IJBPAS, August, 2026, 15(8): 3942-3953

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

EFFECT OF PLYOMETRIC TRAINING ON PAIN AND QUADRICEPS STRENGTH OF MARATHON RUNNERS SUFFERING FROM PATELLO-FEMORAL PAIN SYNDROME: AN EXPERIMENTAL STUDY

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Received 28th July 2025; Revised 26th Sept. 2025; Accepted 1st Feb. 2026; Available online 1st Aug. 2026

https://doi.org/10.31032/IJBPAS/2026/15.8.10417

ABSTRACT

Background:

Patellofemoral Pain Syndrome (PFPS) is a common overuse injury among marathon runners, often resulting in anterior knee pain and quadriceps muscle weakness. Plyometric training (PT), which utilizes the stretch–shortening cycle, may serve as an effective intervention to enhance quadriceps strength and reduce pain in this population.

Methods:

This experimental study employed a pretest–posttest control group design. Twenty marathon runners (N = 20) diagnosed with PFPS were randomly assigned to either a Plyometric Training Group (PTG, n = 10) or a Control Group (CG, n = 10). The PTG underwent a supervised progressive plyometric training program three times per week for four weeks, while the CG performed routine stretching and strengthening exercises. Pain intensity was measured using the Numerical Pain Rating Scale (NPRS), and quadriceps strength was assessed using the One-Repetition Maximum (1RM) test at baseline and after four weeks.

Results:

Both groups showed significant within-group improvements in pain and strength from pre- to post-intervention ($p < 0.05$, Wilcoxon test). However, between-group comparison (Mann–Whitney U test) revealed that the PTG demonstrated significantly greater changes in pain reduction (ΔNPRS: $p = 0.027$) and strength gain (Δ1RM: $p = 0.000$). The PTG showed an average pain reduction of 1.22 points compared to 0.50 points in the CG, and a mean strength gain of 7.22 kg compared to 2.00 kg.

Conclusion:

Both interventions improved pain and quadriceps strength; however, plyometric training was significantly more effective. These results suggest that incorporating plyometric exercises can provide superior outcomes for marathon runners with PFPS.

Keywords: PFPS, Plyometric Training, Quadriceps Strength, NPRS, 1RM, Pain

INTRODUCTION

Patellofemoral pain syndrome (PFPS) commonly called "runner's knee" is a frequent cause of anterior knee pain in physically active populations and is particularly prevalent among runners. Population studies report that PFPS affects a substantial proportion of active adults, with annual prevalence estimates around 20–30% in general adult populations and higher proportions reported in athletic subgroups **[1, 2]**. Among distance runners the knee is one of the most commonly injured sites and PFPS consistently appears as one of the leading diagnoses, making it an important clinical problem for marathon runners who place high and repetitive loads across the patellofemoral joint **[2, 3]**.

PFPS is a multifactorial condition. Proposed contributors include altered lower-limb kinematics (excessive dynamic valgus), abnormal patellar tracking, muscular deficits (particularly in the quadriceps and hip abductors/external rotators), altered neuromuscular control, overuse and training errors, and structural/anatomic factors such as increased Q-angle or trochlear morphology **[2, 4]**. Of these, quadriceps dysfunction including weakness, delayed activation (especially of vastus medialis obliquus), and poor eccentric control has been repeatedly implicated in the pathomechanics of PFPS and is associated with both the presence of symptoms and impaired function **[4, 5]**.

Exercise therapy is the foundation of conservative management for PFPS and a robust body of evidence shows that targeted exercise programs reduce pain and improve function. Systematic reviews and guideline-level summaries find that strengthening programs focused on the quadriceps and/or hip musculature produce clinically meaningful improvements compared with advice alone **[5, 6]**. Debate continues, however, about the optimal exercise types, dosing, and progression: traditional isolated resistance (e.g., open-chain and closedchain quadriceps strengthening) and hip strengthening approaches both show benefit, and combined, multi-component programs are commonly used in practice **[5, 7]**.

Plyometric training (PT) characterized by rapid stretch-shortening cycle activities (e.g., hops, bounds, drop jumps) has been widely applied in sports to increase muscle power, rate of force development, neuromuscular coordination and dynamic joint stability. Because plyometrics trains both force-production and rapid neuromuscular control during functional, sport-specific movements, there is a strong theoretical rationale for its use in runners with PFPS: improved quadriceps power and eccentric control may normalize patellar tracking during high-load activities, reduce abnormal loading patterns, and enhance shock-absorption during stance, thereby reducing symptom provocation during running. Additionally, plyometrics can transfer to improved running economy and performance metrics important to marathoners **[6, 8]**.

