.41)	−67.19 (10.90)	0.44 (0.02)	0.44 (0.02)	0.60 (0.008)
	Control	−71.15 (12.76)	−71.46 (18.27)			
Knee ADD	PFP	3.50 (3.81)	4.18 (3.71)	0.80 (0.002)	0.01[a] (0.16)	0.03[b] (0.13)
	Control	7.58 (5.82)	8.12 (5.71)			
Knee ABD	PFP	−5.07 (5.91)	−4.88 (5.29)	0.44 (0.02)	0.08 (0.08)	0.71 (0.004)
	Control	−1.50 (4.86)	−2.04 (6.57)			
Knee ER	PFP	−3.82 (6.57)	−4.94 (6.24)	0.54 (0.01)	0.37 (0.02)	<0.001[b] (0.27)
	Control	−1.45 (8.71)	−3.03 (8.02)			
Hip flexion	PFP	27.09 (16.59)	39.36 (18.97)	0.87 (0.001)	0.56 (0.009)	<0.001[b] (0.58)
	Control	30.01 (15.30)	42.86 (20.38)			
Hip ADD	PFP	20.09 (9.21)	16.26 (7.19)	0.34 (0.03)	0.53 (0.01)	0.02[b] (0.14)
	Control	17.35 (8.50)	15.71 (10.26)			
Hip IR	PFP	4.34 (5.56)	2.06 (5.87)	0.54 (0.01)	0.36 (0.02)	<0.001[b] (0.29)
	Control	6.84 (12.47)	5.19 (12.24)			
Pelvis anterior tilt	PFP	20.50 (6.31)	15.53 (7.60)	0.48 (0.01)	0.41 (0.02)	<0.001[b] (0.31)
	Control	17.65 (10.24)	14.14 (9.45)			
Pelvis contralat. drop	PFP	−10.41 (5.17)	−7.45 (4.40)	0.30 (0.03)	0.24 (0.04)	0.002[b] (0.23)
	Control	−7.84 (5.94)	−6.32 (5.64)			
Pelvis contralat. FWD rotation	PFP	8.26 (6.91)	5.16 (5.53)	0.08 (0.08)	0.58 (0.008)	0.13 (0.06)
	Control	5.54 (7.21)	5.75 (6.82)			
Trunk flexion	PFP	−46.31 (11.41)	−40.21 (12.70)	0.12 (0.07)	0.69 (0.004)	<0.001[b] (0.29)
	Control	−43.00 (11.65)	−40.48 (13.74)			
Trunk ipsilateral lean	PFP	−9.27 (7.33)	−10.45 (8.06)	0.31 (0.03)	0.96 (0.000)	0.004[b] (0.21)
	Control	−8.80 (8.16)	−11.15 (8.06)			
Trunk contralat. FWD rotation	PFP	13.93 (7.41)	10.09 (7.49)	0.11 (0.07)	0.54 (0.01)	0.06 (0.09)
	Control	13.97 (10.26)	13.63 (12.39)			
Ankle dorsiflexion	PFP	35.86 (6.15)	34.30 (5.79)	0.40 (0.02)	0.74 (0.003)	0.03[b] (0.12)
	Control	36.11 (6.51)	35.40 (7.73)			
Ankle eversion	PFP	2.68 (3.09)	2.26 (2.30)	0.84 (0.001)	0.76 (0.002)	0.23 (0.04)
	Control	2.34 (3.56)	2.04 (3.04)			
Ankle external rotation	PFP	−18.13 (7.69)	−18.70 (8.37)	0.64 (0.006)	0.86 (0.001)	0.02[b] (0.14)
	Control	−17.49 (9.20)	−18.34 (9.09)			

Note: Sagittal plane values + for knee extension, hip flexion, pelvis anterior tilt, trunk flexion, and ankle dorsiflexion; frontal plane values + for knee adduction, hip adduction, contralateral pelvic drop, contralateral trunk lean, and ankle eversion; transverse plane values + for knee internal rotation, hip internal rotation, contralateral pelvic forward rotation, contralateral forward trunk rotation, and ankle internal rotation.

Abbreviations: ABD, abduction; ADD, adduction; contralat, contralateral; deg, degrees; ER, external rotation; FWD, forward; IR, internal rotation; η_p^2, partial eta-squared; PFP, patellofemoral pain; SD, standard deviation; SLSq, single-leg squat; StDn, forward step-down.

[a]Significant group main effect, 2-tailed. Follow-up comparisons for main effects (with Bonferonni correction for multiple comparisons, $p < 0.05$).

[b]Significant task main effect, 2-tailed. Follow-up comparisons for main effects (with Bonferonni correction for multiple comparisons, $p < 0.05$).

