Accepted Manuscript (Uncorrected Proof)

Title: Effects of Gluteus Medius Neuromuscular Training with Electromyographic Biofeedback on Pain and Function in Individuals with Patellofemoral Pain Syndrome

Authors: Hossein Rabieifar[1], Hoda Niknam[2,*], Khosro Khademi Kalantari[2], Seyyed Morteza Kazemi[3], Mahsa Farajabdollahi[1]

1. *Student Research Committee, Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
2. *Physiotherapy Research Center, Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
3. *Department of Orthopedics, School of Medicine Bone, Akhtar Hospiatl, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

To appear in: ***Physical Treatments***

Received date: 2026/05/4

Revised date: 2026/09/18

Accepted date: 2026/10/6

First Online Published: 2026/11/08

Accepted Manuscript (Uncorrected Proof)

This is a “Just Accepted” manuscript, which has been examined by the peer-review process and has been accepted for publication. A “Just Accepted” manuscript is published online shortly after its acceptance, which is prior to technical editing and formatting and author proofing. ***Physical Treatments*** provides “Just Accepted” as an optional service which allows authors to make their results available to the research community as soon as possible after acceptance. After a manuscript has been technically edited and formatted, it will be removed from the “Just Accepted” Website and published as a published article. Please note that technical editing may introduce minor changes to the manuscript text and/or graphics which may affect the content, and all legal disclaimers that apply to the journal pertain.

Please cite this article as:

Rabieifar H, Niknam H, Khademi Kalantari K, Kazemi SM, Farajabdollahi M. Effects of Gluteus Medius Neuromuscular Training with Electromyographic Biofeedback on Pain and Function in Individuals with Patellofemoral Pain Syndrome. ***Physical Treatments.*** Forthcoming 2027. DOI: http://dx.doi.org/10.22034/ptj.2027.830.1

DOI: http://dx.doi.org/10.22034/ptj.2027.830.1

Accepted Manuscript (Uncorrected Proof)

Abstract

Background: Patellofemoral pain syndrome (PFPS) commonly presents with pain localized to the anterior aspect of the knee and is often associated with impaired hip muscle function. Strengthening of the gluteus medius is frequently recommended in rehabilitation programs for PFPS. Electromyographic (EMG) biofeedback may enhance neuromuscular activation during exercise; however, its additional clinical benefits remain unclear.

Purpose: To compare the effects of gluteus medius neuromuscular training with EMG biofeedback and conventional strengthening exercises on pain intensity and functional status in individuals with PFPS.

Method: In this assessor-blinded randomized controlled trial, 32 individuals with PFPS were randomly assigned using a coin-toss method to either an experimental group (EMG biofeedback plus gluteus medius strengthening) or a control group (gluteus medius strengthening alone). The experimental group additionally performed functional tasks (walking, step-up, step-down, side step-up, and side step-down) with real-time EMG biofeedback. Both groups also received the same standardized physiotherapy program over 10 treatment sessions performed three times per week. Pain intensity was measured by a visual analogue scale (VAS) at pre-intervention |(baseline), post-intervention, and a 1-month follow-up. Functional status was evaluated by KOOS questionnaire at baseline and post-intervention. The data were subjected to a two-way mixed repeated-measures ANOVA.

Results: Twenty-nine participants completed the study (experimental, n = 15; control, n = 14). Pain significantly decreased in both groups following the intervention and remained improved at one-month follow-up (main effect of time, $p < 0.001$). Functional status measured by the KOOS also improved significantly in both groups after treatment (main effect of time, $p < 0.001$). No significant between-group differences were observed following the addition of EMG biofeedback to gluteus medius strengthening (time × group interaction and main effect of group: $p > 0.05$, Partial $\eta^2 \leq 0.02$).

Conclusion: Both rehabilitation programs were associated with improvements in pain and functional status in individuals with PFPS. Because both groups received the same standardized physiotherapy modalities, these findings should be interpreted cautiously. Adding EMG biofeedback-assisted neuromuscular training did not provide additional short-term clinical benefits beyond gluteus medius strengthening alone.

Keyword: Patellofemoral Pain Syndrome; Anterior Knee Pain; Hip Abductor Muscles; Electromyographic Biofeedback; Exercise Therapy

Accepted Manuscript (Uncorrected Proof)

Highlights

- Both multimodal rehabilitation programs were associated with improvements in pain and knee-related function in individuals with PFPS after 10 treatment sessions.
- Adding EMG biofeedback-assisted gluteus medius neuromuscular training did not provide additional short-term clinical benefits beyond gluteus medius strengthening alone.
- Progressive gluteus medius strengthening may represent a useful component of rehabilitation programs for individuals with PFPS.

Plain language summary

Patellofemoral pain syndrome (PFPS) commonly presents with pain localized to the anterior aspect of the knee, especially during activities such as running squatting, climbing stairs, or jumping. Weakness or poor control of the hip muscles, particularly the gluteus medius, may contribute to abnormal lower-limb movement and raised stress on the knee joint. In the present study, adults with PFPS participated in one of two rehabilitation interventions: gluteus medius strengthening exercises alone or the same strengthening program combined with electromyographic (EMG) biofeedback-assisted neuromuscular training. Both rehabilitation programs were associated with improvements in pain and knee-related function after 10 treatment sessions, and the reduction in pain was generally maintained one month later. However, adding EMG biofeedback did not demonstrate greater short-term clinical benefits than strengthening exercises alone. Because this study included a relatively small sample, further investigation involving larger cohorts and extended follow-up is warranted to determine whether these findings can be replicated.

