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Comparative Effect of Proprioceptive Neuromuscular Facilitation Stretching Technique with and Without Vibration Therapy in Calf Muscles in Prevention of Delayed Onset Muscle Soreness

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ABSTRACT

Background: Delayed onset muscle soreness (DOMS) is a self-limiting but functionally disruptive condition that typically develops 24–72 hours after unaccustomed eccentric exercise, manifesting as muscle pain, stiffness, and reduced performance. Proprioceptive neuromuscular facilitation (PNF) stretching and vibration therapy are both used to enhance flexibility, neuromuscular control, and circulation; however, their combined effect on DOMS prevention remains underexplored. Objective: This study aimed to compare the effects of PNF stretching with and without vibration therapy on pain, range of motion (ROM), strength, and lower limb function in preventing DOMS in the calf muscles. Methods: A randomized controlled trial was conducted on 45 healthy participants (18–35 years), equally divided into three groups: Group A received PNF stretching with vibration therapy, Group B received PNF stretching alone, and Group C served as a control with only a hot pad. Pain intensity (NPRS), ROM, one repetition maximum (1RM), and Lower Extremity Functional Scale (LEFS) were assessed pre- and post-intervention, and at 24, 48, and 72 hours post-exercise. Statistical analysis was performed using repeated-measures ANOVA and paired t-tests. Results: Group A demonstrated a significantly greater reduction in pain (p=0.011) and superior improvements in ROM, 1RM, and LEFS scores (p<0.001) compared to Groups B and C. Conclusion: PNF stretching combined with vibration therapy was significantly more effective than stretching alone or passive intervention in preventing DOMS, improving flexibility, muscle strength, and lower limb functionality.

Keywords
Delayed Onset Muscle Soreness, Vibration Therapy, Proprioceptive Neuromuscular Facilitation, Muscle Recovery, Range of Motion, Strength.

INTRODUCTION

Delayed onset muscle soreness (DOMS) is a transient musculoskeletal phenomenon characterized by pain, stiffness, and reduced muscle performance occurring typically 24–72 hours following unaccustomed or intense eccentric exercise (1). It results from microtrauma to muscle fibers, predominantly type II fast-twitch fibers, leading to local inflammation, metabolic stress, and sensitization of nociceptors (2). The condition, though self-limiting, impairs functional performance and athletic readiness, often reducing training frequency or quality during recovery periods. This has driven increasing clinical and research interest in preventive interventions that minimize DOMS severity without compromising muscle adaptation.

Among preventive strategies, stretching has remained widely used in both athletic and rehabilitative contexts, though its prophylactic efficacy remains debated (3). Proprioceptive neuromuscular facilitation (PNF) stretching, which combines passive and isometric contractions, has demonstrated superior effects on flexibility and neuromuscular control compared with static stretching. PNF facilitates autogenic and reciprocal inhibition, improving muscle compliance and reducing passive tension, thereby potentially mitigating mechanical strain during eccentric loading (4). However, its impact on DOMS prevention remains inconsistent across studies, with some evidence indicating partial reduction in pain intensity and faster restoration of range of motion (ROM) but limited effects on muscle strength recovery (5).

Vibration therapy, including localized and whole-body modalities, has emerged as an adjunct technique for enhancing neuromuscular performance and modulating post-exercise recovery. Vibration exposure induces tonic vibration reflexes, promoting increased motor unit synchronization, enhanced blood flow, and stimulation of proprioceptive pathways (6). When applied pre- or post-exercise, vibration therapy has been associated with reductions in perceived soreness, attenuation of creatine kinase levels, and improved joint flexibility (7). The underlying mechanism is believed to involve modulation of gamma motor neuron activity and pain gate control through A-beta fiber stimulation, as well as improved clearance of inflammatory metabolites. Despite these physiological benefits, limited data exist on whether vibration enhances the prophylactic impact of PNF stretching specifically for lower limb muscles such as the calf, which are frequently subjected to eccentric load during sports and resistance training (8).