4 | DISCUSSION

The purpose of this study was to compare the knee, hip, pelvis, trunk, and ankle kinematics between males with and without PFP during two movement tasks commonly performed in the clinic: StDn and SLSq. Our hypotheses were partially supported in that there were significant group x task interactions and significant main effects for tasks. However, our hypotheses related to increased KnADD, HADD, contralateral pelvic drop, and ipsilateral trunk lean for males with PFP were not supported. Contrary to our hypothesis, males with PFP had reduced peak KnADD angles compared to pain-free males with a small effect size ($\eta_p^2 = 0.16$). Although there was some evidence that males with PFP had greater peak knee abduction than pain-free males, the difference did not meet statistical significance and there was a very small effect size ($p = 0.08$; $\eta_p^2 = 0.08$). This is consistent with one study of reduced KnADD for males with PFP during running[18] but in contrast to findings of a study reporting increased KnADD during SLSq.[17] Our findings may have differed from earlier studies due to different methodologies. We determined peak angles during the entire SLSq cycle while previous researchers examined the SLSq KnADD angle at the peak knee flexion angle achieved during running.[17] It may be that reduced peak KnADD in male patients with PFP can be considered analogous to the increased peak knee abduction angles often present in female patients with PFP.[8]

Our study found significant group x task interactions for hip and pelvis frontal and transverse planes ROM, meaning that these ROM variables were dependent upon the group and the task. The PFP group had increased hip and pelvis frontal and transverse plane ROM during StDn while ROM for these variables during SLSq was less than or nearly equal to controls. While no previous study of males with PFP reported findings for these variables, our findings during StDn are similar to previous reports of increased peak contralateral pelvic drop and increased hip internal rotation of males with PFP during running.[17,18] Reduced hip and pelvis frontal and transverse plane ROM during SLSq may have been attempts by participants with PFP to reduce patellofemoral joint stress and pain.[46]

Our study also found several main effects for task, most frequently for the frontal and transverse planes. The StDn task produced greater ROM than the SLSq at the hip and pelvis for those planes as well as at the trunk in the transverse plane. StDn also resulted in greater peak HADD, peak hip internal rotation, and peak contralateral pelvic drop than SLSq. These findings may mean that the StDn task is more challenging for males with PFP, making it more difficult for them to limit their ROM in the frontal and transverse planes than SLSq. The finding of greater HADD during StDn versus SLSq was reported in a study of healthy participants.[47] It is possible that maintaining the non-weight-bearing LE in an extended knee position and reaching forward results in more transverse and frontal plane motion compared to the flexed knee position during the SLSq. The different LE position may cause SLSq to be less physically demanding than StDn. Maintaining the raised knee in extension and the foot anterior as in the StDn would move the center of mass anterior compared to the bent-knee position in SLSq, thus more physically challenging for muscles maintaining upright posture. It is also possible that the greater sagittal and frontal plane ROM of the ankle joint during StDn, as well as the greater peak ankle dorsiflexion angle, made the StDn task more challenging than the SLSq. More aberrant movement during StDn is consistent with greatest impairment for patients with PFP found during the anterior reach portion of a Y-balance test.[48] Thus, StDn may be better than SLSq for use by clinicians to detect faulty movement in male patients with PFP.

4.1 | Limitations

This study had some limitations. We did not include a specific level of physical activity as an inclusion criteria. Our participants may have had lower activity levels than those in studies of runners, so our results may not be generalizable to highly active individuals. We did not include a required pain intensity level for the day of testing, which may have minimized any aberrant biomechanics for our PFP group.[49] However, one prior study reported no effect of acute pain on movement patterns in patients with PFP.[50] We did not limit our PFP group participants to unilateral or bilateral symptoms, possibly obscuring kinematic findings that may have been present in those with unilateral or bilateral symptoms. We did not control the depth of the SLSq or StDn, which may impact kinematics. However, there were no differences between groups in peak knee, hip, or trunk flexion indicating that our instructions to squat or step down as far as possible may have been sufficient. We did not standardize participant's footwear and this may have impacted their biomechanics during the tasks, particularly at the ankle joint.

4.2 | Implications for clinical practice and future research

Males with PFP may have different biomechanics than pain-free males and females with PFP. Altered kinematics in males with PFP may include reduced peak KnADD and/or increased frontal or transverse plane ROM of the hip or pelvis during StDn or SLSq. Since greater frontal and transverse plane motion of the hip and pelvis were found during StDn, aberrant movement may be more pronounced during a forward StDn versus a SLSq test. Observational analysis of forward StDn movement patterns is clinically feasible and was found to have moderate-excellent intrarater and interrater reliability.[51] The StDn test may better reveal aberrant movement in males with PFP compared to the SLSq and may suggest possible targeted interventions such as neuromuscular reeducation or strengthening exercise for male patients with PFP. Future research should examine possible contributors to LE and trunk kinematics

TABLE 3 Joint ranges of motion during tasks, comparison using mixed model ANOVA, 2-tailed to examine interaction of group x task and main effects of group and task.