Accepted Manuscript (Uncorrected Proof)

Introduction

Among musculoskeletal conditions affecting the knee, patellofemoral pain syndrome (PFPS) is a frequent cause of anterior knee symptoms, with reported prevalence estimates between 15% and 45%.(1). PFPS is a non-traumatic condition characterized by diffuse pain around or behind the patella that is typically aggravated by activities increasing patellofemoral joint stress, like running, jumping, stair ascent and descent, and squatting (2). Estimates indicate that PFPS occurs annually in 22.7% of the general population and 28.9% of adolescents, and its occurrence appears to be more frequent among females than males (1, 3). Beyond pain, PFPS can substantially impair physical function and quality of life, with its impact on daily activities being comparable to that of knee osteoarthritis (4). Although the etiology of PFPS is multifactorial and includes biomechanical, muscular, and psychological factors, increasing evidence suggests that deficits in lower-extremity biomechanics and hip muscle function play an critical role in the persistence and development of symptoms (5, 6).

Among the biomechanical factors associated with PFPS, impaired function of the gluteus medius has received considerable attention because this muscle plays a key role in controlling hip adduction, internal rotation, and dynamic lower-limb stability during functional activities (7-9). Weakness or impaired neuromuscular control of the gluteus medius may contribute to excessive hip adduction and internal rotation, increased dynamic knee valgus, and greater patellofemoral joint stress, ultimately leading to pain and functional limitations. Consequently, gluteus medius strengthening has become an important component of rehabilitation programs for individuals with PFPS (10). In addition to strengthening exercises, electromyographic (EMG) biofeedback has been proposed as a neuromuscular retraining strategy that provides real-time visual or auditory information about muscle activation, enabling individuals to voluntarily improve motor control and muscle recruitment during functional tasks (11, 12). Therefore, combining gluteus medius strengthening with EMG biofeedback may enhance both muscle capacity and neuromuscular control, potentially improving rehabilitation outcomes.

Exercise-based rehabilitation is commonly used as a key conservative approach in the management of PFPS (13). In recent years, hip muscle function has increasingly been investigated for its potential contribution to the regulation of lower-limb biomechanics (14). Systematic reviews have demonstrated that rehabilitation programs incorporating hip strengthening exercises significantly reduce pain and improve functional outcomes, and that combined hip and knee strengthening may be more effective than knee-focused exercise alone (10, 15). Previous studies have also investigated the use of EMG biofeedback as an adjunct to rehabilitation and reported improvements in selected neuromuscular and clinical outcomes (16, 17). However, the majority of these studies have focused on quadriceps retraining, particularly the vastus medialis and vastus lateralis muscles, whereas the potential benefits of biofeedback-assisted training targeting the gluteus medius have received considerably less attention (18).

Despite growing evidence supporting both hip strengthening and EMG biofeedback in PFPS rehabilitation, it remains unclear whether adding EMG biofeedback-assisted neuromuscular training to gluteus medius strengthening provides additional clinical benefits beyond those achieved with conventional strengthening exercises alone. Addressing this question is

Accepted Manuscript (Uncorrected Proof)

clinically important because improved neuromuscular control during functional activities may offer benefits that are not achieved through strengthening alone. Therefore, the aim of this randomized controlled trial was evaluating gluteus medius neuromuscular training with EMG biofeedback and conventional gluteus medius strengthening exercises on pain intensity and functional status in individuals with PFPS. We hypothesized that the addition of EMG biofeedback would provide additional benefits for pain reduction and functional performance relative to strengthening exercises alone.

Method

Study Design and Participants

A single-blind randomized controlled trial was carried out and reported following the CONSORT (Consolidated Standards of Reporting Trials) recommendations. Ethical approval was obtained from the Ethics Committee of Shahid Beheshti University of Medical Sciences (Ethics code: IR.SBMU.RETECH.REC.1401.840), and the trial was prospectively registered with the Iranian Registry of Clinical Trials (IRCT20230725058919N1). The study procedures adhered to the ethical standards outlined in the Declaration of Helsinki. Before enrollment, all participants received information about the study and provided written informed consent.

The study included male and female adults between 18 and 40 years of age who had received a clinical diagnosis of PFPS.. The diagnosis was established by an experienced orthopedic specialist based on the participants' medical history and a standardized clinical examination. Participants who met the eligibility requirements were recruited using convenience sampling and subsequently allocated at random to either a control (gluteus medius strengthening alone) or an experimental group (EMG biofeedback plus gluteus medius strengthening). Eligibility for participation required the presence of anterior knee pain in the peripatellar region during at least two activities associated with increased patellofemoral joint loading, such as stair climbing or descending, squatting, kneeling, jumping, or running. Additional criteria were a visual analogue scale (VAS) pain score of 3–8 cm on a 10-cm scale, symptoms persisting for at least 3 months, a BMI of 20–30 kg/m², and a positive patellar grind test accompanied by tenderness over either the medial or lateral patellar facets. Participants were excluded if they had patellar tendon injury, knee chondral lesions, osteoarthritis, referred pain from the lumbar spine, neuromuscular or rheumatologic disorders, metabolic diseases associated with neuropathy, or pregnancy. Individuals with a history of lower-extremity trauma or surgery within the previous 12 months, patellar dislocation or subluxation, meniscal or ligament injuries, or those who had received medical or physical therapy treatment for knee pain during the previous three months were also excluded. Imaging was not routinely performed because PFPS is primarily a clinical diagnosis, and participants with clinical findings suggestive of other knee pathologies were excluded during the orthopedic examination. Moreover, participants with BMI values above 30 kg/m² were excluded to minimize the potential confounding effects of obesity on lower-limb biomechanics and patellofemoral joint loading.

Accepted Manuscript (Uncorrected Proof)

Randomization and Blinding

The first participant was allocated to one of the two study groups using a coin toss. To maintain similar group sizes throughout the recruitment period, subsequent participants were assigned alternately to the two groups. Although this procedure ensured balanced group sizes, it may have reduced allocation concealment because future assignments became predictable. Owing to the nature of the interventions, blinding of the participants and treating therapist was not feasible. To minimize the risk of assessment bias, all outcome measures were obtained by an independent assessor who was unaware of the participants' group assignments. .

Sample Size Calculation

An a priori sample size calculation was performed in G*Power (version 3.1), assuming a medium effect size (f = 0.37), a 5% significance threshold, and 95% statistical power (19). The estimated minimum sample size required to detect a significant difference between groups was 26 participants (13 per group). Considering a potential dropout rate of approximately 15–25%, a total of 32 individuals (16 in each group) were recruited for the study.

