

Original Article

Effects of an Eight-Week Proprioceptive Neuromuscular Facilitation (PNF) Stretching Intervention on Functional Movement Patterns in Female Basketball Players: Randomized Controlled Trial

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Abstract

Objective: This study aimed to examine the effects of proprioceptive neuromuscular facilitation (PNF) stretching exercises on functional movement performance in female basketball players. **Methods:** A pre-test/post-test experimental design with intervention and control groups was used. Participants who met the inclusion criteria were randomly allocated to the experimental and control groups in a 1:1 ratio. The experimental group performed PNF stretching exercises in addition to their regular training program, three days per week for eight weeks, while the control group continued with standard training only. Functional movement performance was assessed using the Functional Movement Screen (FMS), with individual FMS subtests analyzed, and all assessments were conducted by a blinded assessor. **Results:** Within-group improvements were observed in several FMS subtests in the experimental group ($p < 0.05$), particularly in measures related to lower-extremity stability, balance, and movement coordination, while no significant changes were found in the control group. Between-group comparisons of change scores (Δ post-pre) demonstrated significantly greater improvements in the experimental group for selected FMS subtests, indicating a beneficial effect of PNF stretching. **Conclusion:** PNF stretching exercises appear to be an effective method for enhancing specific components of functional movement performance in female basketball players. Incorporating PNF-based stretching into regular training programs may contribute to improvements in selected movement quality and performance outcomes.

Keywords: Female Basketball Players, Functional Movement, Functional Movement Screen, Proprioceptive Neuromuscular Facilitation

Introduction

Functional movement skills refer to fundamental abilities that enable athletes to perform movements efficiently across a wide range of physical tasks. These skills are of great importance for maintaining performance, particularly in sports that demand multiple and diverse physical capacities. In this context, basketball is a complex sport

characterized by its dynamic structure, combining various physical components such as speed, agility, endurance, and coordination. The performance of female basketball players is directly associated not only with these physical attributes but also with training methods and rehabilitation processes¹.

Proprioceptive Neuromuscular Facilitation (PNF) stretching exercises are commonly used to enhance flexibility, range of motion, and motor control through increased proprioceptive input^{2,3}. Originally developed in the 1940s for physical rehabilitation purposes, PNF has become increasingly used in recent years to improve sports performance. Research indicates that PNF exercises enable more efficient muscle activation, improve movement control, and minimize the chance of getting injured⁴⁻⁶. Moreover, this technique strengthens

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proprioceptive feedback mechanisms and contributes to the development of neuromuscular coordination in athletes⁷.

Female basketball players are exposed to high levels of physical and psychological stress, which may lead to fluctuations in their performance. Integrating PNF techniques into the training programs of these athletes offers significant benefits in terms of improving technical skills and enhancing sport-specific performance⁸. In addition, PNF exercises have the potential to improve individuals' visuospatial perception, balance control, and motor skills^{9,10}. In this regard, PNF may also help correct muscular imbalances and reduce the risk of injury^{11,12}.

In light of this information, the inclusion of PNF methods in basketball training programs has the potential to support the development of both functional movement skills and overall performance in athletes^{4,13}. Although existing literature includes studies examining the effects of PNF exercises on flexibility, strength, and coordination, research systematically investigating their impact on the functional movement skills of female basketball players remains limited. This gap highlights the significance of the present study and the contribution it aims to make to the current literature.

The Functional Movement Screen (FMS) was used to assess fundamental movement patterns that reflect functional capacity and potential injury risk in athletes. However, it is important to acknowledge that the FMS serves as a surrogate measure and does not directly predict injuries or overall performance, which represents a limitation when interpreting the results.

Aim of the Study

The aim of this research is to investigate the impact of PNF stretching exercises on functional movement performance in female basketball athletes. The findings of this study may provide useful guidance for integrating PNF exercises into basketball training programs. The outcomes of this study are predicted to offer an essential reference for structuring and integrating PNF exercises into basketball training programs.

Research Question

Do PNF stretching exercises significantly improve functional movement skills in female basketball players?

Hypotheses

H1: The pre- and post-test results indicate a statistically significant change in the functional movement performance of female basketball players following PNF training.

H2: PNF exercises improve overall functional movement performance in female basketball players.

H3: PNF applications positively affect balance, flexibility, and movement control in female basketball players.

Materials and Methods

Research Design

The research design consisted of a controlled experimental approach in which participants were tested both prior to and following the intervention. This study was designed as a randomized controlled trial with a pre-test and post-test design, in which participants were randomly assigned to experimental and control groups to evaluate the effect of the independent variable (the PNF exercise program) on the dependent variable (functional movement skills)¹⁴. The study was not prospectively registered in a clinical trial registry, which is acknowledged as a limitation.

