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The influence of pain exacerbation on rear foot eversion and plantar pressure symmetry in women with patellofemoral pain: a cross sectional study

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Abstract

Background The patellofemoral joint (PFJ) stress as a primary mechanical stimulus in the patellofemoral pain (PFP) etiology is affected by plantar pressure symmetry. This study evaluated how pain exacerbation affects rear foot eversion and plantar pressure distribution symmetry.

Method Sixty women with PFP participated in this study. Pain intensity, rear foot eversion, and plantar pressure were evaluated in the two conditions with and without pain exacerbation during double-leg squats. The MANOVA test was used to compare pain intensity, rear foot eversion, and plantar pressure symmetry between the two conditions. The Pearson correlation was used to evaluate the relationship between the pain intensity with the rear foot eversion and the plantar pressure symmetry.

Results The comparison between the two conditions showed a significant difference in pain intensity ($P < 0.001$, $\eta^2 = 0.623$), rear foot eversion ($P < 0.001$, $\eta^2 = 0.485$), plantar pressure distribution symmetry of the right-left foot ($P < 0.001$, $\eta^2 = 0.438$), forefoot and rear-foot of the right foot ($P < 0.001$, $\eta^2 = 0.607$), and forefoot and rear-foot of the left foot ($P < 0.001$, $\eta^2 = 0.548$). An excellent correlation was observed between the pain intensity with rear foot eversion ($P < 0.001$, $r = 0.835$) and plantar pressure distribution symmetry of the right-left foot ($P < 0.001$, $r = 0.812$), forefoot and rear-foot of the right foot ($P < 0.001$, $r = 0.834$), and forefoot and rear-foot of the left foot ($P < 0.001$, $r = 0.811$).

Conclusions After the pain exacerbation, the rear foot eversion was greater, and plantar pressure asymmetrical was observed, which can help in the development of PFP severity.

Keywords Patellofemoral pain, Patellofemoral joint, Pressure, Foot, Pronation

Background

Patellofemoral pain (PFP) is defined as pain in the around or retro-patella region, which is exacerbated during activities with patellofemoral joint (PFJ) loading [1, 2]. The estimated prevalence of this clinical condition in women 18–35 years is 13%, and they are 2.23 times more susceptible to PFP than males [3]. Additionally, PFP accounts for 25% to 40% of knee-related medical visits [1, 4]. Although the cause of PFP is still unknown; However, the PFJ stress is a primary mechanical stimulus to the PFP etiology [5, 6].

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The PFJ stress is affected by distal (foot) and proximal (hip) factors [7]. Rear foot eversion is an intrinsic risk factor for increased PFJ stress and subsequently PFP [8]. In this line of argument, the relationship between rear foot eversion and PFP is based on the coupling mechanism of lower limb joints [8]. Specifically, greater rear foot eversion may increase internal rotation of the tibia and hip, which ultimately leads to decreased contact area and increased PFJ stresses [9]. In this regard, Barton et al. (2012) showed that in patients with PFP, greater rear foot eversion has correlated with increased internal rotation of the tibia and hip [10]. Following this, reported that there is a positive relationship between greater rear foot eversion and increased pressure in the mid foot region [11]. Thus, changes in the foot roll-over pattern can asymmetric the plantar pressure in the mid-foot and forefoot regions [12].

The plantar pressure distribution is a kinetic variable that indirectly evaluates the interaction of the kinetic chain of the foot and the lower limb [13–15]. The plantar pressure distribution technology shows the rate and position of ground reaction forces in plantar regions and provides a scientific basis for PFP rehabilitation [9, 13]. Overall, high forces are transferred to the knee and the PFJ through the foot and kinetic chain [7]. Therefore, plantar pressure asymmetric can cause transfer harmful forces to proximal joints such as the PFJ and ultimately lead to PFP [16]. Rathleff et al. [7] reported in a cross-sectional study that patients with PFP showed forefoot loading patterns during single-leg squats and vertical drop jumps, which can be a risk factor for PFP [7]. In addition, Thijs et al. (2015) in a prospective study of 400 volunteers showed that subjects who developed PFP showed increased pressure in the forefoot region, especially the metatarsal, which could be useful in identifying people at risk of PFP [16]. Specifically, higher PFJ stress is a common assumption in PFP etiology. The PFJ stress is dependent on force dissipation and plantar loading that may be effective in PFP etiology. High pressure in the medially oriented loading pattern of the forefoot can increase the lateral forces on the patella and thus increase the compressive forces in the lateral part of the PFJ and increase the risk of PFP [17]. Interestingly, despite plantar pressure asymmetry being a risk factor for PFP, limited scientific evidence is available in this field [7]. Overall, human movement symmetry defined as the same function of lower limb on both sides. Meanwhile, plantar pressure asymmetries reflect an unequal loading in the different areas of the foot [18–20].

