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Research Article

Progressive Elastic-Resistance Training for Patellofemoral Pain Syndrome: Pain and Functional Movement Outcomes in Student Athletes

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Abstract: Patellofemoral pain syndrome is prevalent in active young adults and compromises participation and quality of life. This study examined the effectiveness of a pragmatic, six-week resistance band program on pain and functional movement in college students with patellofemoral pain syndrome. Using a one-group pretest–posttest design, participants completed three supervised sessions per week structured by a stabilization–strength–controlled power progression. Pain intensity was assessed with the Visual Analog Scale and functional movement with the Functional Movement Screen at baseline and post-intervention. The program produced large, statistically significant improvements: mean pain scores decreased markedly, and functional movement scores increased, indicating enhanced proximal stability, frontal-plane control, and movement efficiency. Effect sizes were very large for both outcomes, consistent with literature showing that targeted strengthening and neuromuscular training reduce patellofemoral joint stress and improve function. The intervention's low cost, portability, and simple progression support scalability in resource-limited educational and community environments. While the design precludes definitive causal attribution, convergence of large effects across symptom and functional domains underscores the clinical promise of elastic resistance as a primary rehabilitation modality for patellofemoral pain syndrome. Future randomized studies should evaluate durability of benefits, dose–response characteristics, and mechanistic mediators using isokinetic, kinematic, and electromyographic assessments to optimize prescription and translation to sport-specific performance.

Keywords: Functional Movement Screen; Patellofemoral Pain Syndrome; Resistance Band Training; Student Athletes; Visual Analog Scale.

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1. Introduction

Patellofemoral pain syndrome (PFPS) is one of the most common musculoskeletal complaints in physically active populations and creates a substantial burden through pain-related disability, training disruption, and reduced quality of life. Conceptually, PFPS is multifactorial and arises from the interaction of mechanical, structural, and neuromuscular factors that disturb loading and tracking of the patellofemoral joint during daily activities and sport-specific tasks (Henderson et al., 2025; Martín-San Agustín et al., 2022; Memain et al., 2024). In adolescents and young adults who are repeatedly exposed to high-impact movements such as running, jumping, and squatting, suboptimal movement strategies may cumulatively increase anterior knee stress and contribute to persistent or recurrent symptoms (Beckwée et al., 2024; Coudeyre et al., 2024; Suarez-Arrones et al., 2020). Beyond nociception, PFPS is also associated with psychosocial consequences, including fear of movement, reduced self-efficacy, and performance anxiety; therefore, effective and scalable rehabilitation strategies are needed for both public health and sport-performance contexts (Islam et al., 2024; Rathleff et al., 2020).

Epidemiologically, PFPS accounts for a large proportion of knee-pain complaints among active groups such as university students and competitive athletes, especially in sports that require repeated knee flexion and precise frontal-plane control (Li et al., 2022; Yuenyongviwat et al., 2020). Growing evidence links quadriceps and hip-abductor weakness, impaired neuromuscular control, and unfavorable foot-ankle mechanics with lower-limb kinematic patterns typically observed in PFPS (Amirabadi et al., 2024; Cavalcante et al., 2024; M. C. Sharma et al., 2025). Knee-strength deficits have also been prospectively associated with higher injury incidence among adolescent and young adult athletes, reinforcing the importance of targeted strengthening as both a preventive and therapeutic approach (Cömert & Grüber, 2025; Ghaderi et al., 2021). In educational and community settings with limited resources, however, rehabilitation models must balance physiological efficacy with accessibility and adherence.

Conservative exercise therapy remains a central pillar of PFPS management. Contemporary multimodal programs emphasize quadriceps and hip strengthening, flexibility training, and neuromuscular re-education to normalize movement patterns (Park et al., 2021; Wilczyński et al., 2021; Xu et al., 2024). Systematic reviews indicate that these components can meaningfully reduce pain and improve function in the short to medium term (Hammami et al., 2024; Vincent et al., 2022). Nevertheless, heterogeneity in exercise dosage, progression criteria, and delivery mode complicates translation across clinical, educational, and community settings (S. Sharma et al., 2021; Silvester et al., 2024). Bridging this implementation gap requires interventions that are physiologically robust, low-cost, portable, and adaptable to different levels of supervision without losing clinical precision.