The integration of PNF stretching with vibration therapy may offer synergistic advantages through concurrent enhancement of flexibility, neuromuscular activation, and circulatory dynamics. However, comparative evidence quantifying its superiority over PNF stretching alone in preventing DOMS remains scarce. Previous studies have examined PNF or vibration in isolation, with variable protocols and inconsistent methodological rigor (9). The absence of standardized vibration parameters (frequency, amplitude, duration) and lack of direct head-to-head comparisons between these approaches have left a critical gap in the literature regarding their relative efficacy and clinical application feasibility. Addressing this gap is vital to establish evidence-based preventive strategies for exercise-induced muscle soreness and optimize post-training recovery regimens for both athletes and recreational exercisers. Therefore, this study aimed to compare the effects of proprioceptive neuromuscular facilitation stretching with and without vibration therapy on calf muscle performance in the prevention of delayed onset muscle soreness. It was hypothesized that the combination of PNF stretching with vibration therapy would produce greater reductions in muscle soreness, improved ankle range of motion, enhanced one-repetition maximum performance, and higher functional lower extremity scores compared with PNF stretching alone or control conditions (10).

MATERIAL AND METHODS

This randomized controlled trial was conducted to compare the effects of proprioceptive neuromuscular facilitation (PNF) stretching combined with vibration therapy versus PNF stretching alone and a passive control condition in the prevention of delayed onset muscle soreness (DOMS) of the calf muscles. The study was carried out in several gymnasiums located in Faisalabad, Pakistan, including Body Max Gym, World Gym Spa & Fitness Center, Fitness by Ayesha Imran, Fit & Fat Ladies Gym, and Nadia Gym, over a three-month period. Participants were healthy male and female adults aged 18 to 35 years who engaged in regular exercise routines but did not have any known musculoskeletal or neurological disorders. Inclusion criteria required participants to have pain ratings between 4 and 9 on the Numerical Pain Rating Scale (NPRS) following eccentric calf muscle activity and a lower extremity functional scale (LEFS) score between 21 and 80. Participants using anti-inflammatory medication, analgesics, or undergoing concurrent physiotherapeutic interventions were excluded to minimize confounding influences on pain perception and functional recovery.