Importantly, previous studies evaluated biomechanical differences between PFP patients and healthy control groups in pain-free and rest-time conditions [4, 21]. Meanwhile, it is unclear whether these observed differences are the cause of pain or whether the pain is caused by compensatory mechanisms [21]. Clinically, assessing the plantar pressure distribution in the pain presence can be closer to real life conditions [17], because the plantar loading pattern has been evaluated in painful conditions. This finding highlight the potential importance of pain exacerbations during painful daily activities on the plantar pressure distribution in women with PFP and can provide a new insight into the foot movement variability and plantar loading in the pain presence. In addition, this finding can provide a realistic insight to help design rehabilitation protocols that are based on modifying biomechanical changes in the pain presence [4, 17]. In this line, recent studies have shown that pain intensity has the potential to influence kinematic and kinetic variables [1, 4, 22, 23]. In other words, during biomechanical analyses and clinical evaluations, different levels of pain in women with PFP can show distinct mechanical strategies [4]. Briani et al. (2017) reported the PFJ loading protocol is a suitable method for pain exacerbation in women with PFP [24]. In this regard, Briani et al. (2018) showed that pain intensity and vertical loading rate increased in patients with PFP after PFJ loading [1]. Furthermore, Yalfani et al. (2024) reported that peak dynamic knee valgus during single-leg squat increased following PFP exacerbation [4].

To our knowledge, no study has evaluated the effect of pain exacerbation on rear foot eversion and plantar pressure symmetry in patients with PFP. Now the question is, rear foot eversion and plantar pressure distribution symmetry can be affected by pain intensity? Therefore, the present study aimed to evaluate the influence of pain exacerbation on rear foot eversion and plantar pressure symmetry in women with PFP. We hypothesized that 1) after pain exacerbation, rear foot eversion would be greater and 2) the plantar pressure distribution would be asymmetric. The results of this study can provide a real insight into the movement pattern and plantar pressure during the pain presence, which is closer to the reality of daily life.

Methods

Participants

We used the G*Power software to calculate the sample size. Using the reference of a related study that evaluated the effect of PFJ loading on pain intensity, and vertical loading rate, alpha level = 0.05, the statistical power of 80%, and an estimated correlation coefficient (r) = 0.50 were set to calculate the power analysis [1]. The software findings showed that at least 26 subjects are required to participate in this study [1]. However, to increase the statistical power, we enrolled 60 women with PFP (age: 38.90 ± 3.33 years, height: 169.53 ± 4.6 cm, mass:

59.13 ± 3.9 kg, BMI: 20.66 ± 1.53 kg/m^2, pain duration: 11.52 ± 3.14 months, kujala score: 49.81 ± 8.70 points) who were visited in the orthopedic clinics of Hamedan city from January to April 2023. Of note, previous studies reported that women show a different movement pattern compared to men [4]. The different movement pattern in the women population includes increased Q-angle, increased dynamic knee valgus, increased hip internal rotation, hip adduction moment, and knee abduction moment, decreased knee flexion angle as well as greater ankle flexion/extension [17]. As a result, our statistical population included only women with PFP, because gender is known to be a confounding factor [4].

