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Trunk and Lower Extremity Kinematics During Stair Descent in Women With or Without Patellofemoral Pain

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Context: There is limited evidence indicating the contribution of trunk kinematics to patellofemoral pain (PFP). A better understanding of the interaction between trunk and lower extremity kinematics in this population may provide new avenues for interventions to treat PFP.

Objective: To compare trunk and lower extremity kinematics between participants with PFP and healthy controls during a stair-descent task.

Design: Cross-sectional study.

Setting: Research laboratory.

Patients or Other Participants: Twenty women with PFP (age = 22.2 ± 3.1 years, height = 164.5 ± 9.2 cm, mass = 63.5 ± 13.6 kg) and 20 healthy women (age = 21.0 ± 2.6 years, height = 164.5 ± 7.1 cm, mass = 63.8 ± 12.7 kg).

Intervention(s): Kinematics were recorded as participants performed stair descent at a controlled velocity.

Main Outcome Measure(s): Three-dimensional joint displacement of the trunk, hip, and knee during the stance phase of stair descent for the affected leg was measured using a 7-camera infrared optical motion-capture system. Pretest and posttest pain were assessed using a visual analogue scale. Kinematic differences between groups were determined using independent-samples t tests. A 2 × 2 mixed-model analysis of variance (group = PFP, control; time = pretest, posttest) was used to compare knee pain.

Results: We observed greater knee internal-rotation displacement for the PFP group (12.8° ± 7.2°) as compared with the control group (8.9° ± 4.4°). No other between-groups differences were observed for the trunk, hip, or other knee variables.

Conclusions: We observed no difference in trunk kinematics between groups but did note differences in knee internal-rotation displacement. These findings contribute to the current knowledge of altered movement in those with PFP and provide direction for exercise interventions.

Key Words: anterior knee pain, knee internal rotation, neuromuscular control

Key Points

- Trunk kinematics did not differ between women with and without patellofemoral pain during stair descent.
- Women with patellofemoral pain demonstrated greater knee internal-rotation displacement during stair descent than women without patellofemoral pain.

Patellofemoral pain (PFP) is one of the most frequent chronic injuries among females.[1,2] The causes of PFP are multifactorial, with patellofemoral malalignment commonly accepted as a major contributor.[2,3] Patellofemoral malalignment increases contact pressure within the patellofemoral joint, leading to abnormal cartilage wear and ultimately degenerative changes if left untreated or if conservative treatment options fail.[4,5]

Lower extremity kinematics may directly influence patellofemoral contact pressure during dynamic tasks. Specifically, the motions of femoral internal rotation, femoral adduction, and knee valgus increase patellofemoral contact pressure.[3,6–8] Extensive research[3,6,9–13] has been conducted to determine alterations in lower extremity kinematics associated with PFP. Lower extremity kinematics may be influenced by other factors that, if recognized, may have a significant effect on treatment interventions for those with PFP.

Although there is evidence that trunk kinematics influence lower extremity kinematics and loading,[14–16] few studies have examined trunk kinematics in participants with PFP.[17,18] The presence of aberrant trunk motion in those with PFP and its influence on lower extremity kinematics has been theorized.[19] In the frontal plane specifically, it has been proposed that individuals with PFP who display hip-abductor weakness compensate by elevating the contralateral pelvis and leaning toward the stance limb. This trunk lean has the potential to alter the orientation of the ground reaction force and subsequent external moments acting on the knee in the frontal plane. In the sagittal plane, trunk flexion moves the ground reaction force vectors anteriorly to both the hip and knee joints, thereby increasing the demand of the hip extensors and decreasing the demand of the knee extensors. Decreasing the quadriceps demand decreases the compressive forces within the patellofemoral joint.[19] Given that previous

Table 1. Inclusion and Exclusion Criteria for the Patellofemoral Pain and Control Groups

Group	Criteria
Patellofemoral pain	
Inclusion criteria	Female
	Age 18–35 y
	Retropatellar knee pain present for at least 2 mo during at least 2 of the following activities:
	• Ascending/descending stairs
	• Hopping/jogging
	• Prolonged sitting with flexed knees
	• Kneeling
	• Squatting
	Pain on palpation of 1 of the following[2,21–23,30,35]
	• Medial or lateral patellar facets
	• Anterior portion of the medial or lateral femoral condyle
	• Patellar tendon (not exclusively)
	Pain rated as at least 3 cm within the week before participation on the 10-cm visual analogue pain scale[21,30,32]
	• Average pain
	• With the above activities
	Negative findings on examination of ligaments, menisci, and bursae[22,52]
	• Valgus and varus at 0° and 30°
	• Sag test, posterior drawer
	• Anterior drawer, Lachman
	• McMurray test, bounce home, Apley compression and distraction
	Insidious onset of knee pain not related to trauma[22,30]
Exclusion criteria	History of knee surgery on the involved extremity[22,28,30]
	History of low back, hip, or ankle injury within the 6 mo before participation
	Currently involved in physical therapy or has undergone physical therapy for a lower extremity injury within the 6 mo before participation[28]
	Any neurologic injury or disease that would influence gait or balance[22,31,32,52]
Control	
Inclusion criteria	Female
	Age 18–35 y
	No prior history or diagnosis of knee pain or injury within the 6 mo before participation[2,21–23]
Exclusion criteria	History of knee surgery
	History of low back, hip, or ankle injury within the 6 mo before participation that resulted in activity modification for more than 2 d
	Any neurologic injury or disease that would influence gait or balance[22,25,26]

researchers[13,14,16] have demonstrated a relationship between trunk and lower extremity kinematics in a healthy population, it is plausible that individuals with PFP may have altered trunk kinematics that indirectly influence patellofemoral contact pressure.