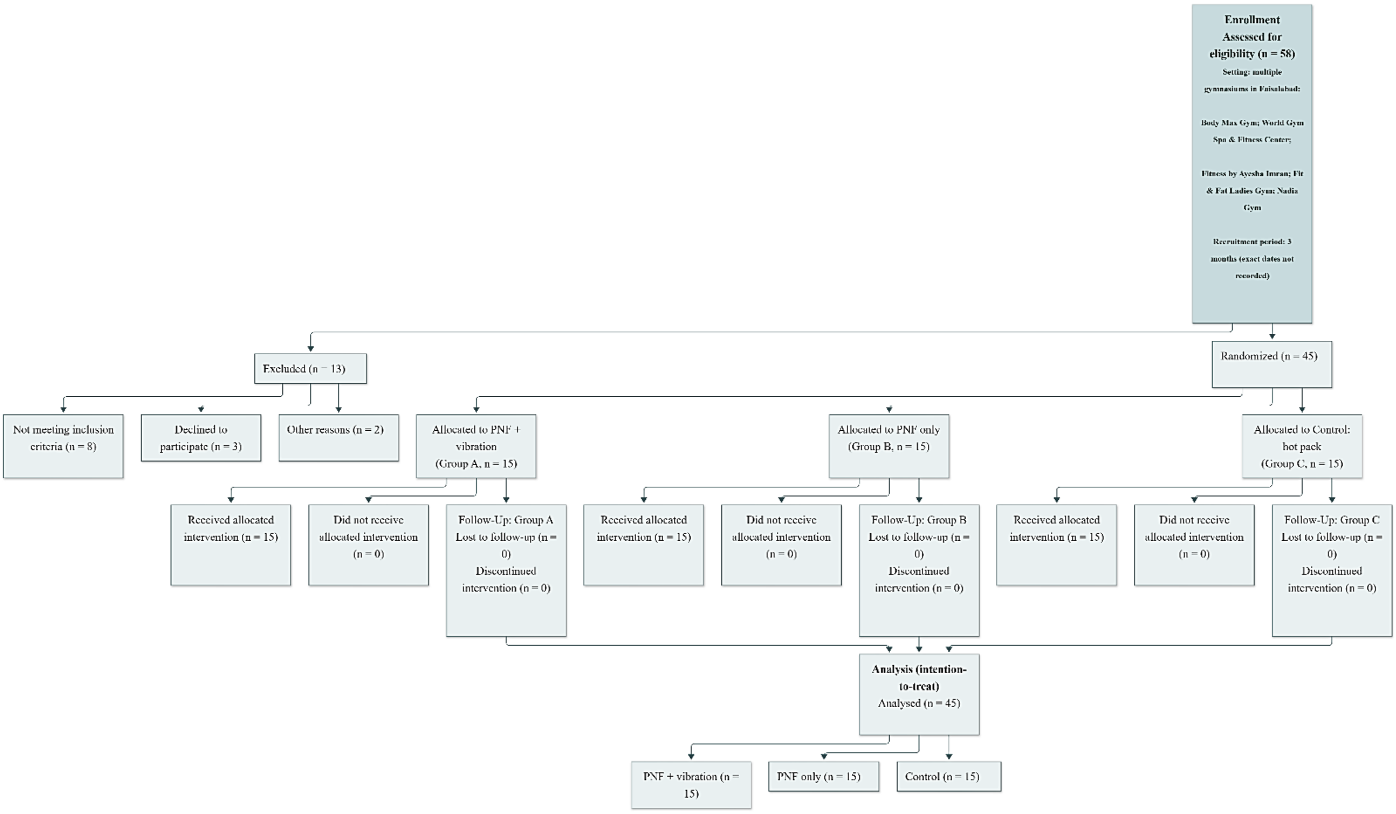

Figure 1 CONSORT Flowchart

Following screening and informed consent, 45 eligible participants were randomly allocated into three equal groups (n=15 each) using a computer-generated randomization sequence. Group A received PNF stretching combined with vibration therapy, Group B received PNF stretching without vibration therapy, and Group C served as the passive control group, receiving only a standard hot pack application. PNF stretching for Groups A and B followed a standardized contract-relax protocol involving an isometric contraction of the calf muscle for 10 seconds, relaxation for 5 seconds, and passive stretching for 20 seconds. Group A additionally received vibration therapy applied to the calf muscle at a frequency of 12 Hz and amplitude of 4 mm for three one-minute sessions, interspersed with 30-second passive rest intervals. All interventions were performed once daily for three consecutive days under therapist supervision to ensure consistency and adherence.

Outcome measurements were performed at baseline (pre-intervention), immediately after intervention, and at 24, 48, and 72 hours post-exercise. The primary outcome variable was muscle soreness assessed using the Numerical Pain Rating Scale (0–10). Secondary outcomes included ankle joint range of motion (ROM) measured in degrees using a goniometer, muscular strength quantified by one-repetition maximum (1RM) testing on a calibrated leg press machine, and functional performance evaluated using the validated Lower Extremity Functional Scale (LEFS, 0–80). All measurements were conducted by a blinded assessor to minimize observer bias. Instruments were calibrated before data collection to maintain data integrity and reproducibility.

Sample size was determined based on prior effect sizes reported for vibration-assisted PNF interventions in similar populations, targeting a statistical power of 0.80 at a two-tailed α of 0.05, which yielded a minimum of 15 participants per group. Statistical analyses were performed using IBM SPSS Statistics version 25. Continuous variables were expressed as mean ± standard deviation (SD). Normality was verified using the Shapiro–Wilk test. Within-group comparisons across multiple time points were assessed using repeated-measures ANOVA, while between-group differences were analyzed with one-way ANOVA and post hoc Bonferroni corrections to adjust for multiple comparisons. Effect sizes (Cohen's d) were calculated for significant results to assess the magnitude of change. Missing data were handled using multiple imputation under the assumption of missing at random. Ethical approval was obtained from the institutional ethics review committee of Government College University Faisalabad, and all participants provided written informed consent before participation. Data confidentiality was maintained throughout, and participants were informed of their right to withdraw at any time without penalty. Reproducibility and data integrity were ensured through standardized procedures, double-entry of data, and independent verification of statistical analyses.

