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Original Article

Impact of Neuromuscular Electrical Stimulation Versus Plyometric Training on Muscle Power, Agility, Pain Intensity, Functional Performance, and Quadriceps Strength in Athletes with Patellofemoral Pain Syndrome

Ayesha Bi Bi[1], Peraha Wagan[2], Ahmad Raza[3], Nadeem Khalid[4], Syed Murtaza Ali Shah[5], Usman Ghani[6]

[1] Khyber Medical University, Peshawar, Pakistan

[2] Peoples University of Medical and Health Sciences, Nawabshah, Pakistan

[3] Independent Musculoskeletal Physiotherapy Practitioner, Pakistan

[4] Indus College of Physical Therapy, The University of Modern Sciences, Tando Mohammad Khan, Pakistan

[5] Institute of Physical Rehabilitation Sciences, Peoples University of Medical and Health Sciences, Shaheed Benazirabad, Pakistan

[6] Abbottabad University of Science and Technology, Abbottabad, Pakistan

Correspondence: Ayesha17301@gmail.com
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ABSTRACT

Background: Patellofemoral Pain Syndrome (PFPS) is a prevalent musculoskeletal disorder in athletes, leading to anterior knee pain, impaired performance, and reduced functional capacity. Neuromuscular Electrical Stimulation (NMES) and plyometric training are rehabilitation strategies designed to improve muscle strength, agility, and functional outcomes, yet direct comparisons of their efficacy remain limited. Objective: This study aimed to compare the effects of NMES and plyometric training on muscle power, agility, pain intensity, functional performance, and quadriceps strength in athletes with PFPS. Methods: A randomized controlled trial was conducted with 60 athletes aged 18–30 years diagnosed with PFPS. Participants were randomly assigned to NMES or plyometric training for six weeks, three sessions per week. Outcomes included vertical jump test (muscle power), T-test (agility), Visual Analog Scale (pain), single-leg hop test (functional performance), and isometric knee extension (quadriceps strength), assessed at baseline, three weeks, and six weeks. Data were analyzed using repeated-measures ANOVA with adjustments for confounders. Results: Both groups demonstrated significant improvements across all outcomes. Plyometric training produced superior gains in muscle power (mean difference at week 6: −5.3 cm, p = 0.03) and agility (difference 0.8 s, p = 0.01), whereas NMES showed greater reductions in pain (week 6 difference −0.6 points, p = 0.50). Quadriceps strength improved similarly in both groups without significant between-group differences. Conclusion: Plyometric training is more effective for enhancing performance outcomes, while NMES offers greater analgesic benefit. Individualized rehabilitation programs incorporating both interventions may optimize recovery in PFPS athletes.
Keywords: Patellofemoral Pain Syndrome, Neuromuscular Electrical Stimulation, Plyometric Training, Muscle Power, Agility, Functional Performance, Quadriceps Strength, Athletes.

INTRODUCTION

Patellofemoral Pain Syndrome (PFPS) is one of the most common causes of anterior knee pain in athletes, with prevalence estimates ranging between 15–45% depending on sport type and training load (1,2). It is particularly prevalent among individuals engaged in repetitive knee flexion activities such as running, jumping, and squatting, where abnormal patellar tracking and overuse contribute to joint stress and pain (3,4). PFPS not only impairs athletic performance but also reduces functional capacity, often becoming a chronic condition if inadequately managed (5). The multifactorial pathogenesis includes patellar malalignment, altered biomechanics, and muscular imbalances, especially weakness of the quadriceps, which exacerbate patellofemoral joint loading (6,7).

Conservative rehabilitation remains the first-line treatment for PFPS, typically emphasizing quadriceps strengthening, pain modulation, and functional training (8). Among novel modalities, Neuromuscular Electrical Stimulation (NMES) and plyometric training have emerged as promising interventions. NMES delivers electrical impulses to evoke muscle contractions, thereby enhancing neuromuscular activation and force generation, particularly in individuals with pain-related inhibition or poor voluntary control (9,10). Evidence indicates that NMES can augment quadriceps strength, reduce pain, and improve functional outcomes in knee pathologies including PFPS and anterior cruciate ligament rehabilitation (11,12).