The primary purpose of our study was to compare trunk and lower extremity kinematics during stair descent between women with and without PFP. Our a priori hypotheses were that women with PFP would have greater trunk rotation and lateral flexion toward the stance leg and greater overall trunk flexion. Based on previously reported observations,[20–25] we also expected to observe greater hip adduction, hip internal rotation, and knee valgus in those with PFP.

METHODS

Participants

Because of the high incidence and prevalence of PFP in this population, our participant recruitment was limited to young, physically active women.[1,26,27] We used a cross-sectional research design for this study. Pilot data were collected on a convenience sample of healthy participants to perform an a priori power analysis and determine an appropriate sample size. Effect sizes were estimated based on these trunk kinematic data (trunk flexion = 5.90° ± 1.52°, trunk lateral flexion = 3.35° ± 0.60°, trunk rotation = 7.73° ± 2.78°) and the expectation that PFP participants would demonstrate 34% to 66% difference in these variables. These percentage differences have been previously observed for hip kinematics during a similar stair-descent task by McKenzie et al[20] in their comparison of PFP and control groups. Based on our anticipated effect sizes for trunk kinematics, we determined that 20 participants per group would provide a priori power of 0.80 to detect a difference in trunk kinematics between groups at an α level of .05.

Using the criteria in Table 1, we recruited 40 female participants from the local university population, of whom 20 constituted the PFP group and 20 served as the control group. We matched the control group to the PFP group based on age, height, mass, and leg dominance.[28–31] The principal investigator (B.G.S.), a certified athletic trainer, evaluated each participant before testing to determine compliance with the inclusion and exclusion criteria provided in Table 1.

Each participant read and signed an informed consent approved by the university institutional review board before data collection. We sampled data from the affected leg for

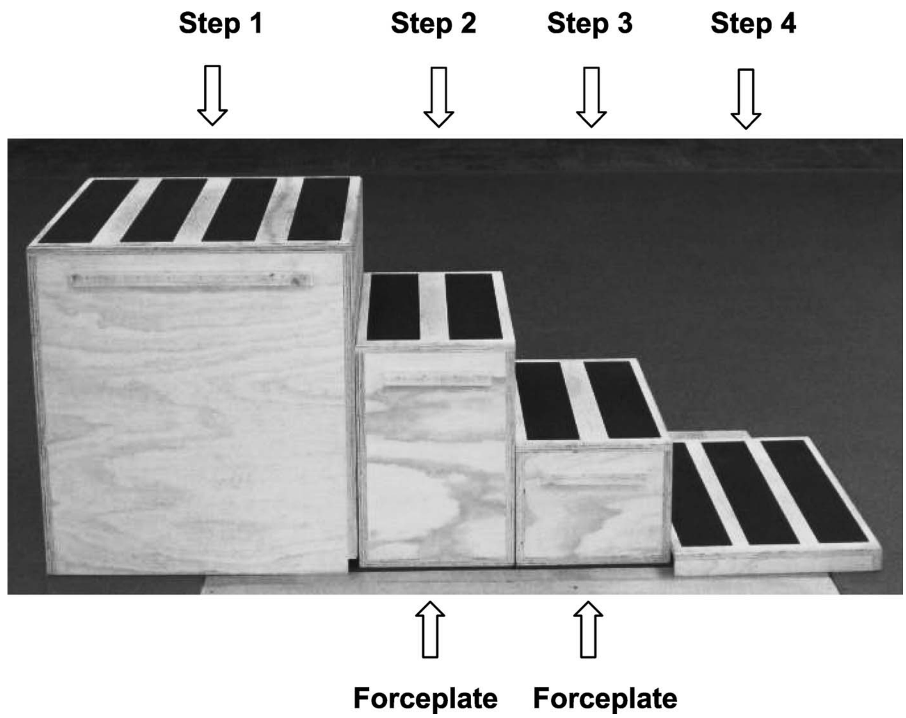

Figure 1. Force-plate setup.

the PFP group. If PFP participants experienced pain bilaterally, we tested the most affected leg, determined as the most painful limb subjectively reported by the participant.[28,29] For the control group, the test leg was the same as for the matched participant with PFP.

Instrumentation

Trunk and lower extremity kinematic data were collected with a 7-camera optical motion-capture system (model MX; Vicon Motion Systems, Los Angeles, CA) during a stair-descent task at a sampling frequency of 120 Hz. The stair-descent task consisted of 4 steps. We constructed the steps based on standard building code specifications for step height and tread, allowing for a step height of 20 cm between steps and a tread depth of 30.5 cm. We used 2 force plates (model FP4060-10; Bertec Corp, Columbus, OH) to collect ground reaction force data and identify the stance phase of stair descent for analysis. We collected force plate data synchronously with the kinematic data at a sampling frequency of 1200 Hz. The force plates were located under the second and third steps (Figure 1).[29,32–34]

Procedures

Each participant attended 2 sessions: an initial screening session to ensure she met inclusion and exclusion criteria for her group and a second session during which all testing was conducted. During the testing session, we recorded demographic information that included age, height, mass, test leg, and leg dominance. We then asked participants to perform a stair-descent task.