Outcome Measures

Pain severity was determined with a 10-cm VAS, ranging from 0 (no pain) to 10 (worst imaginable pain). Each participant independently rated their perceived pain intensity on this scale.

Functional status was evaluated using the Knee Injury and Osteoarthritis Outcome Score (KOOS) (20). The KOOS is a patient-reported, self-administered questionnaire consisting of 42 items divided into five subscales: pain (9 items), symptoms (7 items), activities of daily living (17 items), sport and recreation function (5 items), and knee-related quality of life (4 items). Each item is rated on a five-point Likert scale (0–4). Raw scores for each subscale are transformed to a 0–100 scale, where higher scores indicate fewer knee-related problems and better functional status. The KOOS has been widely used to assess symptoms and functional limitations in individuals with various knee disorders. Although originally developed for knee injury and osteoarthritis, the KOOS has also been used in individuals with PFPS because it provides a comprehensive assessment of pain, function, and knee-related quality of life (21, 22). The Persian version of the KOOS questionnaire has been reported to have acceptable reliability and validity (23).

Functional outcomes were measured with the Knee Injury and Osteoarthritis Outcome Score (KOOS) (20), a self-administered patient-reported measure comprising 42 items across five domains: pain (9 items), symptoms (7 items), activities of daily living (17 items), sport and recreational function (5 items), and knee-related quality of life (4 items). Responses are scored from 0 to 4 using a five-point Likert scale, after which the scores for each domain are converted to a 0–100 scale. Higher KOOS scores represent fewer knee-related difficulties and better functional status. Although the KOOS was initially developed for the assessment of knee injury and osteoarthritis, its use has subsequently been extended to other knee conditions, including PFPS, as it captures multiple aspects of pain, physical function, and knee-related quality of life

Accepted Manuscript (Uncorrected Proof)

(21, 22). The Persian-language version of the KOOS has demonstrated acceptable measurement properties, including reliability and validity (23).

Interventions

Both groups received a standardized physiotherapy program in addition to gluteus medius strengthening exercises. The physiotherapy intervention included transcutaneous electrical nerve stimulation (TENS) for 15 minutes prior to exercise to reduce pain, pulsed ultrasound therapy (75% duty cycle, 1.2 W/cm²) for three minutes, and infrared therapy for five minutes. Participants also performed quadriceps strengthening exercises, including short-arc knee extension and straight-leg raise with hip external rotation, as well as stretching exercises for the hamstring and gastrocnemius muscles. These modalities were administered before the gluteus medius exercise program as part of the clinic's routine standardized physiotherapy protocol and were applied identically to both groups to ensure consistency of background treatment.

Conventional gluteus medius strengthening exercises were performed by participants in both groups using a progressive four-stage protocol (Table 1). The program began with side-lying hip abduction combined with external rotation while the hip and knee were flexed, maintaining a neutral lumbopelvic position through activation of the transversus abdominis. The program then progressed to side-lying hip abduction with the knee fully extended to increase the resistance through a longer lever arm while maintaining the hip in slight extension and less than 25° of external rotation to maximize gluteus medius activation. Once participants were able to complete two sets of 15 repetitions with proper technique, the exercise was advanced to hip abduction in a quadruped position against gravity. In the final stage, external resistance was progressively increased using elastic resistance bands or ankle weights. Resistance was increased by approximately 0.5 kg whenever participants successfully completed two sets of 15 repetitions with proper technique. Participants were instructed to avoid pain exacerbation greater than two points on the VAS during exercise. If this threshold was exceeded, exercise intensity or the number of repetitions was reduced accordingly. Exercise sessions for both groups were conducted three times per week for a total of ten sessions, with each session lasting approximately 20–30 minutes.

Accepted Manuscript (Uncorrected Proof)

Table 1. Progressive Gluteus Medius Strengthening Protocol and Progression Criteria for Both Study Groups

Stage	Exercise	Exercise Description	Progression Criterion
1	Side-lying hip abduction with external rotation	Performed in side-lying with the hip and knee flexed. Participants maintained a neutral lumbopelvic position through activation of the transversus abdominis while lifting the upper knee (hip abduction and external rotation) with the feet together. The movement was stopped at the onset of pelvic rotation.	Initial exercise stage.
2	Side-lying hip abduction	Performed in side-lying with the knee fully extended to increase the resistance through a longer lever arm. The hip was maintained in slight extension and <25° external rotation to optimize gluteus medius activation while minimizing tensor fascia lata activity.	Progressed after correct performance of Stage 1.
3	Quadruped hip abduction	Hip abduction was performed against gravity in the quadruped position.	Initiated after successful completion of **2 sets × 15 repetitions** with proper technique.
4	Progressive resisted hip abduction	External resistance was added using elastic resistance bands or ankle weights. Resistance was applied above the knee during Stage 1 and around the ankle during Stages 2 and 3. External load was progressively increased by approximately 0.5 kg (1 lb) according to participant performance.	External resistance was increased whenever participants successfully completed 2 sets × 15 repetitions with proper technique while limiting pain exacerbation to ≤2 points on the 10-cm VAS.

Footnote: Progression to the next stage was based on successful completion of the prescribed exercise with proper technique while limiting pain exacerbation to no more than two points on the 10-cm VAS

Accepted Manuscript (Uncorrected Proof)

In addition to the conventional gluteus medius strengthening exercises, participants in the experimental group performed functional tasks while receiving real-time visual EMG biofeedback using a portable EMG biofeedback device (Tab-o-Sanat Sharif, Iran) to facilitate activation of the gluteus medius muscle. Surface electrodes were placed over the gluteus medius muscle according to the manufacturer's recommendations. Before each task, participants were instructed to increase gluteus medius activation at the onset of movement and maintain this level throughout the task while monitoring the visual EMG biofeedback display. Functional tasks included walking, step-up, step-down, side step-up, and side step-down. Walking was performed for four 1-minute sets with 30 seconds of rest between sets. The remaining functional tasks were each performed for 20 repetitions per session, with a 30-second rest after every five repetitions. Task difficulty was progressively increased across treatment sessions by reducing the EMG biofeedback gain, so that participants were required to maintain muscle activation while the visual feedback represented a maximum of approximately 50% of their maximal activation level.