Despite the theoretical advantages, clinical evidence specifically examining the effects of plyometric training for people with PFPS and especially for long-distance/marathon runners remains limited but emerging. Comparative studies in athletic populations (e.g., soccer players) have shown that plyometric programs can increase quadriceps strength and functional performance, though improvements are sometimes smaller than those achieved with focused strength training depending on the protocol and outcomes measured **[8]**. A few clinical trials have explored plyometrics as part of multimodal rehabilitation for PFPS and some recent randomized trials directly comparing plyometric versus other exercise modalities report favorable effects of plyometric or combined programs on pain, function and quadriceps performance; however, heterogeneity in participant characteristics, intervention dose/intensity and outcome measures complicates definitive conclusions **[6, 8, 9]**.

Marathon runners represent a distinct subgroup: their training involves high cumulative loads, long ground contact times at relatively low intensities, and specific neuromechanically demands that may both precipitate and perpetuate PFPS. The interaction between a high-volume running stimulus and an explosive, power-oriented intervention such as plyometric requires careful consideration of load management, progression, and monitoring of symptoms. Translating plyometric protocols typically used in power athletes into safe, effective programs for endurance athletes demands graded progressions emphasizing low-impact plyometric, eccentric control, and integration with running training **[2, 6, 10]**.

Given (a) the high burden of PFPS in runners, (b) the central role of quadriceps strength and neuromuscular control in PFPS pathogenesis, and (c) the mechanistic plausibility and preliminary evidence suggesting plyometric training can improve quadriceps power and functional outcomes, a focused experimental study examining the effect of a structured plyometric training program on pain and quadriceps strength in marathon runners with PFPS is both timely and clinically relevant. Such a study should (i) clearly define inclusion criteria to capture symptomatic marathon runners, (ii) use validated pain and function outcome measures alongside objective quadriceps strength testing (e.g., isokinetic or handheld dynamometry), (iii) report training-load and symptom-monitoring procedures to ensure safety, and (iv) compare plyometrics to an active control (e.g., conventional quadriceps/hip strengthening) to clarify relative efficacy and practical implications for rehabilitation and performance **[5, 6, 8]**.

In summary, while exercise is an established first-line treatment for PFPS and quadriceps/hip strengthening are evidence-based components, plyometric training offers a promising but under-investigated adjunct or alternative especially for runners whose sport requires repeated loading and dynamic control. A rigorously designed experimental trial targeting marathon runners with PFPS would fill an important knowledge gap and could directly inform rehabilitation strategies that both reduce pain and restore the performance capabilities required for endurance running.

MATERIALS AND METHODOLOGY

Participants in the included studies were long-distance or marathon runners clinically diagnosed with Patellofemoral Pain Syndrome (PFPS). The diagnosis was typically based on anterior knee pain during running, squatting, stair climbing, or prolonged sitting, with no evidence of structural knee pathology

Inclusion Criteria

- Male and female marathon or long-distance runners aged 18–45 years **[11]**.
- Diagnosed with PFPS for at least 4 weeks.
- Experiencing anterior or retro-patellar pain during functional activities such as running, squatting, or stair climbing **[12]**.
- Pain intensity of at least 3/10 on the Numerical Pain Rating Scale (NPRS) **[13]**.
- Willingness to participate in a structured plyometric training program.

Exclusion Criteria

- History of knee ligament or meniscal injury or prior knee surgery **[14]**.
- Presence of patellar tendinopathy, iliotibial band syndrome, or osteoarthritis **[15]**.
- Neuromuscular disorders or systemic diseases affecting lower limb function **[16]**.
- Current use of analgesic or corticosteroid medications.

Outcome Measures

1. Numerical Pain Rating Scale (NPRS) – Subjective Outcome

Pain intensity was assessed using the NPRS, a reliable and valid subjective measure where participants rate their pain on a 0–10 scale (0 = no pain, 10 = worst imaginable pain) **[17]**. NPRS has excellent test–retest reliability (ICC = 0.95) and is commonly used in PFPS-related studies to measure change in pain perception following intervention **[18]**.

2. One-Repetition Maximum (1RM) Test – Objective Outcome

Quadriceps strength was evaluated using the 1RM test, which measures the maximum load that can be lifted once through a full range of motion during a leg extension exercise **[19]**. This test is a gold standard for assessing muscle strength and has high reliability (ICC = 0.94) in lower limb strength assessment among athletic populations **[20]**.

Participants underwent a plyometric training program designed to improve neuromuscular coordination, eccentric control, and quadriceps strength. The training was conducted 3 sessions per week for 4 weeks, supervised by a certified physiotherapist or strength and conditioning specialist **[21]**.