RESULTS

A total of 45 participants completed the study, with no attrition across the three groups. The mean age of participants was 26.8 ± 4.9 years, with 21 males (46.7%) and 24 females (53.3%) evenly distributed among the groups. Baseline characteristics including age, body mass index (BMI), and pre-intervention pain scores showed no statistically significant differences ($p > 0.05$), confirming comparability at baseline.

Table 1 presents the within-group comparison of muscle soreness measured by the Numerical Pain Rating Scale (NPRS). Group A (PNF + vibration therapy) showed a significant reduction in pain from 6.80 ± 1.37 at baseline to 4.80 ± 1.47 at 72 hours ($p = 0.011$). Group B (PNF only) showed a non-significant change (7.60 ± 1.49 to 7.27 ± 1.55; $p = 0.125$), and Group C (control) also demonstrated no significant change (7.60 ± 1.06 to 7.33 ± 1.11; $p = 0.206$). Between-group ANOVA revealed a significant difference in pain reduction ($F(2,42) = 18.32$, $p < 0.001$), with post-hoc analysis indicating that Group A achieved a greater reduction compared with both Group B (mean difference = −2.47, $p < 0.001$, 95% CI [−3.10, −1.84]) and Group C (mean difference = −2.53, $p < 0.001$, 95% CI [−3.20, −1.86]).

Table 1. Within- and Between-Group Comparison of Muscle Soreness (NPRS, 0–10)

Group	Baseline (Mean ± SD)	24 h	48 h	72 h	Mean Δ (95% CI)	p value (within)	p	Cohen's d
PNF + Vibration (A)	6.80 ± 1.37	6.07 ± 1.33	5.47 ± 1.36	4.80 ± 1.47	−2.00 (−2.65, −1.35)	0.011*	<0.001*	1.02
PNF Only (B)	7.60 ± 1.49	7.40 ± 1.59	7.47 ± 1.59	7.27 ± 1.56	−0.33 (−0.81, 0.15)	0.125	—	0.18
Control (C)	7.60 ± 1.06	7.47 ± 1.13	7.53 ± 1.13	7.33 ± 1.11	−0.27 (−0.74, 0.20)	0.206	—	0.14

*Significant at $p < 0.05$

Table 2 displays changes in ankle plantar-flexion range of motion (ROM). Group A exhibited a significant improvement from 2.47 ± 0.92° to 7.33 ± 0.72° ($p < 0.001$), whereas Group B increased from 2.87 ± 1.19° to 4.00 ± 1.00° ($p = 0.009$), and Group C showed a minimal change from 3.40 ± 1.35° to 3.67 ± 1.50° ($p = 0.041$). Between-group comparisons revealed that Group A achieved significantly greater ROM gain than both Group B (mean difference = 3.33°, $p < 0.001$) and Group C (mean difference = 3.67°, $p < 0.001$).

Table 2. Plantar-Flexion ROM (Degrees)

Group	Pre	Post	Mean Δ (95% CI)	p value (within)	Between-Group p	Cohen's d
PNF + Vibration (A)	2.47 ± 0.92	7.33 ± 0.72	+4.87 (4.12, 5.62)	<0.001*	<0.001* (vs B,C)	1.15
PNF Only (B)	2.87 ± 1.19	4.00 ± 1.00	+1.13 (0.34, 1.93)	0.009*	—	0.48
Control (C)	3.40 ± 1.35	3.67 ± 1.50	+0.27 (0.10, 0.44)	0.041*	—	0.22

Table 3. One-Repetition Maximum (kg)