Elastic-resistance exercise, commonly delivered through resistance bands, offers a pragmatic response to these constraints. Resistance bands allow progressive loading through a broad range of motion with relatively low joint stress, facilitate activation of proximal muscles in multiple planes, and can be integrated into closed-chain tasks that approximate functional demands. These characteristics support motor learning while reducing patellofemoral stress (Barrett et al., 2023; Sellon & Marcellin-Little, 2022; A. Wong et al., 2022). Low cost, portability, and ease of instruction further support implementation in resource-limited settings, dormitories, and sport fields, where adherence may be higher than with equipment-intensive modalities (Huang et al., 2020; Rani et al., 2023). Emerging evidence suggests that elastic resistance can strengthen the quadriceps and hip stabilizers and improve movement quality, which are central mechanisms for symptom modulation and recurrence prevention in PFPS (Hammami et al., 2024; Kumar et al., 2025).

Despite this rationale, evidence focused on university students remains scattered. Existing studies vary in exercise selection, progression frameworks, and outcome batteries, thereby limiting direct comparability and practical guidance. In particular, relatively few PFPS studies in student populations combine an explicitly phased resistance-band protocol with complementary outcomes that capture both symptom reduction and functional movement quality. This limitation is important because pain relief without movement-quality improvement may leave residual risk for recurrence, whereas movement improvement without symptom relief may not be sufficient for return to sport or sustained participation.

The present study addresses this need by evaluating a structured six-week resistance-band strengthening program tailored to university students with PFPS. Pain, measured using the Visual Analog Scale (VAS), and functional movement quality, measured using the Functional Movement Screen (FMS), served as co-primary outcomes. We hypothesized that the intervention would produce clinically and statistically meaningful reductions in pain and improvements in functional movement compared with baseline, reflecting enhanced proximal stability and more optimal movement strategies. The novelty of this study lies in its pragmatic and scalable design, its explicit progression from stabilization to strength-endurance and controlled power, and its dual-domain evaluation of symptoms and movement competence.

2. Literature Review

The optimization of strengthening mechanisms and delivery methods has become a major theme in PFPS rehabilitation. Clinical trials and high-quality protocols support the benefits of targeted strengthening, including isokinetic paradigms, for improving quadriceps torque, pain tolerance, physical function, and health-related quality of life in PFPS (Dabbagh & Sarvestani, 2022; Domínguez-Navarro et al., 2021; Fousekis et al., 2022). Adjunct technologies such as surface electromyography biofeedback may further refine motor-unit recruitment and facilitate neuromuscular retraining, particularly when faulty kinematics sustain patellofemoral overload (Ong et al., 2024). Complementary approaches such as neuromodulation and telerehabilitation are also being investigated for feasibility and effectiveness, collectively pointing toward individualized, feedback-rich, and accessible programs (Ince et al., 2023). However, these innovations often require specialized equipment or intensive supervision, which may be unrealistic in many university environments.

Within this landscape, resistance-band programs represent a relevant compromise between mechanistic rationale and practical feasibility. By facilitating progressive and multiplanar activation of the hip abductors, hip extensors, and quadriceps within functional kinetic-chain tasks, band-based regimens can address frontal-plane knee control and dynamic valgus patterns commonly associated with PFPS (Wilczyński et al., 2021). Gait retraining and movement-quality education can further improve kinematic efficiency in runners with PFPS, suggesting possible synergy when combined with strengthening to modify tissue stress and symptom trajectories (Koldenhoven et al., 2020; Roesel et al., 2022). When nociplastic factors contribute to symptoms, exercise remains a first-line intervention for pain modulation and functional recovery across the nociplastic pain continuum, reinforcing the centrality of well-designed and adaptable strengthening programs (Franco et al., 2020).

Rigorous outcome evaluation is essential for clinical decision-making and program refinement. The VAS is widely used to measure pain intensity in musculoskeletal trials and has strong psychometric properties for detecting post-intervention change (Hayat et al., 2023). The FMS complements pain measurement by assessing fundamental movement patterns and identifying compensations that may increase injury risk, which is especially relevant for symptom resolution and performance readiness in active students (Cömert & Grüber, 2025; Vincent et al., 2022). Using VAS together with FMS allows evaluation through two lenses: subjective pain and movement-quality competence. This combined approach may capture clinically meaningful change and residual movement risk that impairment-based tests alone may miss.