		Mean (SD)		Mixed model ANOVA results *p* value (η_p^2)		
Joint/Plane	**Group**	**StDn (deg)**	**SLSq (deg)**	**Group x task**	**Group**	**Task**
Knee/Sagittal	PFP	62.60 (10.80)	62.36 (10.32)	0.55 (0.01)	0.31 (0.03)	0.67 (0.005)
	Control	66.13 (13.21)	67.50 (19.22)			
Knee/Frontal	PFP	8.57 (4.75)	9.06 (5.54)	0.50 (0.01)	0.57 (0.009)	0.08 (0.08)
	Control	9.08 (3.44)	10.16 (4.13)			
Knee/Transverse	PFP	10.99 (4.66)	11.64 (4.63)	0.74 (0.003)	0.48 (0.01)	0.16 (0.05)
	Control	12.25 (6.00)	12.66 (5.00)			
Hip/Sagittal	PFP	47.96 (14.01)	58.50 (17.59)	0.81 (0.002)	0.76 (0.003)	<0.001[b] (0.42)
	Control	48.91 (11.61)	60.48 (19.76)			
Hip/Frontal	PFP	21.58 (6.89)	16.41 (6.13)	0.03[a] (0.12)	0.60 (0.007)	0.02[b] (0.15)
	Control	18.03 (7.58)	17.65 (9.48)			
Hip/Transverse	PFP	16.05 (4.81)	11.65 (3.66)	0.03[a] (0.13)	0.76 (0.003)	<0.001[b] (0.33)
	Control	14.91 (5.12)	13.62 (5.20)			
Pelvis/Sagittal	PFP	20.20 (7.98)	24.66 (10.50)	0.53 (0.01)	0.91 (0.000)	0.002[b] (0.23)
	Control	18.83 (8.03)	25.40 (11.96)			
Pelvis/Frontal	PFP	17.75 (4.54)	12.81 (3.84)	0.01[a] (0.17)	0.10 (0.07)	<0.001[b] (0.31)
	Control	13.38 (5.22)	12.39 (6.13)			
Pelvis/Transverse	PFP	16.58 (6.80)	11.51 (3.64)	0.04[a] (0.11)	0.82 (0.001)	<0.001[b] (0.29)
	Control	14.38 (6.14)	12.92 (6.83)			
Trunk/Sagittal	PFP	13.42 (7.26)	11.84 (5.04)	0.16 (0.05)	0.57 (0.009)	0.77 (0.002)
	Control	12.45 (5.64)	14.84 (9.39)			
Trunk/Frontal	PFP	12.29 (5.35)	10.45 (5.34)	0.09 (0.08)	0.42 (0.02)	0.30 (0.03)
	Control	9.83 (5.22)	10.28 (5.85)			
Trunk/Transverse	PFP	19.13 (8.67)	13.57 (3.79)	0.08 (0.08)	0.93 (0.000)	0.01[b] (0.16)
	Control	16.69 (8.53)	15.64 (9.30)			
Ankle/Sagittal	PFP	26.78 (5.36)	24.92 (5.69)	0.21 (0.04)	0.43 (0.02)	0.007[b] (0.18)
	Control	27.84 (6.66)	27.13 (8.10)			
Ankle/Frontal	PFP	9.15 (3.07)	8.08 (3.05)	0.32 (0.03)	0.62 (0.007)	0.04[b] (0.11)
	Control	9.36 (4.47)	8.98 (3.51)			
Ankle/Transverse	PFP	11.67 (2.92)	11.61 (2.85)	0.28 (0.03)	0.53 (0.01)	0.36 (0.02)
	Control	11.77 (2.12)	12.45 (2.25)			

Abbreviations: deg, degrees; η_p^2, partial eta-squared; PFP, patellofemoral pain; SD, standard deviation; SLSq, single-leg squat; StDn, forward step-down.
[a]Significant group x task interaction, 2-tailed, $p < 0.05$.
[b]Significant task main effect, 2-tailed. Follow-up comparisons for main effects (with Bonferonni correction for multiple comparisons, $p < 0.05$).

of males with PFP including muscle strength, muscle activation, and pain.

AUTHOR CONTRIBUTIONS

Lisa T. Hoglund: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Thomas Alexander Hulcher**: Data curation; formal analysis; funding acquisition; investigation; methodology; software; writing—original draft; writing—review and editing. **Amy H. Amabile**: Investigation; methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study was approved by the Institutional Review Board of Thomas Jefferson University (Control # 19D.228). Informed consent was obtained from all participants before enrollment into the study. The person shown in the figures gave his consent to be photographed and to have the images published in a journal article.

AUTHOR APPROVAL STATEMENT

All authors have read and approved the final version of the manuscript. Lisa Hoglund had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

The lead author Lisa Thraen Hoglund affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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