Group A (Plyometric group)

- Warm-up: 10-minute dynamic stretching and light jogging.
- Main Plyometric Exercises:
  - Squat jumps
  - Split lunges
  - Lateral hops
  - Box jumps
  - Single-leg hops
  - Depth jumps
    (Progression from bilateral to unilateral tasks)
- Volume and Intensity: Initially 3 sets of 8–10 repetitions, progressing to 4 sets of 12–15 repetitions depending on participant tolerance **[22]**.
- Cool-down: 10-minute static stretching and slow walking.

GROUP B (Control group exercise)

- Iliopsoas strengthening
- Seated knee extension
- Leg press

- Squatting
- Stretching of hamstrings, ankle plantar flexors, quadriceps, and iliotibial band

All exercise to perform between 3-5 sets 10-30 repetitions 3 times a week **[23]**.

Participants were instructed to maintain correct landing mechanics with knee flexion and soft landings to reduce joint stress **[24]**. Rest intervals of 60–90 seconds between sets were maintained to optimize recovery.

Pain and strength outcomes (NPRS and 1RM) were assessed before and after the intervention period.

Statistical analysis

Statistical analysis is done using SPSS version 26.

Normality of pre- and post-intervention scores for NPRS and 1RM bench press was assessed using the Shapiro–Wilk test.

Since the data met normality i.e. ($p > 0.05$), paired t-tests were applied to compare pre- and post-intervention values within the group.

The level of significance was set at $p < 0.05$.

Normality Test Results (Shapiro-Wilk)

The Shapiro-Wilk test was conducted for each measure.

Table 1: Indicates the normality test

Variable	Group	Shapiro-Wilk Statistic	P-value	Result
NPRS	Group A	0.813	0.028	Non-Normal
	Group B	0.655	0.03	Non-Normal
1RM (bench press)	Group A	0.923	0.421	Normal
	Group B	0.64	0.01	Non-Normal

Conclusion: Since the normality assumption was violated for most groups and variables, a non-parametric test (Mann-Whitney U Test) was used to do the further analysis.

Descriptive Statistics (Mean and Standard Deviation)

Table 2: Summarizes the central tendency and variability of the measures

Variable	Statistic	Group A	Group B
pre-nprs	Mean	5.11	4.9
	SD	0.93	0.74
post-nprs	Mean	3.89	4.4
	SD	0.6	0.7
NPRS Change	Mean	1.22	0.5
	SD	0.67	0.53
pre 1RM (kg)	Mean	65.56	59.5
	SD	13.33	6.43
post 1RM (kg)	Mean	72.78	61.5
	SD	12.73	6.26
1RM Change	Mean	7.22	2
	SD	1.39	2.58

- NPRS Change: Group A (mean =1.22) had a larger average reduction in pain compared to Group B (mean =0.50).
- 1RM Change (kg): Group A (mean =7.22 kg) had a larger average increase in strength compared to Group B (mean =2.00 kg).

Table 3: within the group comparison

Group	Variable	Test	N	W Statistic	P-value	Significance (α=0.05)
Group A	NPRS Score	Wilcoxon Signed-Rank Test	9	0	0.009	Significant
Group A	1RM (kg)	Wilcoxon Signed-Rank Test	9	0	0.004	Significant
Group B	NPRS Score	Wilcoxon Signed-Rank Test	10	0	0.025	Significant
Group B	1RM (kg)	Wilcoxon Signed-Rank Test	10	0	0.046	Significant

Interpretation: The results indicate that all comparisons (NPRS Score and 1RM for both Group A and Group B) show a statistically significant change from pre-to-post ($P<0.05$).

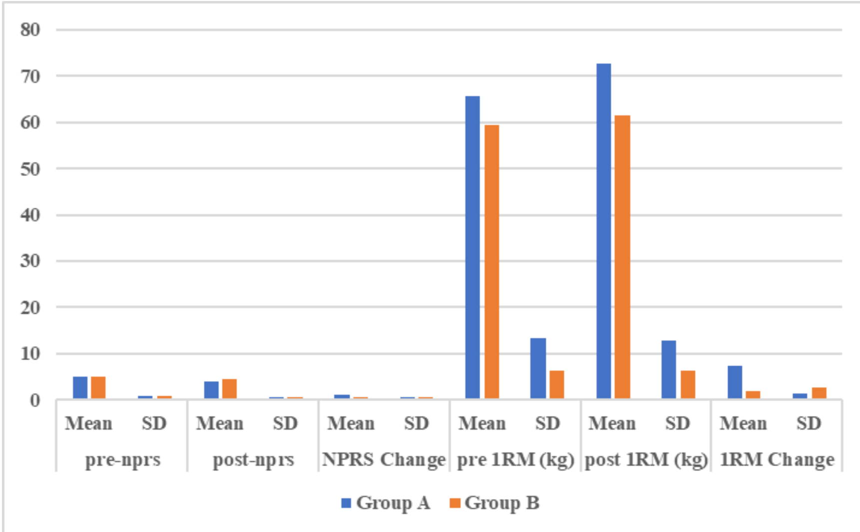
- Both groups showed a significant reduction in NPRS (pain score).
- Both groups showed a significant increase in 1RM (strength score).