The selection process of patients included two stages. First, a knee orthopedic clinician (> 15 years of experience) examined the patients with the step-down and Clark tests. Second, a physiotherapist (> 8 years of experience) screened the eligibility criteria to select eligible patients. Inclusion criteria included self-reported pain of 3 out of 10 visual analog scale (VAS) in resting time, pain exacerbation during weight-bearing activities, normal static alignment of upper and lower limbs, the age range of 18–45, right foot dominant (determined by a kicking ball test), unilateral PFP symptomatic in the right knee (right knee as symptomatic limb), suffering from PFP for more than 6 weeks, and rear foot eversion ≥ 5 degrees [25] during double-leg squat. Exclusion criteria included a history of physical therapy up to 2 months before participating in clinical trial, participation in championship and recreational sports, surgery history, upper and lower limbs malalignment, lower limb length discrepancy, history of balance problem, vestibular and vision disorders, patella instability, left foot dominant, unilateral PFP in the left knee (left knee as symptomatic limb), bilateral PFP symptomatic, and pain in other joints. It is worth noting, patients with flat feet were excluded. Ethical approval of the present study was obtained from the ethics committee of Bu-Ali Sina University (IR.BASU.REC.1402.012) and also adhered to the Declaration of Helsinki of 2008. In addition, before data collection, the patients were informed about the study design and signed the written informed consent.

PFJ loading protocol

To randomize the conditions and the day, a physiotherapist generated computer random numbers. In general, the evaluation process was carried out in four days. Following this, two days were determined for condition 1 (Saturday/Sunday) and two days were for condition 2 (Monday/Tuesday), in randomized order. After patients enter the laboratory and assess demographic characteristics randomization and blinding were conducted by a physiotherapist who were not involved in data collection and were not aware of the study design. First, a physiotherapist generated random codes and put them inside sealed and opaque envelopes. Blocks 1 and 2 were planned for the first and second days of condition 1 and blocks 3 and 4 were planned for the first and second days of condition 2 (Fig. 1). Another physiotherapist who was blind to the codes randomly selected the sealed envelopes and delivered them to the patients. As a result, either the conditions or the days were randomized. Condition 1, patients were asked to indicate the pain intensity at the moment (rest time) on VAS (ICC = 0.91) [26]. Then, the patients were asked to perform three overhead squats as double-leg for data collection. In condition 2, first the PFJ loading protocol was applied to PFP exacerbation [1]. This protocol consisted of a staircase with seven steps patients performed 15 repetitions of stair negotiation with an external load (35% of the subject's body mass) that was carried by backpack [1]. Immediately, pain intensity was evaluated, and they performed three overhead squats as double-leg. Stair negotiation with an external overload increases PFJ stress and PFP exacerbation [4]. Of note, Briani et al. (2017) showed in an electromyography study that the PFJ loading protocol did not cause neuromuscular fatigue [24]. However, to be confident, we evaluated patients' fatigue after the PFJ loading protocol using the Borg scale (ICC = 0.89) [27], because we did not have access to electromyography.

Apparatus

Motion analysis was recorded with a Sony Handycam digital camera (DCR-HC37) with a 40 Hz sampling rate and 10 optical zoom. In addition, a Zebris pressure platform was used to record plantar pressure (ICC = 0.91) [28]. This platform measures 54 × 34 cm and has 2560 active sensors with high sensitivity that record pressure in the range of 1–120 N/cm^2 with a sampling frequency of 50 Hz.

Task and procedure

Rear foot eversion and plantar pressure distribution were evaluated during overhead squats as double-leg. The physiotherapist taught the patients that as double-leg stands on the platform (barefoot), the foot shoulder-width apart, toes straight forward, hands overhead with the elbows extended, and to prevent vestibular system disorder, the head in the position keeps neutral [29, 30]. In addition, the hip and knee were in full extension and the trunk was upright. Patients were taught to perform a controlled squat at a minimum angle of 45∘ and a maximum of 60 ∘ of knee flexion [31, 32]. We set a flexion angle of 45 to 60 ∘ for data collection for several reasons. Firstly, high PFJ stress occur between angles of 0 ∘ to 60 ∘ of knee flexion, and at 70° to 110° of knee