Three-Dimensional Motion Analysis. Before data collection, we provided participants with fitted nonreflective black spandex shorts and shirt and asked each participant to wear the athletic shoes she used on a regular basis. Retroreflective markers (25 static, 21 dynamic) were applied bilaterally on the acromion processes, anterior-superior iliac spines, greater trochanters, anterior thighs, medial and lateral epicondyles, anterior shanks, medial and lateral malleoli, calcanei, first and fifth metatarsal heads, and sacrum using double-sided tape. The medial epicondyle and medial malleolus markers were present for only the static trial and removed before the stair-descent trials.

A global axis system was established before data collection based on a right-hand convention. Once all markers were placed, the participant completed a static trial facing the positive direction of the x-axis of the global axis system with arms abducted to 90°. We defined trunk and hip-, knee-, and ankle-joint centers using the described marker set. The *trunk* was defined as the intersection of the midpoint between the right and left acromion and the longitudinal axis bisecting L4–L5. The *hip-joint center* was estimated based on the marker locations of the anterior-superior iliac spines, posterior-superior iliac spines, and greater trochanters using the Bell method.[35] The *knee-joint center* was estimated as the midpoint between the medial and lateral epicondyle markers. The *ankle-joint center* was defined as the midpoint between the medial and lateral malleolus markers. After completion of the static trial, we removed the medial markers on the knee and ankle for data collection.

Stair-Descent Task. We instructed each participant to descend 4 steps in a step-over-step fashion,[34] leading with the unaffected leg (Figure 2), which allowed data to be collected as she lowered herself using the affected leg from the second to the fourth step. Each participant had to complete a minimum of 2 strides immediately after descent to maintain a continuous movement pattern.[29] Stepping was performed in time to a metronome set at 96 beats per minute to control differences in gait velocity.[29,36,37] Each participant was allowed to practice 5 trials. Then

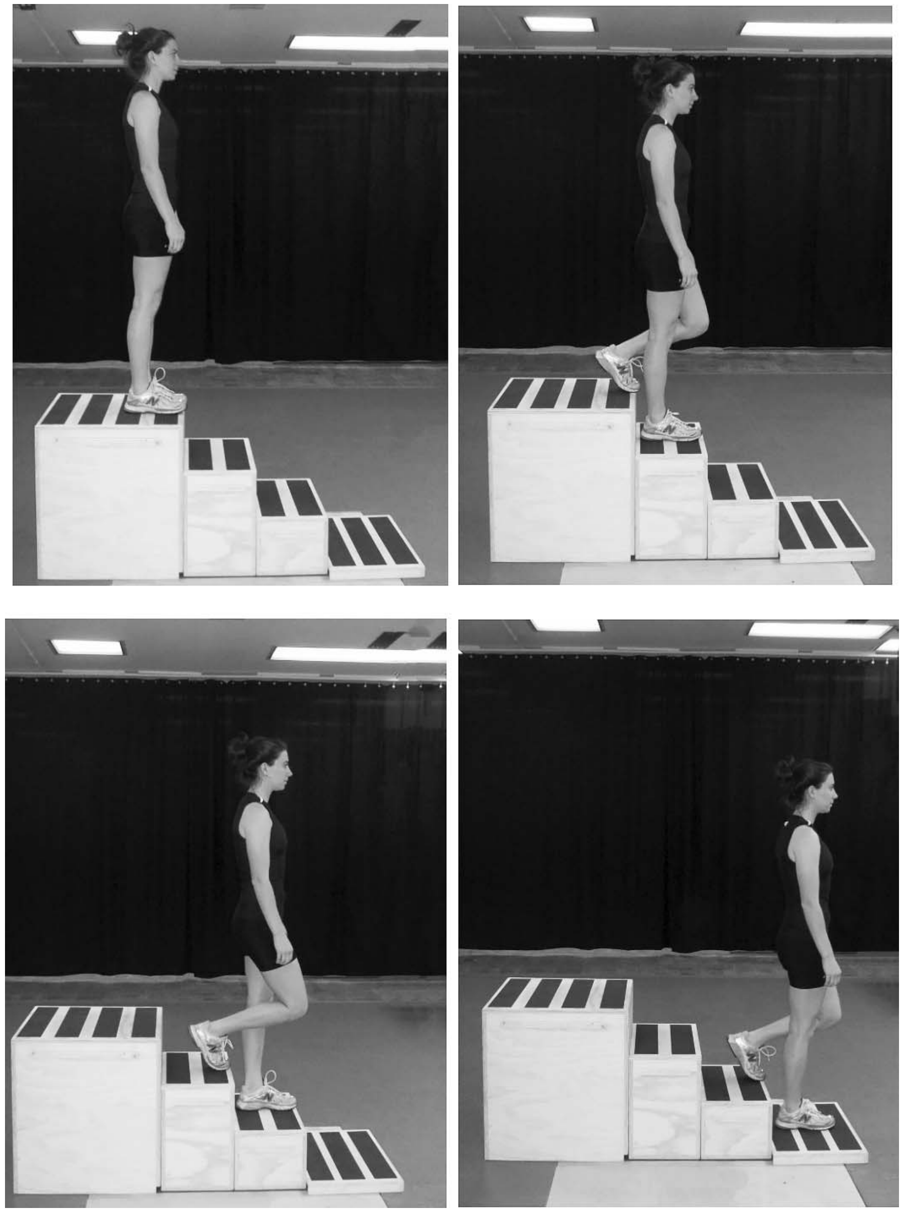

Figure 2. Stair-descent task. Force plates were located under steps 2 and 3.

participants performed 5 acceptable trials with 30 seconds of rest between trials. We collected 5 trials per participant to guard against marker occlusion during testing and ensure 3 adequate trials for data analysis.