Accordingly, a research gap remains at the intersection of efficacy and implementation. First, many studies draw samples from clinical populations or elite athletes under specialized supervision, whereas university settings with limited equipment, time, and personnel remain underrepresented (Kostrub et al., 2021; Manlapaz et al., 2025). Second, interventions frequently lack transparent progression logic and replicable templates. Third, outcome batteries often focus on pain and impairment without simultaneously assessing functional movement quality, limiting ecological validity for return-to-activity decisions (Armshaw et al., 2022). Addressing these gaps requires studies that use accessible strengthening modalities, operationalize progression in a way that is aligned with PFPS pathomechanics, and integrate complementary outcomes such as VAS and FMS.

3. Materials and Method

Research Design

This study used a pre-experimental one-group pretest-posttest design to examine the effect of an elastic-resistance strengthening program on pain and functional movement among university students with PFPS. This design enables within-participant comparison between baseline outcomes (O1) and post-intervention outcomes (O2), and it is commonly used in pragmatic rehabilitation trials when randomization or a concurrent control group is not feasible (Soesana et al., 2023). The absence of a control group limits causal inference and increases susceptibility to history and maturation effects; however, standardized outcome measures and standardized procedures improved the interpretability of observed change (Kaleem et al., 2024). The design scheme is summarized in Table 1.

Table 1. One-group pretest-posttest design

Pre-experimental design	Design scheme	Description
One-group pretest-posttest	O1 - X - O2	O1: pretest score; X: treatment; O2: posttest score

Participants and Sampling

Participants were recruited from an undergraduate Sport Science program through class announcements and brief information sessions. Simple random sampling from eligible volunteers was conducted until the target sample size was reached. Inclusion criteria were age 18-25 years; clinical diagnosis of PFPS by a licensed clinician based on anterior knee pain aggravated by squatting, stair ascent or descent, or prolonged sitting; regular participation in physical activity; and mild-to-moderate pain intensity. Exclusion criteria included a history of cruciate or collateral ligament injury or surgery, other knee pathology such as meniscal injury or tendinopathy, and systemic conditions contraindicating lower-limb strengthening. Twelve students met the criteria, provided written informed consent, and completed all assessments and training sessions. This sample size is consistent with pre-post rehabilitation studies focused on mechanistic change and feasibility (Duong et al., 2023; Wagemans et al., 2023).

Elastic-Resistance Training Program

The intervention consisted of supervised small-group sessions three times per week for six consecutive weeks, with each session lasting approximately 20-30 minutes. The program architecture followed the Optimum Performance Training (OPT) framework of the National Academy of Sports Medicine (NASM) (French & Torres Ronda, 2021). The progression moved from stabilization to strength-endurance and then to controlled power, consistent with staged neuromuscular development in lower-extremity rehabilitation (Meierbachtol et al., 2021). Exercise selection prioritized closed-chain and multiplanar tasks that loaded the quadriceps and hip abductors/extensors while minimizing patellofemoral joint stress, in accordance with evidence that elastic resistance facilitates targeted activation and movement retraining in PFPS (Ramirez et al., 2024).

Phase 1, conducted in weeks 1-2, emphasized postural alignment, lumbopelvic control, and frontal-plane knee stability using banded squats, bridges, side steps, and clamshells. Phase 2, conducted in weeks 3-4, increased movement range and complexity through deeper banded squats, forward lunges, single-leg bridges, and side-lying leg raises to develop strength and endurance. Phase 3, conducted in weeks 5-6, integrated controlled plyometric and higher-velocity tasks, including banded jump squats, lateral lunges, jumping jacks, and step-ups, to consolidate dynamic knee control and functional transfer.

Detailed exercise prescriptions, movement descriptions, and set-repetition schemes are presented in Table 2. Progression criteria included tolerance of training volume without pain increases beyond expected post-exercise muscle soreness, maintenance of technique quality, and the ability to sustain band tension throughout the full range of motion. Band resistance was individualized by selecting a loop thickness that allowed the participant to complete the prescribed repetitions with the final two or three repetitions perceived as challenging while preserving correct technique.