The purpose of the study was to investigate how PNF stretching exercises influence the functional movement abilities of female basketball players. Participants were divided into two groups: an experimental group and a control group. While the experimental group performed a PNF stretching program alongside their usual training sessions, the control group maintained only their regular training regimen. Group allocation was done randomly, and informed consent was obtained from all athletes prior to participation.

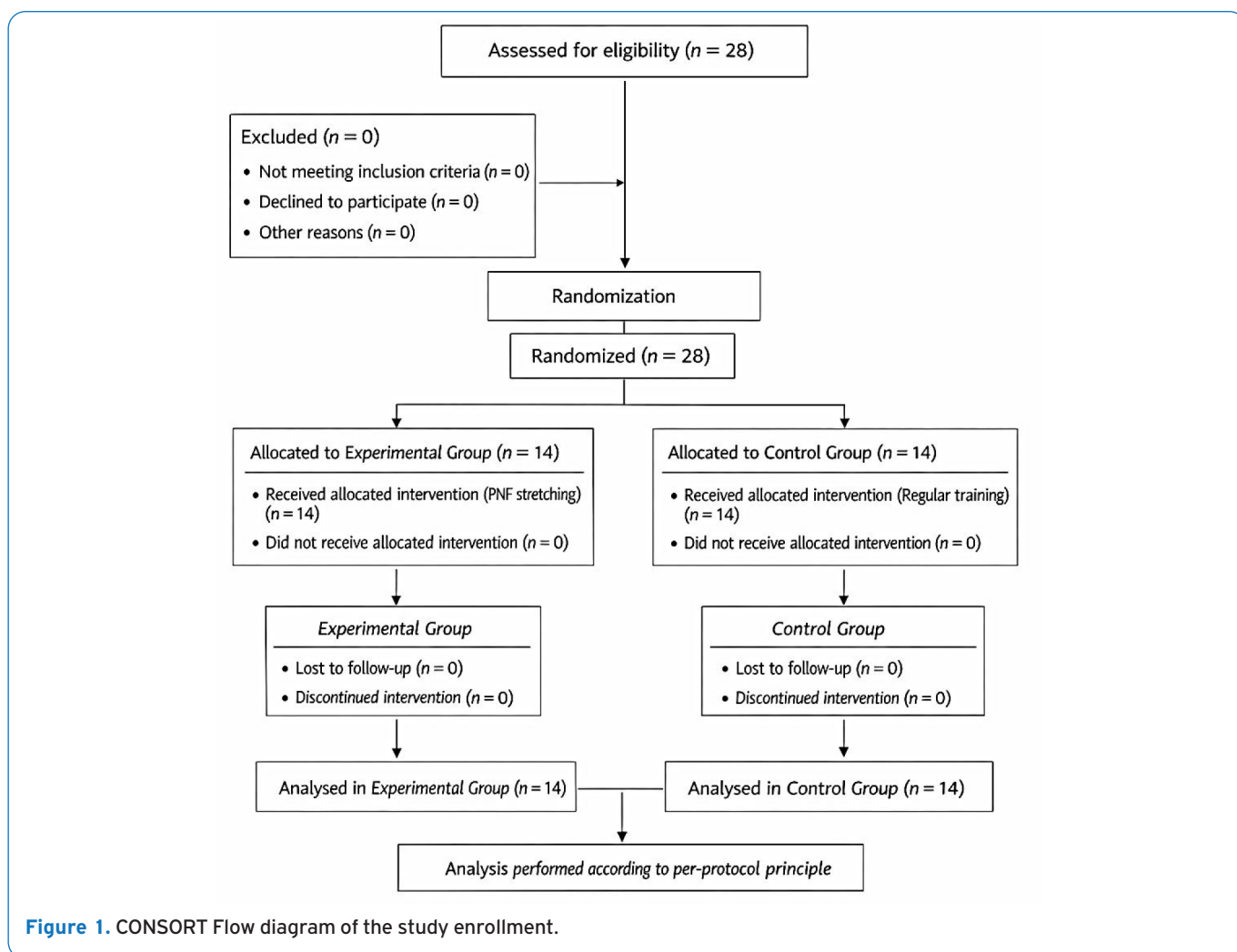
Randomization was performed using a computer-generated random sequence. Allocation was concealed by an independent researcher using sealed opaque envelopes. Due to the nature of the intervention, blinding of participants and trainers was not feasible; however, outcome assessments were conducted by the same evaluator who was blinded to group allocation.