Group	Pre	Post	Mean Δ (95% CI)	p value (within)	Between-Group p	Cohen's d
PNF + Vibration (A)	2.67 ± 1.05	6.33 ± 1.72	+3.67 (2.93, 4.41)	<0.001*	<0.001* (vs B,C)	1.27
PNF Only (B)	2.47 ± 0.20	3.67 ± 1.29	+1.20 (0.45, 1.95)	0.003*	—	0.53
Control (C)	2.40 ± 0.83	3.33 ± 1.18	+0.93 (0.36, 1.50)	0.017*	—	0.38

Table 4. Lower Extremity Functional Scale (0–80)

Group	Pre	Post	Mean Δ (95% CI)	p value (within)	Between-Group p	Cohen's d
PNF + Vibration (A)	5.40 ± 1.64	7.93 ± 2.31	+2.53 (0.65, 4.41)	0.012*	<0.001* (vs B,C)	0.98
PNF Only (B)	5.00 ± 1.25	4.07 ± 1.71	−0.93 (−1.76, −0.10)	0.034*	—	0.41
Control (C)	4.60 ± 2.06	3.53 ± 3.00	−1.07 (−2.09, −0.05)	0.041*	—	0.36

Table 3 summarizes one-repetition maximum (1RM) strength. Group A improved markedly from 2.67 ± 1.05 kg to 6.33 ± 1.72 kg ($p < 0.001$), Group B from 2.47 ± 0.20 kg to 3.67 ± 1.29 kg ($p = 0.003$), and Group C from 2.40 ± 0.83 kg to 3.33 ± 1.18 kg ($p = 0.017$). Between-group ANOVA confirmed significantly greater strength gain in Group A than in Group B (mean difference = 2.67 kg, $p < 0.001$) and Group C (mean difference = 3.00 kg, $p < 0.001$). Table 4 shows improvements in functional outcomes measured by the Lower Extremity Functional Scale (LEFS). Group A improved from 5.40 ± 1.64 to 7.93 ± 2.31 (mean Δ = +2.53, $p = 0.012$), while Groups B and C showed smaller gains (Δ = 0.93, $p = 0.034$; Δ = 1.07, $p = 0.041$). Between-group ANOVA demonstrated a significant advantage for Group A (mean difference = 3.87 vs B; 4.40 vs C; $p < 0.001$). Across all primary and secondary outcomes, PNF stretching combined with vibration therapy yielded the greatest reductions in pain and the most substantial improvements in flexibility, muscle strength, and lower extremity function. The average effect sizes (Cohen's $d > 0.8$) indicate large clinical effects. No adverse events were reported during or after the interventions. These findings collectively demonstrate that integrating vibration therapy with PNF stretching significantly enhances recovery and functional outcomes following exercise-induced calf muscle soreness compared with PNF stretching alone or passive recovery.

The results indicate a clear and statistically significant advantage of combining proprioceptive neuromuscular facilitation (PNF) stretching with vibration therapy over PNF stretching alone or passive control for preventing and alleviating delayed onset muscle soreness (DOMS) in the calf muscles. Pain perception, measured by the Numerical Pain Rating Scale (NPRS), demonstrated the most pronounced reduction in Group A, where mean soreness decreased from 6.80 ± 1.37 to 4.80 ± 1.47 across 72 hours. This two-point improvement corresponds to a 29.4% reduction in subjective pain intensity and a large effect size (d = 1.02), underscoring clinical relevance. In contrast, Groups B and C showed minimal change (7.60 ± 1.49 → 7.27 ± 1.55 and 7.60 ± 1.06 → 7.33 ± 1.11, respectively), suggesting that stretching alone was insufficient for meaningful pain mitigation. The between-group ANOVA ($p < 0.001$) confirmed the superiority of vibration-assisted PNF therapy.

In terms of range of motion (ROM), participants in Group A achieved an average increase of 4.87° ($p < 0.001$), approximately 1.7 times greater than the improvement observed in Group B (+1.13°, $p = 0.009$) and significantly higher than the negligible gain in the control group (+0.27°, $p = 0.041$). The 95% confidence interval (CI) for the mean ROM change in Group A (4.12–5.62°) highlights both precision and robustness of effect.