Outcome measures were reassessed after completion of the intervention period. Pain intensity was also evaluated one month after the end of the intervention to examine short-term follow-up effects.

Statistical Analysis

Descriptive statistics were used to summarize participant characteristics and outcome measures. The normality of data distribution was assessed using the Shapiro–Wilk test. The assumptions for mixed repeated-measures ANOVA were evaluated before analysis. Homogeneity of variance between groups was assessed using Levene's test, and the sphericity assumption was evaluated using Mauchly's test. To examine changes in both outcome measures over time, a two-way mixed repeated-measures analysis of variance (ANOVA) was performed, with time as the within-subject factor and group as the between-subject factor. Within-group changes in pain intensity across the three measurement times were further examined using repeated-measures analysis of variance. Because functional outcome (KOOS score) was assessed at only two time points (baseline and post-intervention), within-group comparisons were performed using paired t-tests. Statistical analyses were performed using SPSS software (version 27), and the significance level was set at $p < 0.05$.

Participant characteristics and study outcomes were summarized using descriptive statistics. The Shapiro–Wilk test was applied to assess the distributional normality of the data. Prior to conducting the mixed repeated-measures ANOVA, the relevant statistical assumptions were examined. Levene's test was used to determine whether variance was comparable between the study groups, whereas Mauchly's test was employed to assess sphericity. Changes in the outcome measures over time were analyzed using a two-way mixed repeated-measures ANOVA, with measurement time specified as the within-subject factor and treatment group as the between-subject factor. For pain intensity, which was recorded at three assessment points, within-group changes were additionally evaluated using repeated-measures ANOVA. Since KOOS was measured only before and after the intervention, within-group differences in functional outcomes were assessed using paired-samples t-tests. All statistical procedures were conducted in SPSS version 27. Statistical significance was defined as $p < 0.05$.

Results

In total, 32 participants were initially enrolled. During the intervention period, three participants (two females and one male) withdrew from the study because of low back pain symptoms, personal reasons or inability to attend the scheduled treatment sessions, as detailed in the participant flow diagram (Figure 1). As a result, 29 participants completed the intervention and were included in the final statistical analysis (control group: $n = 14$; experimental group: $n = 15$) (Figure 1).

Table 2 summarizes the participants' demographic characteristics. No significant between-group differences were observed in age, height, body weight, BMI, or sex distribution (all $p > 0.05$). The normality assessment showed no significant departure from a normal distribution for either group at any assessment point ($p > 0.05$). Levene's test also showed that the assumption of equal variances was satisfied ($p > 0.05$), while Mauchly's test indicated that the sphericity assumption was met for the repeated-measures analysis ($p > 0.05$). Therefore, no correction for violations of sphericity was required. As shown in Table 3, independent-samples

Accepted Manuscript (Uncorrected Proof)

t-tests revealed no significant baseline differences between the groups in pain intensity or functional status before the intervention.

Pain Intensity

Table 3 summarizes the descriptive statistics for pain intensity at baseline, post-intervention, and follow-up. The statistical findings of the two-way mixed ANOVA are shown in Table 4, whereas post hoc within-group comparisons are shown in Table 5.

Analysis of pain intensity revealed a significant effect of time ($p < 0.001$), with pain scores showing an overall decline across the assessment period. In contrast, neither the between-group effect nor the group-by-time interaction reached statistical significance ($p > 0.05$). Thus, the pattern of pain reduction over time was similar in both groups.

Within-group comparisons showed that in the biofeedback + exercise group, pain intensity was significantly lower at both post-intervention and follow-up assessments than at baseline ($p < 0.001$), whereas the difference between the post-intervention and follow-up assessments was not significant. The exercise-only group demonstrated a comparable pattern, with significant decreases in pain intensity at both post-intervention and follow-up relative to baseline, but no significant change between these two post-baseline assessments.

Functional Status

Descriptive statistics for functional status measured by the KOOS questionnaire are presented in Table 3. The results of the two-way mixed analysis of variance are shown in Table 4, and the results of the within-group comparisons are reported in Table 5.

The analysis revealed a significant main effect of time on functional status ($p < 0.001$), with functional outcomes improving across the assessment periods. In contrast, neither the main effect of group nor the group-by-time interaction reached statistical significance ($p > 0.05$), indicating that the changes in functional status over time did not differ significantly between the two groups.

Within-group comparisons indicated that in the biofeedback + exercise group, functional status significantly had more improvement at post-intervention than baseline ($p < 0.001$). The same pattern was observed in the exercise group, with a significant improvement in functional status at post-intervention compared with baseline.

Accepted Manuscript (Uncorrected Proof)