Table 2. Resistance-band program aligned with the NASM OPT framework

Training phase	Exercise	Movement description	Prescription
Phase 1: Stabilization (Weeks 1–2)	Squats with resistance band	Stand shoulder-width; band above knees. Sit hips back and down as if to a chair; knees track over toes; spine neutral; rise to full hip/knee extension.	12–15 reps × 3 sets; 30 s rest
	Bridges with resistance band	Supine; band around thighs. Brace the core; drive through heels to lift hips until shoulder–hip–knee are aligned; brief pause; lower under control.	12–15 reps × 3 sets; 30 s rest
	Side steps with resistance band	Upright stance; slight knee flexion; keep constant band tension. Step laterally right/left with trunk stable; avoid knee valgus.	15 steps/side × 3 sets; 30 s rest
	Clamshells with resistance band	Side-lying; band around thighs; feet together. Abduct the top knee within pain-free range without pelvic rotation; controlled return.	15 reps/side × 3 sets; 30 s rest
Phase 2: Strength and Endurance (Weeks 3–4)	Squats with resistance band	Deeper squat while maintaining knee-over-toe alignment; chest tall; even pressure across whole foot.	10–12 reps × 3 sets; 45 s rest
	Lunges with resistance band	Band on thighs. Step forward; descend until the rear knee nearly touches the floor; push back to start with symmetrical loading.	10 reps/leg × 3 sets; 45 s rest
	Single-leg bridge with resistance band	Supine; one foot planted, other leg lifted; band around knees. Extend hips to neutral without pelvic tilt; controlled eccentric.	12 reps/leg × 3 sets; 45 s rest
	Side-lying leg raises with resistance band	Side-lying; band around thighs; hips neutral. Raise the top leg (abduction) smoothly to tolerance; return without momentum.	12–15 reps/side × 3 sets; 45 s rest
Phase 3: Controlled Power (Weeks 5–6)	Jump squats with resistance band	Band on thighs. Shallow countermovement; soft, quiet landing; knees track over toes; trunk stable.	10–12 reps × 3 sets; 60 s rest
	Lateral lunges with resistance band	Band on thighs. Step sideways; descend to ~90° knee flexion on the working leg; drive back to center under control.	10 reps/leg × 3 sets; 60 s rest
	Jumping jacks with resistance band	Band around ankles. Rhythmic abduction/adduction while maintaining trunk stability and constant band tension.	20 reps × 3 sets; 60 s rest
	Step-ups with resistance band	Band on thighs. Step onto a stable box; drive through the heel of the lead foot; stand tall; controlled step-down.	10 reps/leg × 3 sets; 60 s rest

Each session began with a standardized five-minute warm-up consisting of stationary cycling or brisk walking and dynamic mobility exercises for the hip and ankle. Verbal and tactile cues emphasized dynamic-valgus prevention, trunk stability, and symmetrical loading. When needed, simple external-focus cues were used to optimize motor learning in accordance with neuromuscular-training literature (Bompa & Buzzichelli, 2022; French & Torres Ronda, 2021; Fukuda, 2019). Attendance and adverse responses were recorded to monitor adherence and safety. No adjunct modality, such as taping or electrotherapy, was added during the program, thereby isolating the effect of exercise.

Outcome Measures

Two validated outcome instruments were collected at baseline and after six weeks. Pain intensity was measured using the VAS, a reliable and sensitive patient-reported instrument for tracking short-term change in musculoskeletal rehabilitation (Farazdaghi et al., 2025; Guliya et al., 2021). Functional movement quality was assessed using the FMS, which evaluates fundamental movement patterns related to lower-limb load management and identifies deficits relevant to injury risk, such as dynamic knee valgus and asymmetry (A. Wong et al., 2022; Xu et al., 2024). The dual emphasis on symptom relief and movement competence aligns with contemporary recommendations to combine nociceptive and neuromotor outcomes in PFPS research (Cui et al., 2022).