Acceptable trials included those during which the participant (1) walked with the specified cadence, (2) took a minimum of 2 strides after the stair-descent task, (3) made contact with the second step with the appropriate foot, and (4) completed the task in a step-over-step fashion.

Pain Visual Analogue Scale. To determine if stair descent increased pain in our participants, we asked them before and immediately after completion of the trials to rate their perceived pain using a 10-cm visual analogue scale (VAS).[37,38] The far left side of the VAS scale indicated *no pain* and the far right side indicated *worst pain imaginable*. We asked participants to draw a perpendicular line on the scale at the position that best described the pain they experienced before (pretest) and after (posttest) completion of the trials.[29] Participants rated their pretest and posttest pain on separate sheets of paper to avoid contamination of the posttest data.

Data Processing and Reduction

All data were imported into The MotionMonitor software (version 8.0; Innovative Sports Training Inc, Chicago, IL) for processing. A local axis system was embedded into each segment of interest. Each was defined based on a right-hand convention with the positive direction of the x-axis corresponding with the participant's anterior direction, the positive z-axis in the superior direction, and the positive y-axis as a vector oriented at positive 90° rotation from the x-axis about the z-axis. We defined motion of the trunk relative to the global axis system using a Cardan-Euler sequence of X, Y, Z. We defined motion about the hip as the thigh relative to the pelvis and about the knee as the shank relative to the thigh. We calculated hip- and knee-joint angles using a Cardan-Euler sequence of Y, X, Z. The

Cardan-Euler sequences of the trunk, hip, and knee all corresponded with a first rotation to define sagittal-plane motion, a second rotation to define frontal-plane motion, and a third rotation to define transverse-plane motion. The difference in Cardan-Euler sequences between trunk and lower extremity kinematics was a result of trunk motion being referenced to the global axis system. During stair descent, each participant was facing and moved in the direction of the positive y-axis of the global axis system. Therefore, sagittal-plane motion of the trunk occurred about the x-axis of the global axis system, frontal-plane motion of the trunk occurred about the y-axis of the global axis system, and transverse-plane motion of the trunk occurred about the z-axis of the global axis system. Motion about the local and global x-axes corresponded to knee valgus (–)/varus (+), hip abduction (–)/adduction (+), and trunk flexion (+)/extension (–), respectively. Motion about the local and global y-axes corresponded to knee flexion (+)/extension (–), hip flexion (–)/extension (+), and trunk lateral flexion toward the stance leg (+)/trunk lateral flexion away from the stance leg (–), respectively. Motion about the local and global z-axes corresponded to knee internal rotation (+)/external rotation (–), hip internal rotation (+)/external rotation (–), and trunk rotation toward the stance leg (–)/trunk rotation away from the stance leg (+), respectively.

Kinematic data were filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 12 Hz. Variables of interest included 3-dimensional joint displacements of the trunk, hip, and knee during the *stance phase of stair descent*, defined as the point of initial contact (first time point at which vertical ground reaction force exceeded 10 N) to toe off (first time point at which vertical ground reaction force dropped below 10 N) for the involved limb. *Joint displacements* were defined as the differences between the joint angles at initial contact and the peak joint angle in each direction of motion for each plane of motion, except for the sagittal plane, where only flexion displacement was calculated. This allowed us to quantify the amount of displacement that each joint displayed and the direction in which the displacement occurred. This was necessary to avoid producing an inaccurate representation of joint displacement as a result of sign conventions (ie, +, –) used as directional, rather than quantitative, measures when calculating trial and group means. Average joint displacement for each dependent variable was calculated across 3 trials. Although we collected 5 trials of data, we selected the 3 middle trials of the 5-trial sequence for each participant and used the first and last trials only if 1 of the 3 middle trials was not acceptable. All data reduction was performed using a custom MATLAB program (The MathWorks, Inc, Natick, MA).

Statistical Analysis

We used independent-samples *t* tests (15 total) to compare mean trunk, hip-joint, and knee-joint displacement between the PFP and control groups. Differences in VAS scores between groups before and after stair descent were determined using a 2 × 2 (group = PFP, control; time = pretest, posttest) mixed-model analysis of variance. Post hoc analysis consisted of independent-samples *t* tests (group) and paired *t* tests (time) with a Bonferroni correction (0.0125) for any significance interaction or main effect. All statistical analyses were performed using SPSS statistical software (version 18.0; SPSS Inc, Chicago, IL). Statistical significance was established a priori as $\alpha \leq .05$.