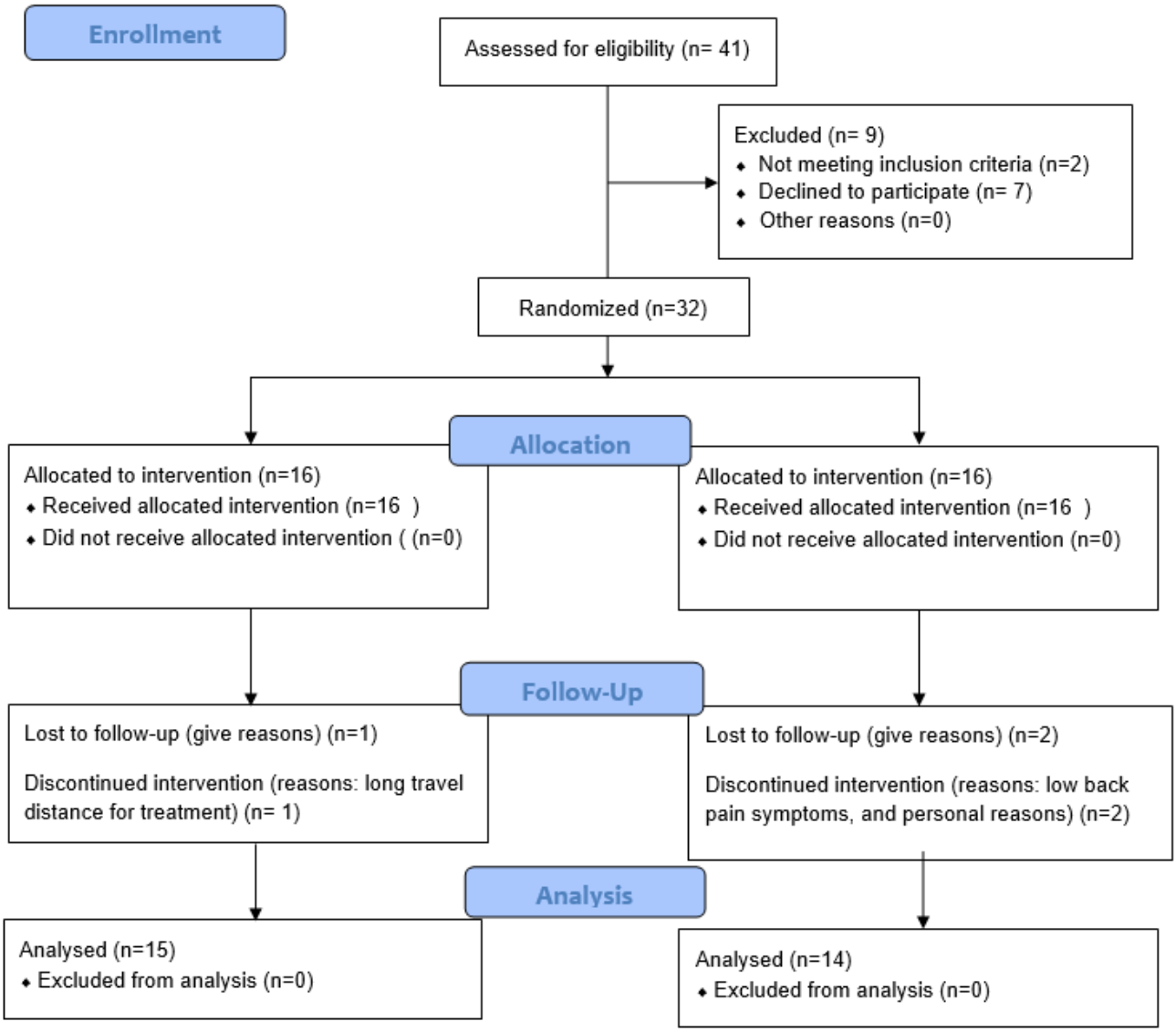


Figure 1. CONSORT flowchart

Table 2. Demographic characteristics of participants in the two groups

Variables	Biofeedback + Exercise (n=15), Mean ± SD	Exercise (n=14), Mean ± SD	p-value
Age (years)	31.50 ± 4.18	32.27 ± 3.15	0.580
Height (cm)	162.07 ± 9.07	169.00 ± 7.29	0.982
Weight (kg)	67.79 ± 11.15	71.20 ± 8.19	0.353
BMI (kg/m^2)	23.65 ± 3.07	24.87 ± 1.58	0.188
Sex (M/F)	7 / 8	6 / 8	0.627

Accepted

Table 3. Mean ± SD of pain intensity and functional status at different assessment times

Outcomes	Group	Baseline, Mean ± SD	Post-intervention, Mean ± SD	Follow-up, Mean ± SD	Baseline p-value
Pain intensity	Biofeedback + Exercise	4.85 ± 1.29	2.31 ± 1.35	2.83 ± 1.65	0.833
	Exercise	4.95 ± 1.16	2.85 ± 1.14	2.43 ± 1.14	
Functional status	Biofeedback + Exercise	63.04 ± 15.71	78.38 ± 13.75	—	0.678
	Exercise	57.58 ± 11.40	76.35 ± 12.28	—	

Table 4. The results of two-way mixed ANOVA

Outcomes	Main effect of time		Time × group interaction		Main effect of group	
	P-value	Partial η^2	P-value	Partial η^2	P-value	Partial η^2
Pain intensity	0.0001**	0.798	0.40	0.01	0.863	0.001
Functional status	0.0001**	0.42	0.411	0.02	0.471	0.01

*P<0.05, ** P<0.001

Table 5. The results within-group comparison

Outcomes	Group	Assessment times		Mean difference	P-value
Pain intensity	Biofeedback + Exercise	Baseline	Post-intervention	2.48	0.0001**
			Follow-up	2.30	0.0001**
		Post-intervention	Follow-up	0.51	0.128

Accepted Manuscript (Uncorrected Proof)

	Exercise	Baseline	Post-intervention	2.10	0.0001**
			Follow-up	2.52	0.0001**
		Post-intervention	Follow-up	0.42	0.249
Functional status	Biofeedback + Exercise	Baseline	Post-intervention	15.34	0.0001**
	Exercise	Baseline	Post-intervention	18.76	0.0001**

*P<0.05, ** P<0.001

Discussion

The present trial evaluated the effects of gluteus medius strengthening exercises with and without EMG biofeedback on pain intensity and functional status in people with PFPS. The findings showed that both interventions led to significant improvements over time. Specifically, pain intensity decreased significantly in both groups from baseline to post-intervention and from baseline to the one-month follow-up, while functional status measured by the KOOS questionnaire increased significantly from baseline to post-intervention. It should be noted that both groups also received the same standardized physiotherapy program, including TENS, ultrasound, and infrared therapy, before the exercise intervention. Therefore, the improvements observed in pain and function likely reflect the combined effects of routine physiotherapy and progressive exercise rather than strengthening exercises alone. Because both groups received identical electrotherapy modalities before the exercise intervention, part of the observed reduction in pain may also be attributable to the analgesic effects of these adjunctive treatments. Contrary to our original hypothesis, the addition of EMG biofeedback did not result in greater improvements in pain intensity or functional outcomes compared with conventional gluteus medius strengthening alone. Although both interventions produced significant improvements over time, the absence of significant between-group differences suggests that adding EMG biofeedback to a structured gluteus medius strengthening program combined with routine physiotherapy did not confer additional short-term clinical benefits for pain or functional outcomes.