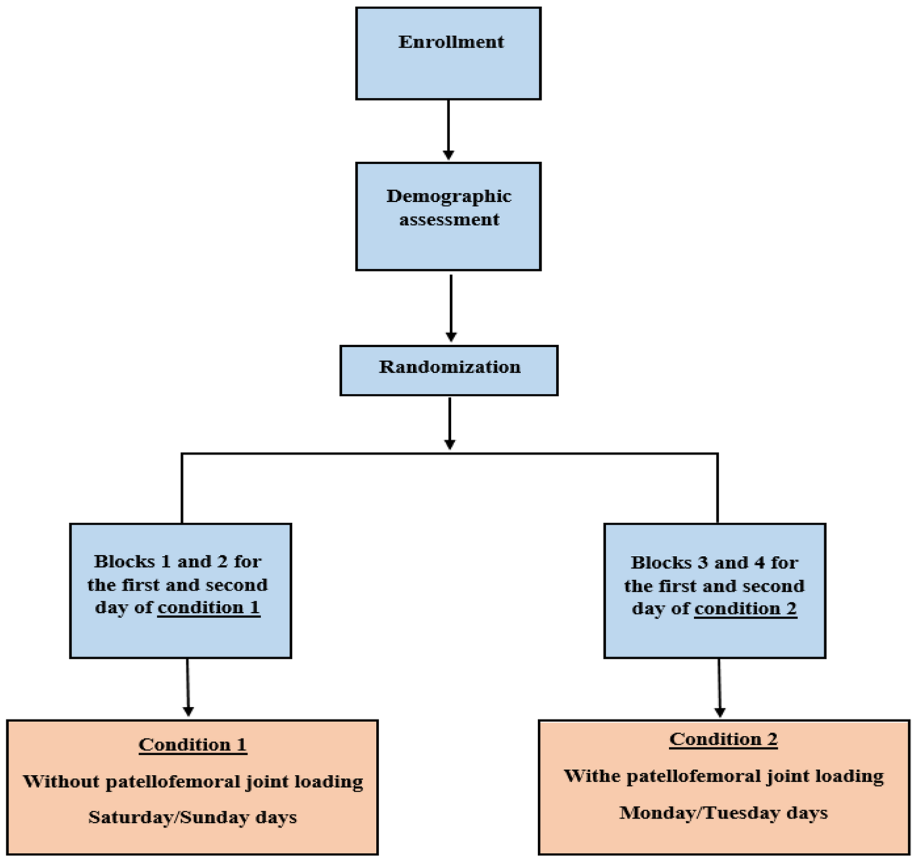

Fig. 1 It shows the study process with details

flexion patellofemoral joint stress is very little. Secondly, 60 ∘ of knee flexion has been highlighted as a pertinent angle in PFP pathology and significance of this angle was underlined by functional motion analysis. Thirdly, and eventually, most of daily activities are performed in the knee flexion angle between 20∘ to 60 ∘. Of note, to control knee flexion, we used a flexible electro-goniometer (M180, Biometrics Ltd, Gwent, UK) (ICC = 0.85) [33] that was attached to the knee joint.

The physiotherapist taught the patients to perform three trial of squats at a standard speed at the 5 s. Using a counter, the first count was considered as the start of the squat, the third count was the lowest point of the squat, and the fifth count was as the return to the starting position. Before starting the assessment, the patients were familiar with the test and practiced the trial 3 times. A 2-min rest was considered between each trial to minimize fatigue. Finally, patients were instructed to perform squats with knee flexion angles between 45∘ and 60∘, maintaining balance and ensuring that the heels remained in contact with the floor.

Data analysis

A digital camera was placed at a distance of 4 m from the behind of the patient [25]. A physiotherapist attached a marker on the insertion center of the Achilles tendon [25]. The rear foot eversion angle was calculated using Quinoa software version 33 (ICC = 0.99) [34] at the lowest point of the squat. Quinoa is a valid and reliable software method which measure in accurate way at distances up to 5 m from the subject with angle range of 45∘ – 90∘ [34]. The angle subtended between the lines that formed the insertion of the Achilles tendon to the vertical line was recorded as the rear foot eversion angle [25]. Of note, the images were coded for blinding. Finally, the average of three trials was used for statistical analysis.

Raw data of plantar pressure distribution was analyzed by Win FDM-S software (Zebris Medical GmbH, Isnyim Allgau, Germany) that reported the average percentage of pressure in the forefoot and rear foot region, as well as for the right and left foot. Of note, the patients were blinded to the computer monitor, which showed values in percentages and the color scale of force distribution (Fig. 2). We calculated the plantar pressure symmetry of the forefoot and rear foot using Eq. 1 and the right and