Table 2. Participant Demographics (Mean ± SD)

	Group	
	Patellofemoral Pain (n = 20)	Control (n = 20)
Age, y	22.2 ± 3.1	21.0 ± 2.6
Height, cm	164.5 ± 9.2	164.5 ± 7.1
Mass, kg	63.5 ± 13.6	63.8 ± 12.7

RESULTS

All 40 participants were retained for data analysis. Takeoff had to be visually estimated for 1 member of the PFP group and 1 member of the control group because of an unrecognized error at the time of data collection in which 1 of the moveable steps came into contact with both force plates. This resulted in an inability to determine when the test leg first came into contact with the step. In addition, 1 member of the PFP group had only 2 usable trials of stair descent because of marker occlusion for more than 10 consecutive frames; therefore, we calculated all variables using only 2 trials for this participant in order to retain as much information for our analysis as possible.

Participant demographics are presented in Table 2. There were no differences in age, height, or mass between the PFP and control groups. Means, standard deviations, 95% confidence intervals, *P* values, *t* values and associated degrees of freedom, and effect sizes for all trunk and lower extremity kinematic variables are presented in Table 3.

Kinematics

No differences were seen for displacement of the trunk and hip between groups. However, we did observe a difference in knee internal-rotation displacement, with the PFP group having approximately 4° greater displacement than the control group (Figure 3). This represented a 30% difference between groups. No other differences were noted for displacement of the knee between groups. Statistical information supporting these results can be found in Table 3.

Visual Analog Scale Scores

Descriptive statistics for VAS pain scores are presented in Table 4. There was a significant group × time interaction. Post hoc analyses revealed that VAS pain scores were greater in the PFP group at pretest and posttest as compared with the control group. The VAS pain scores increased from pretest to posttest for the PFP group but not for the control group. Statistical information supporting these findings can be found in Table 4.

DISCUSSION

The most important findings of our study were that women with PFP did not display differences in trunk displacement but did demonstrate greater knee internal-rotation displacement compared with healthy controls. Our

Table 3. Comparison of Trunk, Hip-Joint, and Knee-Joint Displacements Between Groups During the Stance Phase

Kinematic Variables	Group, °				P Value	t Statistic[a]	Effect Size
	Patellofemoral Pain		Control				
	Mean ± SD	95% CI	Mean ± SD	95% CI			
Trunk							
Flexion	1.7 ± 1.1	1.2, 2.1	1.7 ± 0.9	1.3, 2.1	.905	−0.120	0.04
Lateral flexion[b]	1.7 ± 1.7	0.9, 2.4	1.6 ± 0.8	1.2, 1.9	.781	0.281	0.09
Lateral flexion[c]	−1.5 ± 1.1	−2.0, −1.0	−1.4 ± 1.1	−1.9, −0.9	.877	−0.156	0.05
Rotation[b]	−5.5 ± 4.6	−7.5, −3.5	−4.7 ± 4.3	−6.5, −2.8	.574	−0.567	0.18
Rotation[c]	3.0 ± 3.2	1.6, 4.4	3.6 ± 4.3	1.7, 5.5	.622	−0.498	0.16
Hip							
Flexion	−4.6 ± 3.4	−6.0, −3.1	−4.6 ± 3.9	−6.3, −2.9	.967	0.042	0.01
Adduction	10.5 ± 4.1	8.7, 12.3	10.9 ± 4.2	9.1, 12.7	.780	−0.281	0.09
Abduction	−0.7 ± 1.2	−1.2, −0.2	−0.5 ± 0.9	−0.9, −0.1	.587	−0.562	0.18
Internal rotation	4.4 ± 3.3	3.0, 5.9	4.0 ± 3.3	2.6, 5.4	.692	0.399	0.13
External rotation	−3.9 ± 2.4	−5.0, −2.9	−4.3 ± 2.3	−5.3, −3.3	.602	0.526	0.17
Knee							
Flexion	79.7 ± 5.9	77.1, 82.3	79.3 ± 5.8	76.7, 81.8	.821	0.227	0.07
Valgus	−2.6 ± 5.1	−4.9, −0.4	−2.7 ± 3.0	−4.1, −1.4	.942	0.074	0.02
Varus	5.3 ± 3.4	3.8, 6.8	3.5 ± 2.6	2.4, 4.7	.077	1.816	0.58
Internal rotation	12.8 ± 7.2	9.6, 16.0	8.9 ± 4.4	6.9, 10.8	.044[d]	2.082	0.68
External rotation	−1.5 ± 2.2	−2.5, −0.5	−0.9 ± 1.0	−1.4, −0.5	.330	−0.992	0.33

Abbreviation: CI, confidence interval.

[a] All t statistics reported as t_{38} except for trunk lateral flexion[c] ($t_{26.89}$) and knee external rotation ($t_{26.80}$) because of significant Levene test.
[b] Indicates toward the stance leg.
[c] Indicates away from the stance leg.
[d] Indicates significance at the .05 level (2 tailed).

hypotheses were not supported, as we expected women with PFP to have greater trunk motion during stair descent. We also expected, based on prior research, those with PFP to have greater hip adduction, hip internal rotation, and knee valgus.[20–22,24,25,39]

Trunk Kinematics

We observed no difference in trunk kinematics—specifically trunk flexion and ipsilateral trunk lean—as we initially hypothesized. These are movement patterns we expected to observe in our sample of patients with PFP, as they may increase contact pressure at the patellofemoral joint by increasing sagittal- and frontal-plane moments of the knee.[19] In addition, in the limited research that has examined 3-dimensional trunk kinematics for those with PFP, increased trunk flexion and lateral flexion toward the stance leg compared with healthy controls have been seen.[17,18] Nakagawa et al[17,18] noted increased ipsilateral trunk lean in PFP participants compared with healthy control participants during a single-leg–squat task and a stepping maneuver. A possible explanation for this digression may be that it is the result of a mixed-sex cohort, as evidence has indicated differences in trunk kinematics between sexes.[40] The differences may also be attributed to the task, as the stepping maneuver and single-leg squat may have required greater demand to be placed on the gluteus medius and a resulting movement compensation using the trunk. The stair descent used in our study may not have been challenging enough to elicit differences between groups, but we chose it because individuals with PFP often complain of pain with stair descent.