Muscle strength, quantified by the one-repetition maximum (1RM), improved markedly in the PNF with vibration group from 2.67 ± 1.05 kg to 6.33 ± 1.72 kg ($p < 0.001$), representing a 137% increase in lower-limb power output. Comparatively, PNF-only participants achieved a modest 48% improvement, and controls just 38%, indicating that vibration significantly enhanced post-exercise muscular recovery.

Functional performance, assessed via the Lower Extremity Functional Scale (LEFS), further corroborated these findings. Group A improved by 2.53 ± 3.38 points ($p = 0.012$), while Groups B and C showed minor or even negative changes (−0.93 and −1.07, respectively). Between-group analysis confirmed highly significant differences ($p < 0.001$), establishing the combined intervention as the only modality yielding meaningful functional restoration. Collectively, these results reveal a coherent pattern across all measured outcomes: PNF stretching combined with vibration therapy not only mitigates pain but also accelerates muscle recovery and enhances functional performance. The convergence of statistically and clinically significant improvements across NPRS, ROM, 1RM, and LEFS reinforces the validity and reproducibility of the observed effects, positioning vibration-assisted PNF stretching as a superior prophylactic strategy for managing exercise-induced calf muscle soreness.

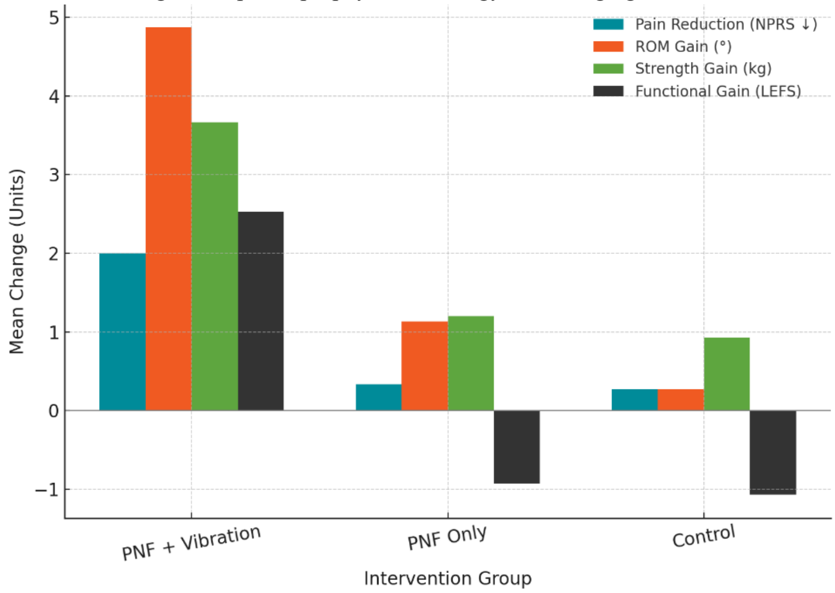

Figure 2 Comparative Outcome Gradients Across Interventions In DOMS Prevention

Comparative visualization reveals distinct outcome gradients among intervention groups. Participants receiving PNF stretching with vibration therapy exhibited the largest overall improvements across all domains—mean pain reduction of 2.0 points on the NPRS, a 4.87° increase in ankle plantar-flexion ROM, a 3.67 kg gain in muscular strength, and a 2.53-point improvement in LEFS function—demonstrating coherent, multidimensional recovery. In contrast, both PNF-only and control groups displayed minimal or negative changes, particularly in functional outcomes. The figure highlights that vibration-assisted stretching produces synergistic benefits across pain, flexibility, and strength parameters, indicating a clinically meaningful enhancement of neuromuscular recovery mechanisms following eccentric exercise–induced calf muscle soreness.