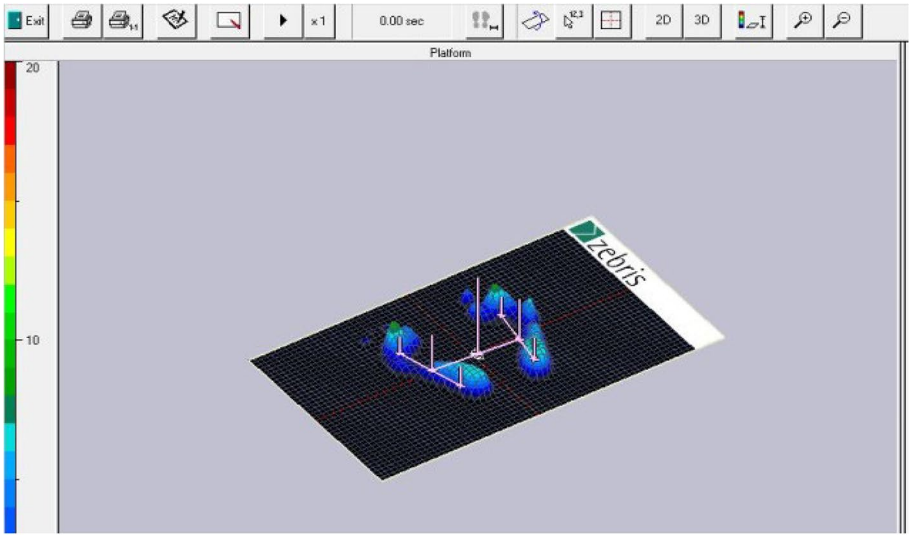

Fig. 2 Display of foot pressure distribution in Win FDM-S software

left foot using Eq. 2 [35]. Overall, the pressure distribution normal in the forefoot and rear foot region has been reported as 33% and 66%, respectively [35]. Furthermore, the pressure distribution normal under the right and left of the foot is 50% [35]. Specifically, a SI < 0.50 indicates a high pressure in the right foot, and SI > 0.50 indicates a high pressure in the left foot. In addition, a SI > 33 indicate the high pressure in the forefoot and vice versa a SI < 33 indicate the high pressure in the rear-foot [36].

$$SI = \frac{Forward\ Pressure}{Forward\ Pressure + Backward\ Pressure} \quad (1)$$

$$SI = \frac{Right\ Pressure}{Right\ Pressure + Left\ Pressure} \quad (2)$$

Statistical analysis

After assessment and verification of the normal distribution of the data with the Shapiro–Wilk test. Consistent with previous studies with the same aim [4, 17] the Pearson's correlation was used to evaluate the relationship between the pain intensity with the rear foot eversion and the plantar pressure distribution symmetry. The score change (i.e. the final score) from condition 1 to condition 2 (i.e. condition 1- condition 2 = score change) was used to calculate the correlation [1]. The positive and negative values indicate higher values in condition 1 and condition 2, respectively [1]. Finally, correlation was interpreted in four categories poor (r = 0.00—0.25), fair (r = 0.25—0.50), moderate to good (r = 0.50—0.75), or excellent (r = 0.75—1) [37].

In addition, consistent with previous studies with the same goal the multivariate analysis of variance (MANOVA) test was used to compare the results between the two conditions [4, 17]. Moreover, descriptive statistics including mean and standard deviation, percentage of changes, confidence interval and mean difference were reported for all variables. Using parietal eta squared (η^2) data, the effect size was interpreted as small (d < 0.20), medium (d = 0.21–0.79), and large (d > 0.80) [38]. All statistical analyses were performed with SPSS version 26 software and the significance level was set at $p < 0.05$.

Results

Table 1 showed no significant difference in the demographic characteristics (age: 38.90 ± 3.33 years; height: 169.53 ± 4.6 cm; mass: 59.13 ± 3.9 kg; BMI: 20.66 ± 1.53 kg/m^2; pain duration: 11.52 ± 3.14 months; kujala score: 49.81 ± 8.70 points); So the data distribution is normal ($p > 0.05$). The comparison between the two conditions showed a significant difference in pain intensity ($P < 0.001$;

Table 1 Baseline demographic characteristics data

Variables	Mean ± SD	*P*-value
Age (years)	38.90 ± 3.33	0.166
Height (cm)	169.53 ± 4.6	0.330
Weight (kg)	59.13 ± 3.9	0.203
BMI (kg/m^2)	20.66 ± 1.53	0.153
Pain duration (months)	11.52 ± 3.14	0.127
Kujala score (points)	49.81 ± 8.70	0.142