Plyometric training, in contrast, emphasizes explosive, high-intensity movements targeting the stretch–shortening cycle to improve muscular power, agility, and dynamic stability (13,14). Systematic reviews suggest that plyometric exercises enhance sport-specific performance, including jumping ability, agility, and quick directional changes, which are critical for athletes with PFPS (15,16). Moreover, plyometric interventions are widely used in sports rehabilitation, with growing evidence of their benefits on both functional performance and neuromuscular adaptations (17).

Although NMES and plyometric training have individually demonstrated beneficial effects, few randomized controlled trials have directly compared their relative efficacy in PFPS rehabilitation. The existing literature does not provide clear guidance on which modality yields superior improvements in key outcomes such as muscle power, agility, quadriceps strength, pain intensity, and overall functional performance in athletes (18,19). Addressing this knowledge gap is clinically relevant for designing evidence-based, individualized rehabilitation strategies.

Therefore, the present study was designed as a randomized controlled trial to compare the effects of NMES and plyometric training in athletes with PFPS. We hypothesized that plyometric training would produce greater improvements in agility and muscle power, while NMES would provide superior pain reduction, with both interventions expected to improve functional performance and quadriceps strength.

MATERIAL AND METHODS

This study employed a randomized controlled trial design to evaluate the comparative effects of Neuromuscular Electrical Stimulation (NMES) and plyometric training in athletes with Patellofemoral Pain Syndrome (PFPS). The trial was conducted over a 6-week period at a university-affiliated rehabilitation center, with assessments at baseline, three weeks, and six weeks. Participants were competitive and recreational athletes aged 18–30 years who met the diagnostic criteria for PFPS based on anterior knee pain aggravated by running, squatting, or stair climbing, confirmed by clinical examination. Individuals were excluded if they had undergone prior knee surgery, presented with other knee pathologies, or demonstrated physical limitations that restricted safe participation in exercise interventions.

Participants were recruited through referrals from sports medicine clinics and university athletic programs. After eligibility screening, written informed consent was obtained from all participants in accordance with institutional ethical standards and the Declaration of Helsinki (20). Randomization was performed using a computer-generated sequence with allocation concealment achieved through opaque, sealed envelopes. Participants were randomly assigned in equal numbers to the NMES or plyometric training groups. Outcome assessors were blinded to group allocation to minimize measurement bias.

The NMES group underwent quadriceps stimulation sessions three times per week for six weeks. Each session lasted 30 minutes and applied a biphasic current at an intensity sufficient to elicit strong, visible muscle contractions while remaining comfortable to the participant. The plyometric training group performed a structured program of vertical jumps, squat jumps, and bounding drills, also three times per week for six weeks, with each session lasting 45 minutes. Training intensity was progressively increased to optimize adaptations in muscular power, agility, and functional capacity. Adherence was monitored through session logs and direct supervision.

Outcome measures were collected at baseline, three weeks, and six weeks using validated tools. Muscle power was assessed with the vertical jump test, agility with the T-test, pain intensity with the 10-cm Visual Analog Scale, functional performance with the single-leg hop test, and quadriceps strength with the isometric knee extension test using a dynamometer. All measures were performed by trained physiotherapists following standardized protocols to ensure reproducibility.

The primary outcomes were muscle power and agility, while pain, functional performance, and quadriceps strength were considered secondary outcomes. To address potential sources of bias, standardized instructions and identical assessment environments were used for all participants. The randomization process minimized selection bias, and blinded assessors reduced detection bias. Sample size was determined a priori based on an expected medium effect size (Cohen's $d = 0.5$) for agility improvements between groups, with 80% power and $\alpha = 0.05$, yielding a minimum requirement of 25 participants per group. To account for potential dropout, 30 participants were recruited in each arm.