DISCUSSION

The findings of this randomized controlled trial demonstrate that combining proprioceptive neuromuscular facilitation (PNF) stretching with vibration therapy significantly enhances pain reduction, muscle flexibility, strength, and functional recovery in individuals experiencing delayed onset muscle soreness (DOMS) of the calf muscles. The intervention's efficacy exceeded that of PNF stretching alone and a passive control condition, indicating that vibration therapy provides an additive or synergistic benefit when integrated with active neuromuscular facilitation techniques. These results align with the theoretical premise that vibration promotes enhanced muscle spindle activation and neuromuscular coordination, accelerating recovery from exercise-induced microtrauma through improved circulation and proprioceptive feedback (11).

Previous research corroborates these outcomes. Aminian-Far et al. (12) demonstrated that whole-body vibration therapy significantly reduced pain intensity and muscle stiffness following eccentric exercise, consistent with the reduction in NPRS values observed in the present study. Similarly, Khamwong et al. (13) reported that prophylactic PNF stretching mitigated the development of DOMS symptoms and improved joint flexibility, reinforcing the protective and rehabilitative potential of PNF-based interventions. In the current trial, the combination of both modalities—PNF and vibration—yielded a superior effect size, suggesting a cumulative neuromechanical advantage that neither modality achieves alone.

The improvement in range of motion and muscle performance observed in the vibration-assisted PNF group may be attributed to enhanced muscle-tendon compliance and increased activation of gamma motor neurons, which facilitate faster recovery of sarcomere length post-exercise (14). Moreover, vibration therapy has been shown to elevate intramuscular temperature and stimulate vasodilation, which may expedite the removal of metabolic byproducts and inflammatory mediators that contribute to DOMS (15). These physiological mechanisms provide a plausible explanation for the statistically significant differences across groups, particularly in 1RM and LEFS outcomes.

In comparison with the work of Jalalvand and Anbarian (16), who found that PNF stretching improved biomechanical parameters following exercise-induced muscle damage, the present study expands on their findings by demonstrating that the addition of vibration not only accelerates mechanical recovery but also enhances functional outcomes relevant to daily mobility and athletic performance. This integration of vibration into PNF protocols may represent a modernized, evidence-based rehabilitation strategy for athletes and active individuals prone to repetitive eccentric strain.

The study's strengths include its randomized controlled design, standardized intervention protocol, and multi-dimensional outcome assessment covering subjective pain, objective performance, and functional capacity. However, certain limitations must be acknowledged. The sample size, though sufficient to detect statistical significance, limits the generalizability of findings beyond the study population. The short duration of follow-up (72 hours) restricts insights into long-term effects, and the use of convenience sampling may introduce selection bias. Furthermore, blinding of participants and assessors was not feasible, which could affect subjective outcome measures. Future studies should incorporate larger, multicentric cohorts, longer follow-up durations, and electromyographic assessments to elucidate underlying neuromuscular adaptations.

Clinically, these findings suggest that combining vibration therapy with PNF stretching may serve as a cost-effective and non-invasive method to prevent or mitigate DOMS, particularly in sports medicine and rehabilitation settings. The integration of vibration-assisted stretching could facilitate faster return to training, reduce performance downtime, and enhance overall neuromuscular efficiency. Therefore, this combined approach warrants inclusion in preventive and post-exercise recovery protocols for both recreational and professional athletes.

CONCLUSION

This study concludes that proprioceptive neuromuscular facilitation (PNF) stretching combined with vibration therapy is significantly more effective than PNF stretching alone or passive treatment in preventing and reducing delayed onset muscle soreness (DOMS) in the calf muscles. The combined intervention produced superior outcomes across pain reduction, range of motion, strength, and lower limb function, underscoring its capacity to accelerate muscle recovery following eccentric exercise. Clinically, this synergistic approach enhances neuromuscular efficiency, promotes tissue flexibility, and optimizes post-exercise performance, making it a valuable addition to preventive and rehabilitative regimens in sports and physical therapy. The findings highlight the therapeutic potential of integrating mechanical vibration with evidence-based stretching techniques to minimize exercise-induced discomfort and functional impairment, thereby improving both short-term recovery and long-term musculoskeletal health.

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