Abbreviations: *BMI* Body Mass Index, *p*-values (P): based Shapiro–Wilk test, *SD* standard deviation

η^2 = 0.623; CI: 6.77, 7.32; mean ± SD = 7.05 ± 1.09; MD = + 2.72), rear foot eversion (P < 0.001; η^2 = 0.485; CI: 10.98, 11.87; mean ± SD = 11.43 ± 1.96; MD = + 3.35), plantar pressure distribution symmetry of the right-left foot (symptomatic and non-symptomatic limb respectively) (P < 0.001; η^2 = 0.438; CI: 0.440, 0.455; mean ± SD = 0.447 ± 0.02; MD = + 0.044), forefoot and rear-foot of the right foot (symptomatic limb) (P < 0.001; η^2 = 0.607; CI: 0.442, 0.454; mean ± SD = 0.447 ± 0.02; MD = + 0.055), and forefoot and rear-foot of the left foot (non-symptomatic limb) (P < 0.001; η^2 = 0.548; CI: 0.443, 0.455; mean ± SD = 0.448 ± 0.03; MD = + 0.052) (Table 2). Descriptively, the findings showed that after pain exacerbation, self-reported pain and rear foot eversion increased. In addition, after the pain exacerbation, the plantar pressure distribution increased in the forefoot region of the right and left foot (symptomatic and non-symptomatic limb respectively). Also, the findings showed that after the pain exacerbation, the plantar pressure in the left foot (non-symptomatic limb) was higher than in the right foot (symptomatic limb).

Pearson correlation showed an excellent correlation between the pain intensity with rear foot eversion (P < 0.001; r = 0.835) and plantar pressure distribution symmetry of the right-left foot (symptomatic and non-symptomatic limb respectively) (P < 0.001; r = 0.812), forefoot and rear-foot of the right foot (symptomatic limb) (P < 0.001; r = 0.834), and forefoot and rear-foot of the left foot (non-symptomatic limb) (P < 0.001; r = 0.811).

Discussion

The present study for the first time evaluated the effect of pain exacerbation on rear foot eversion and plantar pressure symmetry in women with PFP. Our findings showed that there was a correlation between pain intensity with rear foot eversion and plantar pressure distribution symmetry. Therefore, our hypothesis was supported. A pressure increase in the forefoot region can be due to a kinematics alteration in the trunk and lower limb. Unfortunately, due to the unavailability of Three-dimensional motion analysis, we did not evaluate trunk kinematics and used the findings of previous studies with a similar purpose to argue. Overall, pain can lead to plantar pressure asymmetry which indicates changes in the musculoskeletal chain [14, 39].

The findings of the previous study showed that after the PFP exacerbation, the compensatory movement patterns of the trunk and lower limb may be used to reduce the PFJ stress [22, 23]. In this regard, Briani et al. (2022) reported that trunk leaning forward can increase hip extensor moment and decrease knee extensor moment [22, 23]. Overall, the PFJ stress is dependent on the rate of quadriceps force and knee flexion angle [40]. As a result, patients try to reduce the PFJ stress and subsequently pain by reducing knee extensor moment [22, 23]. Meanwhile, Teng et al. (2020) reported that a 17.8% decrease in PFJ loading was observed following a trunk flexion 10.10° [41]. Although the compensatory mechanism of trunk flexion can be beneficial to reduce the PFJ stress, it may change the relationship between the body's center of mass and center of pressure and finally shift forward the ground reaction force vector [22, 42].

Of note, the center of pressure excursion has correlated with the plantar pressure distribution [35]. Therefore, with the anterior displacement of the center of pressure, a larger part of the body's weight is transferred to the forefoot region, which leads to an higher plantar pressure in this area [43]. In this line, Thijs et al. (2015) reported that greater loading on the second and third metatarsals can transmit higher vertical forces to the knee joint, which is an important factor in identifying individuals at risk of PFP [16]. Furthermore, Rathleff et al. [7] reported that patients with PFP showed more medially oriented loading of the forefoot, which

Table 2 The results of the MANOVA test compare pain, rear foot eversion, and plantar pressure which show there has been a significant difference after pain exacerbation in the interest variables. Descriptive statistics show the changes amount related to the pain, rear foot eversion, and plantar pressure during two conditions