The improvements observed in pain intensity and functional status are generally consistent with previous evidence supporting the role of hip muscle strengthening in the management of PFPS (10, 15, 24). Several studies have reported that strengthening the hip abductors and external rotators can improve lower-limb biomechanics while also enhancing neuromuscular control and movement quality during functional activities. These mechanisms are believed to reduce patellofemoral joint loading and contribute to improvements in pain and functional performance in individuals with PFPS (10, 15, 24).

Despite these improvements, the statistical findings did not indicate significant between-group differences for pain or functional outcomes. One possible explanation is that both groups

Accepted Manuscript (Uncorrected Proof)

received similar baseline physiotherapy interventions and strengthening exercises targeting the gluteus medius muscle. Because these exercises are known to be beneficial in improving pain and function in PFPS, the additional biofeedback component may not have produced a sufficiently large incremental effect to create a statistically significant difference between groups. In other words, while biofeedback may enhance neuromuscular awareness and motor control (25), its added value for clinical outcomes such as pain and functional performance may be limited when effective strengthening programs are already implemented.

Previous studies investigating the use of EMG biofeedback in knee rehabilitation have reported findings similar to those of the present study (26-28). Several clinical trials demonstrated that although the addition of biofeedback to rehabilitation programs may improve muscle activation patterns, it does not necessarily lead to greater reductions in pain or improvements in functional outcomes compared with exercise therapy alone in individuals with PFPS (26-28). Similar observations have also been reported in other knee conditions. For instance, studies in patients following knee surgery have shown that while biofeedback may enhance neuromuscular recovery and accelerate certain aspects of rehabilitation, it does not consistently produce superior improvements in pain or functional outcomes compared with conventional exercise-based rehabilitation programs (29-31). Collectively, these findings suggest that biofeedback interventions may primarily influence neuromuscular control rather than directly improving clinical outcomes such as pain and functional disability.

Another possible explanation for the absence of significant between-group differences relates to the multifactorial nature of pain in PFPS. Pain in these patients is influenced by a complex interaction of biomechanical, psychological, and behavioral factors (32, 33). Chronic musculoskeletal pain, including PFPS, is increasingly understood within a biopsychosocial framework in which psychological factors such as fear of movement, anxiety, depression, and pain catastrophizing may influence pain perception and functional limitations (34, 35). Studies have demonstrated associations between psychological factors and pain intensity in individuals with PFPS (36, 37). Because the present study primarily targeted neuromuscular factors through strengthening and biofeedback training, other factors influencing pain may have remained unchanged, potentially limiting the observable differences between interventions.

From a clinical perspective, the present findings suggest that progressive gluteus medius strengthening should remain a core component of PFPS rehabilitation. Although EMG biofeedback did not produce superior clinical outcomes, it may still serve as an adjunctive tool for facilitating neuromuscular awareness and motor learning in selected patients.

To our knowledge, this is one of the few randomized controlled trials to specifically evaluate EMG biofeedback targeting the gluteus medius muscle rather than the quadriceps in individuals with PFPS. Although no additional clinical benefit was demonstrated, these findings provide valuable evidence regarding the role of hip-focused biofeedback within contemporary rehabilitation programs.

The follow-up findings of the present study indicated that the reduction in pain observed after the intervention was largely maintained one month after the completion of treatment in both groups. Although slight fluctuations in pain levels were observed between the post-intervention

Accepted Manuscript (Uncorrected Proof)

and follow-up assessments, these changes were not statistically significant. The persistence of these improvements may reflect the short-term effects of the rehabilitation program, which may have encouraged participants to continue similar activities after the treatment period. Interestingly, a small increase in pain was observed in the biofeedback group at follow-up; however, this change was not statistically significant and may suggest that longer intervention periods or additional training sessions could be required to achieve more stable long-term neuromuscular adaptations with biofeedback-based training.

Limitations and Suggestions

Several limitations should be taken into account when interpreting the findings of this study. The first relates to the relatively small sample size,, partly due to the difficulty of recruiting individuals with PFPS and maintaining their participation throughout the intervention period. Second, participants were recruited using convenience sampling, which may have introduced selection bias and limited the generalizability of the findings to the broader PFPS population. Third, although participants with obesity (BMI >30 kg/m²) were excluded, the inclusion of both normal-weight and overweight individuals may have introduced some variability in lower-limb biomechanics and clinical outcomes. Fourth, participants' physical activity levels were not objectively measured or recorded, and the sample was not limited to a specific population such as athletes or runners. Because physical activity may influence pain severity, muscle performance, and response to rehabilitation, this factor may have contributed to heterogeneity in treatment response. Fifth, both groups received adjunctive physiotherapy modalities, including TENS, ultrasound, and infrared therapy, as part of the standardized treatment program. Although these modalities were applied equally to both groups, they may have contributed to pain reduction, making it difficult to attribute improvements in pain solely to the exercise interventions. Sixth, all outcome measures used in this study were patient-reported and therefore inherently subjective, making them potentially susceptible to response bias. The inclusion of objective measures, such as hip muscle strength, EMG activity, movement analysis, or functional performance tests, would provide a more comprehensive and objective evaluation of treatment effects. Seventh, PFPS is a multifactorial condition involving biomechanical, muscular, and neuromuscular factors, and it was not possible to classify participants based on these underlying mechanisms. Potential confounding variables, particularly psychosocial factors known to influence pain perception, could also not be fully controlled. Finally, although the outcome assessor was blinded, the therapist delivering the intervention could not be blinded, which may have introduced some degree of performance bias.