Hip Kinematics

Although the results did not support our hypotheses, our finding of no difference in hip adduction and internal rotation between groups agrees with previous research.[21,24,28,29] Similar to our findings, Bolgla et al[29] did not observe differences in hip adduction or internal rotation between females with and without PFP during stair descent. Grenholm et al[28] also observed no difference in hip adduction between females with and without PFP during a stair-descent task.

We believe the reason for the lack of difference in hip adduction and internal rotation in our study, as in the others, may be that stair descent is not challenging enough to elicit differences between groups. The total number of steps used for these analyses may not be adequate to elicit pain or kinematic alterations such as would be elicited by

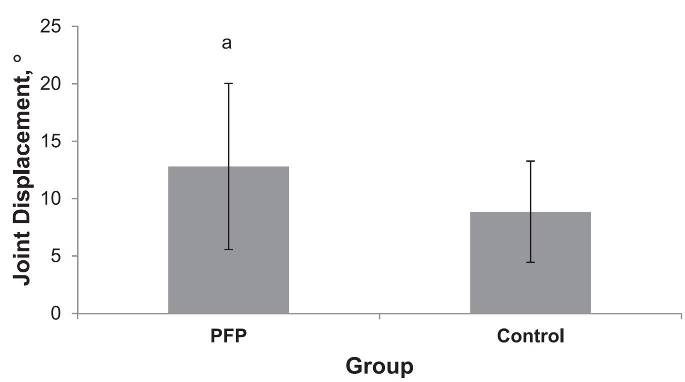

Figure 3. The effect of stair descent on knee internal rotation. [a] Indicates a statistically significant difference between groups. Abbreviation: PFP, patellofemoral pain.

Table 4. Pretest and Posttest Visual Analog Scale Scores

Time	Group, mm				P Value	Effect Size
	Patellofemoral Pain		Control			
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Pretest	17.3 ± 14.3	11.1, 23.6	0.0 ± 0.0	0.0, 0.0	.001	0.36
Posttest	22.7 ± 15.2	16.0, 29.4	0.2 ± 0.7	−0.1, 0.4	.001	0.45

Abbreviation: CI, confidence interval.

descending several flights of steps. Souza and Powers[21] demonstrated this point, as they observed greater peak hip internal rotation for females with PFP when averaged across the 3 tasks of a drop jump, running, and step down but no significant interaction for the tasks. In addition, although the authors did not demonstrate a significant difference for hip adduction during these tasks, those with PFP displayed lateral trunk lean toward the stance leg and attributed this to a compensatory strategy to reduce hip adduction in the presence of hip-abductor weakness.[21] As discussed earlier, contralateral pelvic elevation with ipsilateral trunk lean is a common compensation for hip-abductor weakness in those with PFP.[19]

Knee Kinematics

Our current observation of greater knee internal-rotation displacement during stair descent in those with PFP adds to the current literature, as few authors have examined knee internal rotation in this population.[41,42] To better explain our observations, we performed additional post hoc analyses and noted no difference between groups for knee-rotation angle at initial contact (PFP = –13.72° ± 6.08°, control = –10.54° ± 5.62°; t_{38} = –1.72; P = .09). We also found no difference in peak knee internal-rotation angle between groups (PFP = –0.92° ± 8.49°, control = –1.68° ± 5.41°; t_{38} = 0.34; P = .74) but did identify a difference between groups for peak knee external rotation (PFP = –15.21° ± 6.05°, control = –11.48° ± 5.26°; t_{38} = –2.08; P = .04). Our observed difference in knee internal-rotation displacement may have been attributed in large part to our PFP patients making initial contact in slightly more knee external rotation and achieving a slightly greater peak knee internal-rotation angle. It is important to note that although we did see greater knee internal-rotation displacement, our PFP patients maintained an externally rotated position of their knees during stair descent. Barton et al[41] examined knee internal rotation in a mixed-sex cohort during a walking task and found no difference in knee internal rotation between those with PFP and healthy controls. This suggested that assessing movement displacement may provide information that is not gained by assessing peak kinematic values alone, as we would have made similar observations had we limited our analysis to peak kinematic values.

Knee internal rotation is not typically associated with PFP. Research conducted on cadaver specimens has shown that knee external rotation increases lateral patellar contact pressure, whereas knee internal rotation has little to no effect on medial or lateral patellar contact pressure.[43–45] Increased knee internal-rotation displacement may be a compensatory mechanism to move the knee out of an externally rotated position. After reviewing the data collected for the PFP participants during the screening session, we noted that they had experienced knee pain on average for 4 to 5 years. It is possible that over time these participants began compensating to decrease their knee pain.