	Condition1		Condition 2		MANOVA results				
Parameter	Mean ± SD	(95% CI)	Mean ± SD	(95% CI)	MD	Δ (%)	F	Eta squared	*P value*
Pain (VAS)	4.33 ± 1.03	(4.06, 4.60)	7.05 ± 1.09	(6.77, 7.32)	+ 2.72	+ 62.81	194.705	0.623 (M)	0.001*
Rear-foot eversion (degree)	8.08 ± 1.47	(7.64, 8.52)	11.43 ± 1.96	(10.98, 11.87)	+ 3.35	+ 41.46	111.330	0.485 (M)	0.001*
SI right vs left (N/ %)	0.396 ± 0.02	(0.389, 0.404)	0.447 ± 0.02	(0.440, 0.455)	+ 0.044	+ 11.11	91.935	0.438 (M)	0.001*
SI forefoot vs rear-foot right (N/ %)	0.392 ± 0.01	(0.387, 0.398)	0.447 ± 0.02	(0.442, 0.454)	+ 0.055	+ 14.03	182.030	0.607 (M)	0.001*
SI forefoot vs rear-foot left (N/ %)	0.396 ± 0.01	(0.391, 0.402)	0.448 ± 0.03	(0.443, 0.455)	+ 0.052	+ 13.13	142.816	0.548 (M)	0.001*

Abbreviations: *MD* mean difference, *SI* symmetrical index, Δ percentage of changes, *CI* confidence interval, *VAS* visual analog scale, * Significant difference, N/ % newton/percentage, L large effect size (>0.80), M medium effect size (0.21-0.79), S small effect size (<0.20)

NOTE. + show an increase

has the potential to transfer harmful forces to the external area of the PFJ and develop PFP [7].

Interestingly, high pressure in the medial forefoot region indicates greater rear foot eversion which can be a risk factor for PFP [44]. Rear-foot eversion could lead to an excessive medial rotation of the tibia [12]. This rotation could induce a compensatory medial rotation of the femur and a lateralization of the patella in relation to the femur, increasing the PFJ stress [12]. Generally, changes in subtalar alignment during the stance can lead to changes in plantar pressure distribution. In this regard, Buldt et al. (2018) reported that people with flat feet have high pressure in the forefoot region [45]. A systematic review found that foot pronation displayed higher pressure, force and contact area values in the medial arch, forefoot and hallux [46]. Reduced pressure and force in the lateral forefoot for foot pronation can be explained by kinematic studies that reported that foot pronation displayed greater frontal and transverse plane motion of the rear-foot and mid-foot [46]. Such motion is associated with subtalar joint pronation, which can result in load being distributed away from the lateral and towards the medial forefoot [47]. Such a foot loading pattern may alter forces acting on the PFJ and finally increase the risk of PFP [7, 12]. Clinically, one of the suspected mechanisms of foot orthotics is that they decrease peak rear-foot eversion, which is associated with less medial loading of the foot and decreased loading at the knee [7]. This could potentially decrease lateral PFJ stress and thereby help treat PFP. Importantly, frontal plane motion of the rear-foot and transverse plane motion of the mid-foot and forefoot may be important clinical [46]. Consistent with the above studies, our results showed that after the pain exacerbation, the rear foot eversion and forefoot pressure distribution increased. Another reason for this finding may be partly due to the inhibiting of the quadriceps and gluteus medius muscles. The quadriceps eccentric contraction has an important role in shock absorption [48, 49]. Therefore, quadriceps avoidance increases loading rate and plantar pressure [23, 50]. In addition, Yalfani et al. (2024) argued that following the PFP exacerbation, the ability of the gluteus medius muscle to control adduction and internal rotation of the hip decreases, and subsequently, dynamic knee valgus and the Q angle increases [4]. Finally, the inward displacement of the lower limb leads to foot pronation, and the loading axis is oriented to the foot medial region [51]. Meanwhile, Elvan et al. (2019) showed that there is a positive correlation between increasing the Q angle and plantar pressure in the forefoot region [52]. Thus, these findings suggest a dynamic interaction between the knee and foot, contributing to PFP etiology.