Data Management and Statistical Analysis

Data analysis was performed using complete cases. Before inferential testing, distributional assumptions were examined using the Kolmogorov-Smirnov normality test and visual inspection of histograms. For normally distributed variables, pre-post differences in VAS and FMS scores were analyzed using paired-samples t-tests with a two-tailed alpha level of 0.05 (Júnior et al., 2024). Effect sizes were calculated using Cohen's d for paired samples to quantify the magnitude of change and support interpretation alongside statistical significance. Values of approximately 0.2, 0.5, and 0.8 were interpreted as small, moderate, and large, while acknowledging that clinical meaning may vary by context (Ghaderi et al., 2021)

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4. Results and Discussion

Descriptive Statistics

Twelve participants completed pre- and post-intervention assessments. Descriptive statistics for pain and functional movement are presented in Table 3. VAS scores decreased from a mean of 5.25 to 2.17, with comparable standard deviations at both measurement points, indicating relatively consistent dispersion of pain scores across the sample. Composite FMS scores increased from 12.50 to 16.50, with identical standard deviations at pretest and posttest, indicating a uniform shift toward better movement quality after the intervention. This pattern is consistent with previous studies reporting meaningful pain reduction and functional improvement after structured strengthening programs that incorporate elastic resistance and neuromuscular retraining for PFPS and related lower-limb conditions (Amirabadi et al., 2024; Li et al., 2022; Vincent et al., 2022; Wilczyński et al., 2021).

Table 3. Descriptive statistics of VAS and FMS at baseline and after six weeks of elastic-resistance training

Instrument	N	Range	Min	Max	Sum	Mean	SD	SEM	Variance
VAS (pre-test)	12	3	4	7	63	5.25	0.96	0.27	0.93
VAS (post-test)	12	3	1	4	26	2.17	0.93	0.27	0.87
FMS (pre-test)	12	3	11	14	150	12.50	1.00	0.28	1.00
FMS (post-test)	12	3	15	18	198	16.50	1.00	0.28	1.00

Normality Test

Kolmogorov-Smirnov testing showed that all outcome variables approximated normal distribution at both time points (Table 4). Specifically, VAS pretest and FMS pretest scores were not significant ($p = 0.200$ for both), and FMS posttest was also not significant ($p = 0.200$). VAS posttest approached the threshold for non-normality ($p = 0.061$) but remained above alpha = 0.05, supporting the use of parametric tests. These normality results are consistent with recommendations for paired t-test analysis in pre-post rehabilitation studies (Ghaderi et al., 2021; Júnior et al., 2024; Silvester et al., 2024).

Table 4. Kolmogorov-Smirnov tests for normality of VAS and FMS distributions

Instrument	statistic	df	Sig.	Interpretation
VAS (pre-test)	0.198	12	0.200	Normal distribution
FMS (pre-test)	0.191	12	0.200	Normal distribution
VAS (post-test)	0.237	12	0.061	Normal distribution
FMS (post-test)	0.191	12	0.200	Normal distribution

Main Pre-post Changes

Paired-samples t-tests indicated statistically significant improvement in both primary outcomes (Table 5). For pain, the reduction in VAS from 5.25 to 2.17 was associated with a very large effect size (Cohen's d = 3.24) and a highly significant two-tailed p value ($p = 0.001$). For functional movement, the increase in FMS from 12.50 to 16.50 also produced a very large effect size (Cohen's d = 4.00) with $p = 0.001$. These magnitudes exceed conventional thresholds for large change and align with literature demonstrating the benefits of targeted strengthening, elastic-resistance exercise, and movement-quality interventions for individuals with knee pain (Hammami et al., 2024; Li et al., 2022; Rathleff et al., 2020). Clinically, the observed VAS reduction exceeded commonly cited minimal clinically important differences for musculoskeletal pain, supporting the practical relevance of symptom relief and improved participation.