Future studies should consider longer follow-up periods to determine whether the observed improvements in pain and functional outcomes are maintained over time. Studies with larger sample sizes are also recommended to increase statistical power and reduce the potential influence of confounding variables. In addition, including a control group receiving routine physiotherapy may help better clarify the specific contribution of strengthening or biofeedback-based interventions. From a clinical perspective, EMG biofeedback-assisted training may be considered as a complementary strategy to facilitate neuromuscular awareness during rehabilitation. However, further high-quality studies with larger participant samps, extended

Accepted Manuscript (Uncorrected Proof)

follow-up periods, and objective outcome measuresare needed to determine whether it provides clinically meaningful advantages over conventional strengthening programs.

Conclusion

The present trial indicate that both intervention programs were associated with improvements in pain intensity and functional outcomes in individuals with PFPS. Because both groups also received the same standardized physiotherapy modalities, these improvements should be interpreted as reflecting the combined effects of multimodal rehabilitation rather than strengthening exercises alone. The addition of EMG biofeedback did not provide additional short-term clinical benefits beyond conventional gluteus medius strengthening. Future randomized controlled trials should include larger participant samples, extended follow-up periods, and objective measures of outcome to further to clarify the role of hip-focused EMG biofeedback in PFPS rehabilitation.

Research Ethics Statement: The study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (Ethics code: IR.SBMU.RETECH.REC.1401.840), registered in the Iranian Registry of Clinical Trials (IRCT20230725058919N1)

Conflict of Interest Statement: The authors declare that there is no conflict of interest

Authors' Contribution: Conceptualization: Hoda Niknam and Seyyed Morteza Kazemi; Methodology: Khosro Khademi Kalantari and Hossein Rabieifar; Investigation: Hossein Rabieifar; Statitical Analysis: Hossein Rabieifar; Writing-original draft: Mahsa Farajabdollahi and Seyyed Morteza Kazemi, and editing: Khosro Khademi Kalantari and Hoda Niknam.

Funding Statement: There was no funding for this research

AI Use Statement: We used ChatGPT for editing the manuscript.

Informed consent: Written informed consent or assent (as appropriate) was obtained from all participants and their legal guardians.

Consent for publication: It has not been published elsewhere, and that it has not been submitted simultaneously for publication elsewhere.

Accepted Manuscript Corrected Proof

References

1. Smith BE, Selfe J, Thacker D, Hendrick P, Bateman M, Moffatt F, et al. Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. PloS one. 2018;13(1):e0190892.
2. Crossley KM, van Middelkoop M, Callaghan MJ, Collins NJ, Rathleff MS, Barton CJ. 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). British journal of sports medicine. 2016;50(14):844–52.
3. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scandinavian journal of medicine & science in sports. 2010;20(5):725–30.
4. Coburn SL, Barton CJ, Filbay SR, Hart HF, Rathleff MS, Crossley KM. Quality of life in individuals with patellofemoral pain: a systematic review including meta-analysis. Physical Therapy in Sport. 2018;33:96–108.
5. Neal BS, Lack SD, Lankhorst NE, Raye A, Morrissey D, Van Middelkoop M. Risk factors for patellofemoral pain: a systematic review and meta-analysis. British journal of sports medicine. 2019;53(5):270–81.
6. Na Y, Han C, Shi Y, Zhu Y, Ren Y, Liu W. Is isolated hip strengthening or traditional knee-based strengthening more effective in patients with patellofemoral pain syndrome? A systematic review with meta-analysis. Orthopaedic journal of sports medicine. 2021;9(7):23259671211017503.
7. Xie P, István B, Liang M, editors. The relationship between patellofemoral pain syndrome and hip biomechanics: A systematic review with meta-analysis. Healthcare; 2022: MDPI.
8. Payne K, Payne J, Larkin TA. Patellofemoral pain syndrome and pain severity is associated with asymmetry of gluteus medius muscle activation measured via ultrasound. American journal of physical medicine & rehabilitation. 2020;99(7):595–601.
9. Syed N, Veqar Z, Khan S, Khan Z. Gluteus medius muscle activity in patellofemoral pain syndrome during squats: A Systematic Review. Journal of Bodywork and Movement Therapies. 2024;40:1536–43.
10. Zhang Z, Zhang Z, Zheng B, Yang Y, Sun Y. Effects of lower limb strengthening training on lower limb biomechanical characteristics and knee pain in patients with patellofemoral pain: a systematic review and meta-analysis. European Journal of Medical Research. 2025;30(1):90.
11. Daryabor A, Naghizad J, Jamehbozorgi A, Kalantari KK, Rezaei M. The evaluation of electromyography biofeedback on proprioception and balance in healthy young athletes. Journal of Modern Rehabilitation. 2023.
12. Goodarzi Z, Jamebozorgi AA, Irani A, Baghban AA, Daryabor A. Effect of visual biofeedback on fine motor function and activity daily of life in stroke patients: A pilot study. Journal of Bodywork and Movement Therapies. 2025;41:109–14.
13. van der Heijden RA, Lankhorst NE, van Linschoten R, Bierma-Zeinstra SM, van Middelkoop M. Exercise for treating patellofemoral pain syndrome. Cochrane Database of Systematic Reviews. 2015(1).
14. Shadi E, Sheikhhoseini R, Piri H, Seyedi M, Dashkhaneh M, Ebrahimi E. The role of calf muscle strength in shaping proximal joint mechanics during jump-landing in female