Although we found that participants with PFP had a significant increase in VAS scores from before to after stair descent, the change in VAS scores was only 5.4 mm. Research studies assessing pain,[46–51] patient satisfaction,[52] and sleep quality[53] have found that a minimal clinically significant difference in VAS scores is between 9 and 13 mm, with the lowest reported minimal clinically significant difference being 7 mm[52] and the highest being 30 mm.[54] Therefore, although the change in VAS scores for the PFP group was statistically significant, it was likely not clinically meaningful. The relatively small change in VAS scores supports knee internal rotation as a compensatory mechanism.

Limitations

Our study is not without limitations. We included only female participants in the study because this population has a higher incidence and prevalence of PFP compared with males.[1,26,27] We did not include women over the age of 35 to reduce the likelihood of osteoarthritic changes within the patellofemoral joint. Furthermore, we did not include adolescents in this study because the causes of PFP within this population may differ from the causes of PFP within an adult population.

Our study was restricted to a single task of stair descent because participants with PFP most often complain of pain with stair descent. The task may not have been challenging enough to reveal altered trunk or lower extremity kinematics, as we only asked participants to descend 4 steps. During initial screening, many participants reported that their knee pain would be greater if they had to descend several flights of stairs as opposed to 3 to 4 steps. We could not add additional steps to the task because of limited laboratory space and safety concerns, but future researchers could use a fatigue protocol to elicit knee pain before a stair-descent task.

Another limitation of our study was the 10-cm VAS pain scale criterion. We found it difficult to locate PFP participants who rated their average pain as at least 3 cm within the past week. We modified the criteria and included individuals who were able to rate their pain as at least 3 cm with at least 2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting with flexed knees, kneeling, or squatting. Because many of the PFP participants had experienced knee pain for several years, it is possible that they had become accustomed to their pain, as they often expressed during the screening, and rated their pain at a low level. The relatively low amount of pain experienced by the PFP participants could also be a result of mild lower extremity dysfunction. It is plausible that the PFP participants did not exhibit a severe enough alteration in lower extremity kinematics to elicit pain, which could explain why we did not see differences in kinematic variables other than knee internal-rotation displacement.

Clinical Significance

We observed no difference in trunk displacement for women with and without PFP during stair descent. Therefore, neuromuscular control of the trunk may not play a role in a low-demand task such as stair descent for the assessment of patients with PFP. Evaluating joint displacement during movement tasks may provide better information about those with PFP, as indicated by our observation of differences in knee internal-rotation displacement.

REFERENCES

1. DeHaven KE, Lintner DM. Athletic injuries: comparison by age, sport, and gender. *Am J Sports Med*. 1986;14(3):218–224.
2. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2003;33(11):671–676.
3. Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *J Orthop Sports Phys Ther*. 2003;33(11):639–646.
4. Insall J. Current concepts review: patellar pain. *J Bone Joint Surg Am*. 1982;64(1):147–152.
5. Utting MR, Davies G, Newman JH. Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? *Knee*. 2005; 12(5):362–365.
6. Lee TQ, Anzel SH, Bennett KA, Pang D, Kim WC. The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. *Clin Orthop Relat Res*. 1994;302:69–74.
7. Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. *J Bone Joint Surg Am*. 1984;66(5):715–724.
8. Souza RB, Draper CE, Fredericson M, Powers CM. Femur rotation and patellofemoral joint kinematics: a weight-bearing magnetic resonance imaging analysis. *J Orthop Sports Phys Ther*. 2010;40(5): 277–285.
9. Salsich GB, Perman WH. Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. *J Orthop Sports Phys Ther*. 2007;37(9): 521–528.
10. Mizuno Y, Kumagai M, Mattessich SM, et al. Q-angle influences tibiofemoral and patellofemoral kinematics. *J Orthop Res*. 2001; 19(5):834–840.
11. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. *J Appl Biomech*. 2006;22(1):41–50.
12. Hollman JH, Ginos BE, Kozuchowski J, Vaughn AS, Krause DA, Youdas JW. Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. *J Sport Rehabil*. 2009;18(1):104–117.
13. 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(3):449–456.
14. Blackburn JT, Padua DA. Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clin Biomech (Bristol, Avon)*. 2008;23(3):313–319.
15. Blackburn JT, Riemann BL, Myers JB, Lephart SM. Kinematic analysis of the hip and trunk during bilateral stance on firm, foam, and multiaxial support surfaces. *Clin Biomech (Bristol, Avon)*. 2003; 18(7):655–661.
16. Houck JR, Duncan A, De Haven KE. Comparison of frontal plane trunk kinematics and hip and knee moments during anticipated and unanticipated walking and side step cutting tasks. *Gait Posture*. 2006;24(3):314–322.
17. Nakagawa TH, Moriya ET, Maciel CD, Serrao AF. Frontal plane biomechanics in males and females with and without patellofemoral pain. *Med Sci Sports Exerc*. 2012;44(9):1747–1755.
18. Nakagawa TH, Moriya ET, Maciel CD, Serrao FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during single-leg squat in males and females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther*. 2012; 42(6):491–501.
19. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *J Orthop Sports Phys Ther*. 2010;40(2):42–51.
20. McKenzie K, Galea V, Wessel J, Pierrynowski M. Lower extremity kinematics of females with patellofemoral pain syndrome while stair stepping. *J Orthop Sports Phys Ther*. 2010;40(10):625–632.
21. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2009;39(1):12–19.
22. Dierks TA, Manal KT, Hamill J, Davis IS. Proximal and distal influences on hip and knee kinematics in runners with patellofemoral pain during a prolonged run. *J Orthop Sports Phys Ther*. 2008;38(8): 448–456.
23. Wilson NA, Press JM, Zhang LQ. In vivo strain of the medial vs. lateral quadriceps tendon in patellofemoral pain syndrome. *J Appl Physiol*. 2009;107(2):422–428.
24. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. *Am J Sports Med*. 2009; 37(11):2108–2116.
25. Salsich GB, Long-Rossi F. Do females with patellofemoral pain have abnormal hip and knee kinematics during gait? *Physiother Theory Pract*. 2010;26(3):150–159.
26. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports*. 2010;20(5):725–730.
27. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*. 2002;36(2):95–101.
28. Grenholm A, Stensdotter AK, Hager-Ross C. Kinematic analyses during stair descent in young women with patellofemoral pain. *Clin Biomech (Bristol, Avon)*. 2009;24(1):88–94.
29. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Hip strength and hip and knee kinematics during stair descent in females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther*. 2008; 38(1):12–18.
30. Brechter JH, Powers CM. Patellofemoral joint stress during stair ascent and descent in persons with and without patellofemoral pain. *Gait Posture*. 2002;16(2):115–123.
31. Powers CM. Patellar kinematics, part II: the influence of the depth of the trochlear groove in subjects with and without patellofemoral pain. *Phys Ther*. 2000;80(10):965–978.
32. Costigan PA, Deluzio KJ, Wyss UP. Knee and hip kinetics during normal stair climbing. *Gait Posture*. 2002;16(1):31–37.
33. Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. *Gait Posture*. 2002;15(1):32–44.
34. Protopapadaki A, Drechsler WI, Cramp MC, Coutts FJ, Scott OM. Hip, knee, ankle kinematics and kinetics during stair ascent and