Comparison of Pre and Post Data

Table 4: Between the group analysis was used to determine if the mean difference between pre- and post-intervention scores is statistically significant

Variable	Test	Test Statistic	P-value	Significance (α=0.05)
NPRS	Mann-Whitney U Test	70	0.027	Significant
1RM (bench press)	Mann-Whitney U Test	88	0.046	Significant

- NPRS Change (Pain Reduction): The p-value of 0.027 is less than the significance level (α=0.05). This indicates a statistically significant difference in the reduction of NPRS (pain score) between Group A and Group B. Group A showed a significantly greater reduction in pain.
- 1RM Change (Strength Gain): The p-value of 0.046 is less than α=0.05. This indicates a statistically significant difference in the increase of 1RM (strength) between Group A and Group B. Group A showed a significantly greater gain in strength.



Graph 1: Represent of mean ± SD of NPRS and 1RM bench press

The above graphs represent of mean ± SD of NPRS and 1RM bench press

DISCUSSION

The purpose of this analysis was to evaluate the effects of two distinct interventions (Group A and Group B) on pain (NPRS score) and maximal strength (1-Repetition Maximum or 1RM in kg). The results demonstrated significant pre-to-post improvements in both pain reduction and strength gain within each group, but critically, the intervention administered to Group A resulted in significantly superior outcomes compared to Group B. This suggests that the specific treatment in Group A may be a more effective strategy for concurrent improvements in pain and strength.

The within-group analysis, performed using the non-parametric Wilcoxon Signed-Rank Test, revealed that both Group A and Group B experienced statistically significant improvements in both outcome measures ($p<0.05$).

Both groups achieved a significant reduction in their NPRS scores from the pre-test to the post-test (Group A: $p=0.009$; Group B: $p=0.025$). This finding is consistent with the established principle of exercise-induced hypoalgesia (EIH), where an acute or chronic bout of exercise can lessen pain sensitivity **[25, 26]**. Exercise, including resistance training, is widely recognized as a key component in the management of chronic pain conditions and typically leads to a reduction in self-reported pain intensity **[27, 28]**.

Similarly, both groups demonstrated a significant increase in 1RM strength (Group A: $p=0.027$; Group B: $p=0.046$). This effect is the expected outcome of any systematic resistance training protocol. Training with varying loads and repetitions, even low-intensity protocols, is known to stimulate improvements in maximal dynamic strength [29, 30].

The primary clinical relevance of this study lies in the between-group comparison, analyzed using the non-parametric Mann-Whitney U Test, which showed statistically significant differences favoring Group A for both primary outcomes.

Group A achieved a significantly greater reduction in NPRS score (mean change of 1.22) compared to Group B (mean change of 0.50), with a statistically significant difference (p=0.027). This result suggests that the intervention in Group A was more potent in managing or reducing the participants' pain over the intervention period. The mechanisms for this superior effect could be related to a greater release of endogenous opioids or changes in pain modulation pathways, which may be differentially affected by distinct exercise intensities or protocols **[1]**. For instance, certain dynamic resistance exercise parameters may be more effective at producing EIH than others **[26]**.

Group A also demonstrated a significantly greater increase in 1RM strength (mean change of 7.22 kg) compared to Group B (mean change of 2.00 kg), with the difference being highly significant. This finding aligns with meta-analytic data that generally supports the use of heavier loads (high-load training) over lighter loads (low-load training) for optimizing maximal strength gains when training volume is equivalent **[31, 32]**. While both protocols resulted in significant strength increases (as noted in the within-group analysis), the magnitude of the improvement was clearly superior in Group A, suggesting its protocol likely involved higher intensity or a program manipulation that prioritized maximum strength development.

CONCLUSION

while both Group A and Group B experienced positive and statistically significant changes in pain reduction and strength gain from pre-to-post intervention, Group A's protocol resulted in significantly greater improvements for both the NPRS and 1RM outcomes. These results suggest that the intervention used by Group A offers a more effective approach for simultaneously improving maximal strength and reducing pain, which is a key objective in many rehabilitation and performance settings. Further discussion on the specific exercise parameters (e.g., intensity, volume, frequency) of Group A versus Group B would be required to fully understand the mechanistic differences leading to the observed superior outcomes.

Acknowledgement

I would like to take this opportunity to heartily acknowledge those who helped me throughout our project work. This would not been possible without them. I would like to express our deep sincere gratitude to our respected guide Dr. Pooja for her keen interest shown in our project work.

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