Functional movement skills were assessed using the standardized FMS (Functional Movement Screen) protocol during both the pre-test and post-test phases. All measurements were conducted in the same setting and by the same evaluator; furthermore, the injury and health status of the participants was monitored regularly throughout the study.

Participants

In the study conducted by Bereket and Bayram (2022), an effect size ($d = 1.7088$) was reported for proprioceptive neuromuscular facilitation-based upper extremity exercises¹⁵. This value was used as a reference for estimating the sample size in the present study. However, considering the differences in participant characteristics, outcome measures, and intervention focus, the current study was designed as a pilot investigation. In this context, the previously reported large effect size was not interpreted as directly generalizable, but rather as a reference to inform an initial sample size estimation for feasibility purposes. Accordingly, using G*Power analysis with an assumed effect size of $d = 1.7088$, a significance level of $\alpha = 0.05$, and a statistical power of $1 - \beta = 0.95$, a minimum sample size of 20 participants (10 per group) was estimated.

In the present study, a total of 28 female basketball players were randomly assigned into two groups of 14 athletes



each. Participants had comparable basketball experience, with approximately 6–8 years of training. All participants completed the intervention period, and no dropouts were recorded. Adherence to the PNF protocol was monitored by the supervising coach, and participants attended the vast majority of the scheduled sessions. Therefore, data from all 28 participants were included in the final analysis, which was conducted using a per-protocol approach.

The athletes in the experimental group performed a PNF stretching program alongside their routine training for 8 weeks, three times per week, whereas the control group followed only their usual training schedule. Participants were instructed to avoid additional stretching outside the intervention, and compliance was monitored through weekly self-reports and session logs. Although the FMS protocol was applied, the total FMS score was not calculated in this study, as the focus was on individual subtests to evaluate specific functional movement components.

The inclusion criteria for the participants are as follows:

- No musculoskeletal injury within the last 6 months,
- Regular participation in training at least 3 days per week,
- No contraindications to performing PNF stretching exercises.

The flow of participants through each stage of the study is outlined according to the CONSORT guidelines. A total of 28 participants were assessed for eligibility, all of whom met the inclusion criteria and agreed to participate. Following randomization, 14 participants were allocated to the experimental group, receiving the PNF stretching intervention, and 14 participants were allocated to the control group, continuing with regular training. No participants were lost to follow-up or discontinued the intervention in either group. Data from all participants were included in the analysis, which was performed according to the per-protocol principle. The participant enrollment and allocation process is illustrated in Figure 1.

Data Collection Process

The Functional Movement Screen (FMS)

The Functional Movement Screen (FMS) is a test battery that provides a general assessment of movement abilities. This assessment tool helps analyze athletes' movement patterns in order to determine their physical performance levels and potential indicators of injury risk¹⁶. FMS is widely used as a method for evaluating the functional movement skills of basketball players. The seven fundamental movement tests included in the FMS are as follows:

1. *Deep Squat*: This test measures lower extremity range of motion, and the stability of the knees, hips, and spine. The participant attempts to perform a proper squat, demonstrating how the body moves in this position. An inadequate squat provides information about movement restrictions and muscle imbalances.

2. *Hurdle Step*: This test involves stepping over an obstacle while maintaining balance. It aims to assess lower-body stability, balance, and leg mobility.

3. *In-line Lunge*: This test evaluates stability between the legs and the participant's ability to maintain balance. It also measures flexibility in hip flexion and knee stability.

4. *Shoulder Mobility*: This test assesses the range of motion around the shoulder joint. It is important for evaluating upper-body movement capacity, especially in sports such as basketball where shoulder use is frequent.

5. *Active Straight-Leg Raise*: While lying on the back, the participant raises one leg while keeping it straight. This test measures flexibility of the hip flexors and hamstring muscles.

6. *Trunk Stability Push-up*: This test evaluates the stability of the core muscles. The participant gets into a push-up position and demonstrates how well they can control their body during the movement.

7. *Rotary Stability*: This test measures the body's coordination and stability. The participant lifts one leg and the opposite arm simultaneously, assessing balance and stability during rotational movement.

FMS uses a scoring system in which each movement is evaluated on a scale from 0 to 3.

- 3: The movement is performed perfectly with no compensations.
- 2: The movement is completed, but with minor errors or limitations.
- 1: The movement is performed incorrectly, with noticeable restrictions.
- 0: The movement is associated with pain and cannot be completed.

The total score reflects the participant's overall movement proficiency. Lower scores indicate a higher risk of potential injury and highlight areas in need of physical performance improvement. The FMS results will serve as a critical tool in assessing the effects of the PNF stretching exercises on participants' functional movement abilities. No single primary outcome was prespecified in this study.

Individual FMS subtests were analyzed as exploratory outcomes.