Table 5. Paired t-test results for VAS and FMS with effect sizes

Outcome	Time point	Mean	SD	SEM	t	Sig. (2-tailed)	Cohen's d
VAS	Pre	5.25	0.96	0.27	10.8	0.001	3.24
VAS	Post	2.17	0.93	0.27	13.4	0.001	3.24
FMS	Pre	12.50	1.00	0.28	6.93	0.001	4.00
FMS	Post	16.50	1.00	0.28	12.7	0.001	4.00

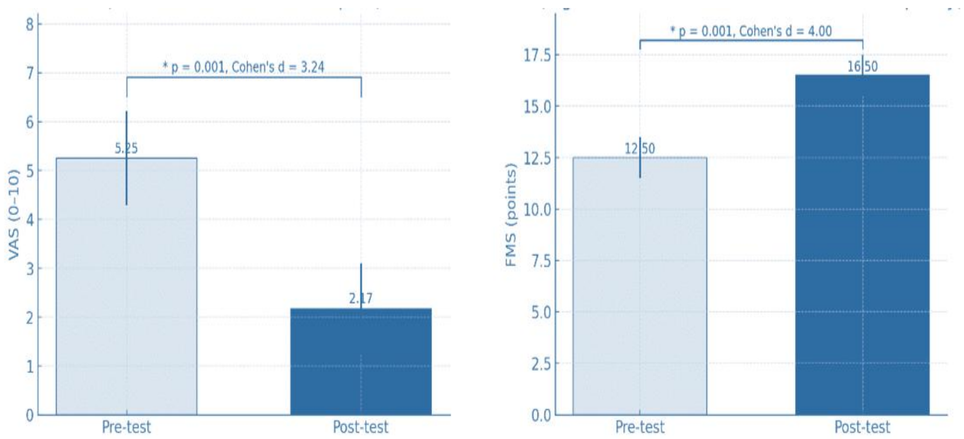

Figure 1. Cohen's d for within-participant changes in VAS and FMS following six weeks of elastic-resistance training.

Figure 1 summarizes standardized mean differences for the two outcomes. The very large effects for pain reduction and functional movement improvement indicate favorable and relatively uniform shifts across participants. These findings are compatible with trials combining hip and knee strengthening, neuromuscular cueing, and progressive loading to improve frontal-plane knee control and reduce patellofemoral joint stress (Kocent et al., 2021; Manlapaz et al., 2025). Although isokinetic strengthening paradigms may produce large torque gains, the present results suggest that a pragmatic minimal-equipment approach can also yield meaningful functional benefits in university environments.

Overall, the six-week progressive resistance-band program produced statistically and clinically meaningful reductions in pain and improvements in functional movement among students with PFPS. The parallel improvement in VAS and FMS supports the hypothesized benefits of accessible neuromuscular strengthening and provides a rationale for future controlled trials to confirm efficacy and examine durability of effects (Ghaderi et al., 2021; Perry et al., 2022; Wagemans et al., 2023).

Discussion

This study found a large and statistically significant decrease in pain and a parallel improvement in functional movement after a six-week resistance-band program among university students with PFPS. As shown in Tables 3 and 5, VAS scores decreased markedly from pretest to posttest, whereas FMS scores increased with very large effect sizes. The VAS change exceeded minimal clinically important difference thresholds for musculoskeletal pain and is consistent with evidence that structured strengthening provides strong analgesic effects in PFPS (Beckwée et al., 2024; Cömert & Grüber, 2025; Hammami et al., 2024). The parallel improvement in FMS indicates that symptom relief was accompanied by improved integrated movement quality, consistent with evidence linking movement competence to injury risk and return-to-activity readiness in athletic populations (Ali et al., 2021; Beckwée et al., 2024). Together with the normality results in Table 4, these findings suggest that improvement was coherent across outcomes rather than being driven by isolated outliers.

The observed pattern is consistent with neuromuscular and biomechanical adaptations expected from progressive elastic resistance. Targeted loading of the quadriceps, hip abductors, and hip extensors can improve joint stability and reduce aberrant patellofemoral stress, thereby decreasing nociceptive input (Carboch et al., 2025; Fältström et al., 2025; Katz et al., 2025). The phased program architecture, moving from stabilization to strength-endurance and controlled power, aligns with neuromuscular-training principles that prioritize lumbopelvic control, frontal-plane knee alignment, and efficient force transmission before introducing higher-velocity demands (Kawama et al., 2021). Resistance bands provide continuous, direction-specific tension across the range of motion and act as clear external cues, which may enhance proprioceptive input and technique consistency while reducing dynamic valgus and suboptimal patellar tracking (Madu et al., 2025; Malige et al., 2022).