Accepted Manuscript (Uncorrected Proof)

athletes with and without dynamic knee valgus. BMC Sports Science, Medicine and Rehabilitation. 2026.
15. Halabi MH, Alturkistani BA, Abuhadi RH, Garout AN, Almuqbil FB, Alshehri MS. The Efficacy of Hip and Knee Muscles Strengthening Versus Knee Muscle Strengthening Alone in Managing Patellofemoral Pain Syndrome: A Systematic Review and Meta-Analysis. Musculoskeletal care. 2025;23(1):e70059.
16. Alonazi A, Hasan S, Anwer S, Jamal A, Parvez S, Alfaiz FAS, et al. Efficacy of electromyographic-biofeedback supplementation training with patellar taping on quadriceps strengthening in patellofemoral pain syndrome among young adult male athletes. International journal of environmental research and public health. 2021;18(9):4514.
17. Hasan S, Alonazi A, Anwer S, Jamal A, Parvez S, Alfaiz FAS, et al. Efficacy of patellar taping and electromyographic biofeedback training at various knee angles on quadriceps strength and functional performance in young adult male athletes with patellofemoral pain syndrome: A randomized controlled trial. Pain Research and Management. 2022;2022(1):8717932.
18. Banan Khojasteh M, Khalkhali Zavieh M, Kalantari KK, Akbarzadeh Baghban A, Daryabor A, Mikaili S. Effect of biofeedback training of hip muscles on pain, muscle strength and their electromyography in patellofemoral pain syndrome. Archives of Rehabilitation. 2024;25(3):520–39.
19. Willy RW, Scholz JP, Davis IS. Mirror gait retraining for the treatment of patellofemoral pain in female runners. Clinical biomechanics. 2012;27(10):1045–51.
20. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. Journal of Orthopaedic & Sports Physical Therapy. 1998;28(2):88–96.
21. Crossley KM, Macri EM, Cowan SM, Collins NJ, Roos EM. The patellofemoral pain and osteoarthritis subscale of the KOOS (KOOS-PF): development and validation using the COSMIN checklist. British journal of sports medicine. 2018;52(17):1130–6.
22. Petersen W, Ellermann A, Rembitzki IV, Scheffler S, Herbort M, Brüggemann GP, et al. Evaluating the potential synergistic benefit of a realignment brace on patients receiving exercise therapy for patellofemoral pain syndrome: a randomized clinical trial. Archives of Orthopaedic and Trauma Surgery. 2016;136(7):975–82.
23. Salavati M, Mazaheri M, Negahban H, Sohani S, Ebrahimian M, Ebrahimi I, et al. Validation of a Persian-version of Knee injury and Osteoarthritis Outcome Score (KOOS) in Iranians with knee injuries. Osteoarthritis and Cartilage. 2008;16(10):1178–82.
24. Alammari A, Spence N, Narayan A, Karnad SD, Ottayil ZC. Effect of hip abductors and lateral rotators' muscle strengthening on pain and functional outcome in adult patients with patellofemoral pain: A systematic review and meta-analysis. Journal of back and musculoskeletal rehabilitation. 2023;36(1):35–60.
25. Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. Journal of neuroengineering and rehabilitation. 2013;10(1):60.
26. Dursun N, Dursun E, Kiliç Z. Electromyographic biofeedback–controlled exercise versus conservative care for patellofemoral pain syndrome. Archives of physical medicine and rehabilitation. 2001;82(12):1692–5.
27. Yip SL, Ng GY. Biofeedback supplementation to physiotherapy exercise programme for rehabilitation of patellofemoral pain syndrome: a randomized controlled pilot study. Clinical rehabilitation. 2006;20(12):1050–7.

Accepted Manuscript (Uncorrected Proof)

28. Korkmaz MÇ, Ağırman M, Tolu S, Dinç A, Göktepe AS. Evaluation of the effectiveness of electromyographic biofeedback training in patients with patellofemoral pain syndrome. Haydarpaşa Numune Medical Journal. 2023;63(1):46.
29. Akkaya N, Ardic F, Ozgen M, Akkaya S, Sahin F, Kilic A. Efficacy of electromyographic biofeedback and electrical stimulation following arthroscopic partial meniscectomy: a randomized controlled trial. Clinical rehabilitation. 2012;26(3):224–36.
30. Xie Y-J, Wang S, Gong Q-J, Wang J-X, Sun F-H, Miyamoto A, et al. Effects of electromyography biofeedback for patients after knee surgery: A systematic review and meta-analysis. Journal of Biomechanics. 2021;120:110386.
31. Ananías J, Vidal C, Ortiz-Muñoz L, Irarrázaval S, Besa P. Use of electromyographic biofeedback in rehabilitation following anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Physiotherapy. 2024;123:19–29.
32. Gragnani BC, Hart HF, Forsyth A, Barton CJ, De Oliveira Silva D. Patellofemoral Pain is a Multifactorial Complex Condition; Are We Missing a Multidisciplinary Approach to its Management? Time for a Paradigm Shift. Open Access Journal of Sports Medicine. 2025:1–13.
33. Burns JR, Kennedy JL, Parker AD. Patellofemoral Pain: Correlations between hip strength, pain severity, and function. Philippine Journal of Physical Therapy. 2024;3(2):4–14.
34. Vicenzino BT, Rathleff MS, Holden S, Maclachlan L, Smith BE, de Oliveira Silva D, et al. Developing clinical and research priorities for pain and psychological features in people with patellofemoral pain: an international consensus process with health care professionals. journal of orthopaedic & sports physical therapy. 2022;52(1):29–39.
35. Gilgallon TJ, Kim S, Glaviano NR. The influence of psychological factors on physical activity in individuals with patellofemoral pain. Journal of Sport Rehabilitation. 2024;33(6):461–6.
36. Rethman KK, Mansfield CJ, Moeller J, De Oliveira Silva D, Stephens JA, Di Stasi S, et al. Kinesiophobia is associated with poor function and modifiable through interventions in people with patellofemoral pain: a systematic review with individual participant data correlation meta-analysis. Physical therapy. 2023;103(9):pzad074.
37. Leite OHC, Navarro GJ, Rodrigues NLM, de Paula Gomes CAF, Barton GJ, Vallio CS, et al. Pain, fear, and movement: Cognitive-behavioural connections in patellofemoral pain. Clinical Biomechanics. 2025:106716.

Accepted Manuscript (Uncorrected Proof)