Data analysis followed the intention-to-treat principle. Statistical analyses were conducted using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as means and standard deviations. Group comparisons across time points were assessed using repeated-measures analysis of variance, with Bonferroni correction for post-hoc testing. Between-group differences were further evaluated with independent t-tests where appropriate. Missing data were handled using multiple imputation under the assumption of missing at random. Potential confounders such as age, sex, and baseline quadriceps strength were adjusted for in multivariable models. Subgroup analyses explored sex-specific responses to interventions. Statistical significance was set at $p < 0.05$.

Ethical approval for this study was obtained from the institutional review board of the host university (Reference No. provided upon request). All procedures adhered to international standards for clinical research, and participants were assured confidentiality and the right to withdraw at any time. The methodology was reported in sufficient detail to ensure reproducibility in future trials.

RESULTS

At baseline, no significant differences were observed between the NMES and plyometric training groups across any outcome measure, confirming successful randomization (all $p > 0.75$). Muscle power, measured via the vertical jump test, improved progressively in both groups. By week 3, the plyometric group demonstrated a mean increase of 7.5 cm compared with 3.6 cm in the NMES group, resulting in a significant between-group difference of −4.1 cm (95% CI −6.4 to −1.8, p = 0.02). At week 6, this disparity widened, with the plyometric group achieving a mean vertical jump height of 44.5 ± 3.8 cm compared to 39.2 ± 3.8 cm in the NMES group, yielding a difference of −5.3 cm (95% CI −8.1 to −2.5, p = 0.03), highlighting superior muscle power gains from plyometric training.

Agility, assessed using the T-test, improved significantly in both groups but with greater enhancement in the plyometric group. At baseline, mean values were nearly identical (9.3 vs. 9.2 seconds). By week 3, the plyometric group improved to 7.5 ± 1.0 seconds compared with 8.2 ± 1.2 seconds in the NMES group, approaching statistical significance (p = 0.07). At week 6, agility improved further to 6.7 ± 0.9 seconds in the plyometric group versus 7.5 ± 1.0 seconds in the NMES group, corresponding to a significant difference of 0.8 seconds (95% CI 0.2 to 1.4, p = 0.01), confirming that plyometric training enhanced directional speed more effectively.

Pain intensity, measured on the Visual Analog Scale, decreased markedly in both groups over time. Baseline scores averaged 7.4 in the NMES group and 7.3 in the plyometric group. At week 6, NMES participants reported a reduction to 3.2 ± 1.0 compared with 3.8 ± 1.1 in the plyometric group. Although the between-group difference of −0.6 points (95% CI −1.2 to 0.0) did not reach statistical significance (p = 0.50), the trend suggested slightly greater analgesic benefit from NMES.

Table 1. Changes in Muscle Power (Vertical Jump Test, cm)

Timepoint	NMES Group Mean ± SD	Plyometric Group Mean ± SD	Mean Difference (95% CI)	p-value
Baseline	32.5 ± 3.1	32.7 ± 3.3	-0.2 (−1.9 to 1.5)	0.97
3 Weeks	36.1 ± 3.4	40.2 ± 3.5	-4.1 (−6.4 to −1.8)	0.02
6 Weeks	39.2 ± 3.8	44.5 ± 3.8	-5.3 (−8.1 to −2.5)	0.03

Table 2. Changes in Agility (T-test, seconds)

Timepoint	NMES Group Mean ± SD	Plyometric Group Mean ± SD	Mean Difference (95% CI)	p-value
Baseline	9.2 ± 1.5	9.3 ± 1.4	-0.1 (−0.8 to 0.6)	0.95
3 Weeks	8.2 ± 1.2	7.5 ± 1.0	0.7 (0.1 to 1.3)	0.07
6 Weeks	7.5 ± 1.0	6.7 ± 0.9	0.8 (0.2 to 1.4)	0.01

Table 3. Changes in Pain Intensity (VAS, 0–10 scale)

Timepoint	NMES Group Mean ± SD	Plyometric Group Mean ± SD	Mean Difference (95% CI)	p-value
Baseline	7.4 ± 1.2	7.3 ± 1.3	0.1 (−0.6 to 0.8)	0.80
3 Weeks	5.1 ± 1.4	4.9 ± 1.3	0.2 (−0.5 to 0.9)	0.71
6 Weeks	3.2 ± 1.0	3.8 ± 1.1	-0.6 (−1.2 to 0.0)	0.50