The findings are also consistent with broader PFPS rehabilitation evidence. Júnior et al. (2024) reported significant VAS reduction and functional improvement after gait retraining combined with strengthening, reflecting a dual benefit similar to the present study. Hammami et al. (2024) demonstrated that isokinetic strengthening improved pain tolerance and functional capacity, indicating that both machine-based and band-based modalities can be effective when progression and technique are carefully managed. Complementary evidence suggests that electromyography-based neuromuscular biofeedback may refine motor-unit recruitment and movement quality, potentially offering synergistic benefits when integrated with elastic resistance in future protocols (Huang et al., 2020). In musculoskeletal pain more broadly, structured exercise can reduce nociplastic contributions to symptom persistence, supporting the role of exercise-based pain modulation (Armshaw et al., 2023).

From a translational perspective, resistance-band training is inexpensive, portable, and adaptable, making it suitable for educational and community settings with limited equipment and variable supervision. Previous studies emphasize that low-resource approaches can still preserve progression, individualization, and safety while supporting adherence, which is essential for scalability among students (Rathleff et al., 2020; Wong et al., 2022). The consistent shift in VAS and FMS scores, with stable variance, suggests that the benefits were broadly distributed across participants. Clinically, hip- and knee-targeted tasks that limit frontal-plane collapse and promote symmetrical loading align with trials reporting reduced dynamic valgus and improved balance after targeted strengthening (Wilczyński et al., 2021; Cömert & Grüber, 2025). As pain decreases, patients may tolerate higher training volume and intensity, creating a positive cycle of strength development and movement optimization that supports safe return to sport and daily activity (Vincent et al., 2022; Franco et al., 2020).

Methodologically, the one-group pretest-posttest design facilitated sensitive detection of within-participant change while reducing the influence of between-subject variability. However, the absence of a concurrent control group limits causal inference and leaves open the possibility of regression to the mean, expectation effects, or unmeasured co-interventions (Silvester et al., 2024). Even so, the very large effect sizes across two conceptually distinct outcomes, combined with adherence monitoring and the exclusion of adjunct modalities, reduce the likelihood that improvement was due solely to history or placebo effects. Future research should use randomized controlled designs, extend follow-up to evaluate durability, and include mechanistic endpoints such as isokinetic torque, three-dimensional kinematics, and electromyography to separate the relative contributions of strength gains and movement-control adaptations (Hammami et al., 2024; Armshaw et al., 2022).

5. Comparison

Compared with machine-based strengthening, isokinetic protocols, electromyography biofeedback, or telerehabilitation approaches, the resistance-band program in this study offers a strong balance between clinical benefit, portability, low cost, and implementation feasibility. The approach does not require large equipment, making it more realistic for practical classes, student sport units, campus clinics, and community sport environments with limited resources.

The main contribution of this study is a replicable phased exercise template that begins with stabilization, progresses to strength-endurance, and ends with controlled power. A second distinctive contribution is the use of two complementary outcomes: VAS for pain symptoms and FMS for movement quality. Consequently, the findings describe not only symptom relief but also functional movement readiness, which is relevant for return-to-activity decisions in student athletes.

6. Conclusion

This study demonstrated that a six-week phased resistance-band program produced large, statistically significant, and clinically meaningful improvements in pain intensity and functional movement among university students with PFPS. VAS scores decreased substantially, while FMS scores increased, indicating that symptom relief was accompanied by improved integrated movement quality. These findings are consistent with contemporary rehabilitation theory, in which targeted strengthening of the quadriceps and hip abductors/extensors, combined with improved neuromuscular control and proprioception, reduces patellofemoral stress and dynamic valgus.

The accessible nature of the intervention and its minimal equipment requirements support scalability in university and community environments where resources and supervision may be limited. Although the one-group pretest-posttest design limits causal inference, the very large effect sizes across two conceptually distinct endpoints strengthen confidence in the internal coherence of the findings. This study contributes a replicable and implementation-ready PFPS rehabilitation template that integrates symptom and movement-quality outcomes. Future studies should test the protocol in randomized controlled trials, include objective mechanistic endpoints such as isokinetic torque, kinematic analysis, and electromyography, and evaluate long-term effects, cost efficiency, and transfer to sport-specific performance.

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