descent in healthy young individuals. *Clin Biomech (Bristol, Avon)*. 2007;22(2):203–210.
35. Bell AL, Pedersen DR, Brand RA. A comparison of the accuracy of several hip center location prediction methods. *J Biomech*. 1990; 23(6):617–621.
36. Gilleard W, McConnell J, Parsons D. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Phys Ther*. 1998;78(1): 25–32.
37. Crossley KM, Cowan SM, Bennell KL, McConnell J. Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. *J Orthop Res*. 2004;22(2):267–274.
38. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Arch Phys Med Rehabil*. 2001;82(2):183–189.
39. Willson JD, Davis IS. Lower extremity strength and mechanics during jumping in women with patellofemoral pain. *J Sport Rehabil*. 2009;18(1):76–90.
40. 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(3):461–466.
41. Barton CJ, Levinger P, Webster KE, Menz HB. Walking kinematics in individuals with patellofemoral pain syndrome: a case-control study. *Gait Posture*. 2011;33(2):286–291.
42. Noehren B, Pohl MB, Sanchez Z, Cunningham T, Lattermann C. Proximal and distal kinematics in female runners with patellofemoral pain. *Clin Biomech (Bristol, Avon)*. 2012;27(4):366–371.
43. Lee TQ, Yang BY, Sandusky MD, McMahon PJ. The effects of tibial rotation on the patellofemoral joint: assessment of the changes in in situ strain in the peripatellar retinaculum and the patellofemoral contact pressures and areas. *J Rehabil Res Dev*. 2001;38(5):463–469.
44. Csintalan RP, Schulz MM, Woo J, McMahon PJ, Lee TQ. Gender differences in patellofemoral joint biomechanics. *Clin Orthop Relat Res*. 2002;402:260–269.
45. Li G, DeFrate LE, Zayontz S, Park SE, Gill TJ. The effect of tibiofemoral joint kinematics on patellofemoral contact pressures under simulated muscle loads. *J Orthop Res*. 2004;22(4):801–806.
46. Kelly AM. Does the clinically significant difference in visual analog scale pain scores vary with gender, age, or cause of pain? *Acad Emerg Med*. 1998;5(11):1086–1090.
47. Todd KH, Funk KG, Funk JP, Bonacci R. Clinical significance of reported changes in pain severity. *Ann Emerg Med*. 1996;27(4):485–489.
48. Gallagher EJ, Liebman M, Bijur PE. Prospective validation of clinically important changes in pain severity measured on a visual analog scale. *Ann Emerg Med*. 2001;38(6):633–638.
49. Todd KH. Clinical versus statistical significance in the assessment of pain relief. *Ann Emerg Med*. 1996;27(4):439–441.
50. Bodian CA, Freedman G, Hossain S, Eisenkraft JB, Beilin Y. The visual analog scale for pain: clinical significance in postoperative patients. *Anesthesiology*. 2001;95(6):1356–1361.
51. Nordby PA, Staalesen Strumse YA, Froslie KF, Stanghelle JK. Patients with neuromuscular diseases benefit from treatment in a warm climate. *J Rehabil Med*. 2007;39(7):554–559.
52. Singer AJ, Thode HC Jr. Determination of the minimal clinically significant difference on a patient visual analog satisfaction scale. *Acad Emerg Med*. 1998;5(10):1007–1011.
53. Zisapel N, Nir T. Determination of the minimal clinically significant difference on a patient visual analog sleep quality scale. *J Sleep Res*. 2003;12(4):291–298.
54. Lee JS, Hobden E, Stiell IG, Wells GA. Clinically important change in the visual analog scale after adequate pain control. *Acad Emerg Med*. 2003;10(10):1128–1130.

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