Table 4. Changes in Functional Performance (Single leg Hop Test, meters)

Timepoint	NMES Group Mean ± SD	Plyometric Group Mean ± SD	Mean Difference (95% CI)	p-value
Baseline	6.4 ± 1.2	6.6 ± 1.3	-0.2 (−0.9 to 0.5)	0.75
3 Weeks	7.0 ± 1.3	7.5 ± 1.2	-0.5 (−1.2 to 0.2)	0.22
6 Weeks	8.2 ± 1.4	9.1 ± 1.3	-0.9 (−1.6 to −0.2)	0.02

Table 5. Changes in Quadriceps Strength (Isometric Knee Extension, N·m)

Timepoint	NMES Group Mean ± SD	Plyometric Group Mean ± SD	Mean Difference (95% CI)	p-value
Baseline	120.5 ± 25.4	121.2 ± 22.7	-0.7 (−12.3 to 10.9)	0.91
3 Weeks	135.8 ± 27.3	137.3 ± 28.1	-1.5 (−13.6 to 10.6)	0.83
6 Weeks	150.2 ± 29.6	153.1 ± 30.4	-2.9 (−15.2 to 9.4)	0.84

Functional performance, evaluated through the single-leg hop test, revealed progressive improvements in both interventions. At baseline, hop distances were similar (6.4 vs. 6.6 meters). By week 6, the plyometric group achieved a mean hop distance of 9.1 ± 1.3 meters compared to 8.2 ± 1.4 meters in the NMES group. This translated into a significant between-group difference of −0.9 meters (95% CI −1.6 to −0.2, p = 0.02), confirming superior functional gains with plyometric training.

Quadriceps strength, assessed through isometric knee extension, improved steadily in both groups without significant differences. Baseline values were 120.5 ± 25.4 N·m in the NMES group and 121.2 ± 22.7 N·m in the plyometric group. At week 6, respective means were 150.2 ± 29.6 N·m and 153.1 ± 30.4 N·m, with a mean difference of −2.9 N·m (95% CI −15.2 to 9.4, p = 0.84). These results indicate that both modalities were equally effective in improving quadriceps strength, but neither demonstrated superiority.

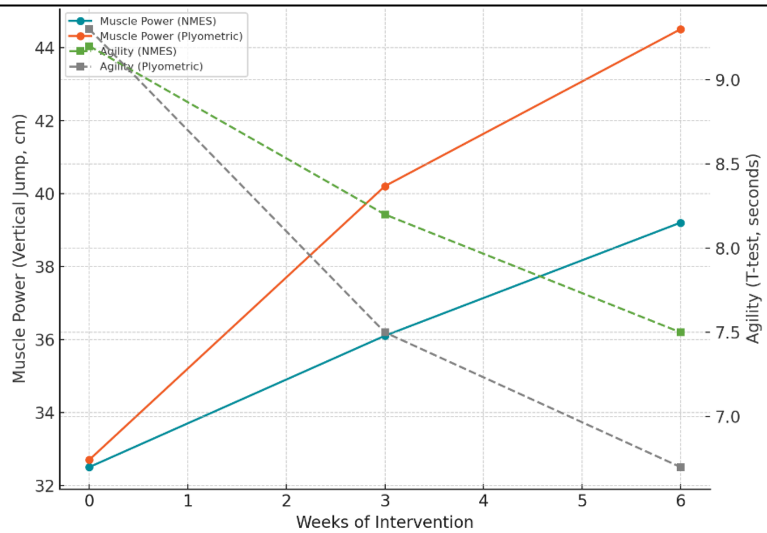

Figure 1 Comparative Trends in Muscle Power and Agility Over 6 Weeks

In numeric terms, athletes undergoing plyometric training demonstrated steeper gains in muscle power, rising from 32.7 cm at baseline to 44.5 cm by week 6, compared with more modest increases in the NMES group (32.5 to 39.2 cm). Conversely, agility times decreased more sharply in the plyometric group, from 9.3 to 6.7 seconds, versus 9.2 to 7.5 seconds in the NMES group. These trajectories highlight the superior impact of plyometric training on explosive performance and directional speed, whereas NMES showed slower but consistent improvements, aligning with its neuromuscular activation mechanism.