On the other hand, the findings showed that the left foot (asymptomatic limb) has a higher loading than the right foot (symptoms limb). In general, psychological factors such as fear of movement have a strong correlation with pain and can change movement patterns in women with PFP. In this line, Yalfani & Ahmadi. (2023) reported that patients with PFP use the compensatory mechanism of loading/unloading to avoid pain and catastrophizing [40]. Also, Silva et al. (2015) showed that patients with PFP cautiously performed loading on the symptomatic limb and transferred body weight to the asymptomatic limb to avoid pain catastrophizing [3]. However, the compensatory mechanism of unloading may over time increase the support and loading rate in the asymptomatic limb, ultimately leading to overuse injury and knee osteoarthritis [40]. Specifically, response to pain has a protective aim and is mostly due to central sensitization secondary to persistent nociceptor activity that leads to kinesiophobia in the symptoms limb [28, 53]. Movement planning and movement control are influenced by attention, emotional, memory, cognitive information from the environment, and sensory and perceptual feedback [54]. This point indicate that PFP can bias attention and emotion toward pain processing, resulting in a more rapid onset of kinesiophobia [28]. Moreover, kinesiophobia have play a more important role in self-reported pain, function, and disability and have greater influence on movement impairments in women with PFP [55, 56]. Importantly, change behavior due to kinesiophobia in patients with PFP may change kinematics and lead to detrimental effects at the PFJ [55, 56]. Thus, psychological features are also important to consider in the appropriate treatment of PFP [28]. In support, findings of previous studies showed correlations between concurrent improvements in catastrophizing and kinesiophobia and improvements in pain and function [55, 56]. In addition, Yalfani & Ahmadi (2024) reported following the neuro-psychological intervention in patients with PFP, kinesiophobia decreased and the plantar pressure distribution symmetry improved [28]. Finally, emphasizing psychological factors to reduce kinesiophobia can be useful to restoring proper movement pattern, reducing pain, improve symptoms, and restoring plantar pressure symmetrical.

Limitations

The present study had limitations that must be acknowledged. First, only female volunteers participated in this study. Therefore, since women show a different movement pattern than men, these findings cannot be generalized to men with PFP. Second, due to instrument limitations, we were unable to assess muscle activity and

Three-dimensional motion analysis. Specifically, we use of a digital camera with a low sampling rate (40 Hz) may affect the precision of the kinematic analysis of rear-foot eversion. In this line, a higher sampling rate (e.g., 100 Hz or above) would capture more accurate motion data. Third, since the current study was cross-sectional, it was not able to determine the cause-and-effect relationship. Fourth, we evaluated the effect of the pain exacerbation on rear foot eversion and plantar pressure distribution symmetry in the squat task. Thus, findings may not be generalizable to other challenging activities such as stair negotiations and landing. Fifth, we were unable to assess whether the observed changes were due to proximal or distal faulty mechanics. Therefore, future studies must evaluate the effect of pain exacerbation on rear foot eversion and plantar pressure distribution symmetry in different tasks separately in men and women. In addition, it is recommended that future studies strengthen the present study findings by using electromyography and Three-dimensional motion analyses.

Clinical applications

According to the traditional view, hip and knee muscle weakness may development of PFP. Recently, it has been shown that the compensatory movement pattern can help in the development of PFP intensity [4, 41]. Therefore, the findings of our study highlight the importance of adding the trunk modification program to traditional strengthening exercises [41, 57]. In addition, the use of anti-pronation orthosis and strengthening exercises for the intrinsic foot muscles, such as short foot exercises, can be effective in normalizing the plantar pressure and shock absorption, and prevent the transfer of harmful forces to the knee joint [35, 58, 59].

Conclusion

After the pain exacerbation, the rear foot eversion was greater, and plantar pressure asymmetrical was observed in the forefoot and left foot (asymptomatic limb), which can help in the development of PFP severity and knee osteoarthritis.

Abbreviations

PFP	Patellofemoral pain
PFJ	Patellofemoral joint
SI	Symmetrical index
N	Newton
BMI	Body mass index
SD	Standard deviation

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Authors' contributions

FA initiated the study. MA and AA collected and analyzed the data. FA and MA wrote the manuscript under the supervision of AY. All authors read and approved the final manuscript.

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Data availability

The datasets used and analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee in biomedical research of Bu-Ali Sina University (Number: IR.BASU.REC.1402.012) and before data collection, the patients were informed about the study design and declared their informed consent to participate in this study. Moreover, the researchers adhered to the Declaration of Helsinki of 2008.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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