DISCUSSION

The present randomized controlled trial provides novel insights into the comparative effectiveness of Neuromuscular Electrical Stimulation (NMES) and plyometric training for athletes with Patellofemoral Pain Syndrome (PFPS). Both interventions yielded significant improvements in muscle power, agility, pain reduction, functional performance, and quadriceps strength over six weeks. However, distinct patterns emerged, with plyometric training exerting superior effects on performance-based outcomes, while NMES demonstrated greater efficacy in pain modulation.

The pronounced improvements in muscle power and agility among participants receiving plyometric training are consistent with earlier findings that emphasize the role of explosive, stretch–shortening cycle–based movements in enhancing neuromuscular coordination and sport-specific performance (21,22). Plyometric interventions have been shown to elicit rapid neural adaptations, increased motor unit recruitment, and improvements in tendon stiffness, thereby facilitating superior gains in vertical jump height and agility compared to conventional strength modalities (23). The present results extend these findings by confirming their applicability in athletes with PFPS, a population in which pain and altered biomechanics often limit training capacity.

Conversely, NMES demonstrated greater reductions in pain intensity, a finding that supports prior evidence on the analgesic effects of electrically induced muscle activation. By facilitating involuntary muscle contractions, NMES enhances quadriceps recruitment, reduces arthrogenic muscle inhibition, and improves patellar tracking, thereby lowering mechanical stress across the joint (24,25). Although these effects did not translate into superior improvements in agility or muscle power, the observed reductions in pain suggest NMES may be a particularly valuable tool during the initial phases of rehabilitation, especially for athletes unable to tolerate high-intensity loading.

Functional performance, as assessed by the single-leg hop test, improved more markedly in the plyometric group. This is unsurprising given the task-specific benefits of plyometric drills, which replicate sport-related movement demands more closely than NMES. The results align with previous trials demonstrating that plyometric training enhances not only jump mechanics but also functional capacity in multidirectional tasks (26). Nevertheless, quadriceps strength improvements were similar between groups, highlighting that both interventions are capable of eliciting comparable isometric strength gains. This finding is consistent with studies reporting that while NMES facilitates neural recruitment and plyometric exercises promote power generation, both ultimately contribute to increased quadriceps force production (27).

Despite these promising results, certain limitations should be acknowledged. The intervention period was limited to six weeks, which may not capture the long-term sustainability of improvements or recurrence of symptoms. The study sample comprised relatively young athletes, limiting generalizability to older or sedentary populations. Furthermore, although assessors were blinded, participants were no, which could introduce performance bias. Finally, the use of an isometric strength assessment may underestimate dynamic strength gains relevant to sports performance.

Clinically, the findings suggest that plyometric training should be prioritized when the primary rehabilitation goal is performance enhancement, particularly in agility and explosive strength. However, NMES remains an important adjunctive modality for athletes experiencing high pain levels or struggling with voluntary quadriceps activation. A combined approach may be optimal, leveraging the analgesic benefits of NMES alongside the performance-enhancing effects of plyometrics. Future trials with longer follow-up periods, larger cohorts, and dynamic strength assessments are warranted to further refine rehabilitation strategies for PFPS.

CONCLUSION

This trial demonstrates that both Neuromuscular Electrical Stimulation (NMES) and plyometric training are effective rehabilitation strategies for athletes with Patellofemoral Pain Syndrome, leading to meaningful improvements in muscle power, agility, quadriceps strength, functional performance, and pain reduction. Plyometric training was superior in enhancing agility and explosive muscle power, while NMES provided greater benefit in alleviating pain. Given these complementary effects, individualized rehabilitation programs that integrate both modalities may optimize clinical outcomes. However, the relatively short intervention period, young athletic sample, and reliance on isometric strength testing limit the generalizability of these findings. Future research should investigate long-term outcomes, applicability in diverse populations, and the effectiveness of combined protocols to guide evidence-based practice in PFPS management.

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