Experimental Procedure

The experimental procedures were scheduled and implemented during the pre-season period, coinciding with the beginning of the athletes' preparation phase for the competitive season. In this way, the effects of the PNF stretching protocol were evaluated in conjunction with the athletes' training load and pre-season adaptation processes.

In terms of timing, the post-training cool-down phase was identified as a suitable period for administering the PNF stretching exercises. Stretching performed during this phase allows for greater muscle elongation, reduces muscle fatigue and stiffness, and accelerates the recovery process. In addition, since the muscles are already active throughout the training session, the stretching exercises could be applied more effectively¹⁷.

Experimental Group

Participants in the experimental group performed PNF stretching exercises for eight weeks, three days per week, at the end of their routine basketball training sessions. Each session lasted approximately 20 minutes. The procedure was conducted as follows:

PNF Stretching Exercise Protocol

Proprioceptive Neuromuscular Facilitation (PNF) is a stretching technique widely used to improve muscle flexibility. The main techniques of PNF include Hold-Relax, Contract-Relax, and Hold-Relax with Agonist Contraction (HR-AC). These techniques aim to increase muscle length by incorporating both isometric and concentric muscle contractions¹⁷.

- *Hold-Relax*: The participants performed an isometric contraction of the target muscle group, followed by a passive stretching phase.
- *Contract-Relax*: The participants concentrically contracted the target muscles and subsequently applied an additional stretch.
- *Hold-Relax with Agonist Contraction*: The participants actively contracted not only the target muscle but also the agonist muscle.

These exercises consisted of 3 sets for each muscle group, with a 30-second rest interval between each set;

The muscle groups included in the study were as follows:

- Hamstrings
- Quadriceps
- Hip flexors
- Gastrocnemius (calf muscles)
- Shoulder flexors and rotator cuff muscles
- Hip abductors

At the end of each exercise, every movement was completed with a stretching duration of approximately

Table 1. Description of the PNF stretching protocol.

| Muscle Gr. | PNF Tech. | Contr. Type | Intensity | Contr. Dur. | Stretch Dur. | Sets | Rest | App. Method | Total Dur. |
|------------------|----------------|---------------------|------------|-------------|--------------|------|------|------------------|------------|
| Hamstrings | Hold-Relax | Isometric | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Quadriceps | Contract-Relax | Concentric | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Hip Flexors | Hold-Relax | Isometric | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Gastrocnemius | Contract-Relax | Concentric | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Shoulder Flexors | HR-AC | Isometric + Agonist | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Rotator Cuff | HR-AC | Isometric + Agonist | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |
| Hip Abductors | Hold-Relax | Isometric | Submaximal | ~10 s | 20–30 s | 3 | 30 s | Partner-assisted | ~2–3 min |

PNF = Proprioceptive Neuromuscular Facilitation; Contr. = Contraction; Dur. = Duration; HR-AC = Hold-Relax with Agonist Contraction.

20–30 seconds. All exercises were performed bilaterally under the supervision of a qualified coach to ensure proper technique and standardization. Participants were instructed to avoid additional stretching outside the intervention, and adherence was monitored by session logs and coach supervision. A detailed description of the PNF stretching protocol is provided in Table 1.

Control Group

The participants in the control group continued their regular basketball training for 8 weeks. This group did not receive any additional stretching protocol; instead, their training-related adaptations was monitored as they maintained their usual training routine. The duration and content of the training sessions were kept equivalent to those of the experimental group.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for participants' age, height, body weight, and BMI values.

Given that Functional Movement Screen (FMS) subtest scores are ordinal variables scored on a discrete 0–3 scale, FMS outcomes were summarized using medians and interquartile ranges (IQRs). Accordingly, nonparametric statistical methods were selected a priori based on the measurement level rather than distributional assumptions; the Wilcoxon signed-rank test was used for within-group comparisons and the Mann-Whitney U test for between-group comparisons.

No single primary outcome was prespecified in this study. Individual FMS subtests were analyzed as exploratory outcomes. To examine group \times time effects, between-group comparisons were performed on change scores (post-pre). Between-group differences were evaluated using the Mann-Whitney U test and quantified by Hodges-Lehmann median differences with 95% confidence intervals. Effect sizes ($r = Z/\sqrt{N}$) were calculated and interpreted according to Cohen's criteria (small = 0.10, medium = 0.30, large = 0.50)¹⁸. Statistical significance was set at $p < 0.05$ for all analyses.

Results

A total of 28 participants completed the study protocol, and all collected data were included in the analyses. Participants' adherence to the intervention, any reported adverse events, and the outcomes of the Functional Movement Screen (FMS), including both within-group changes and between-group comparisons, are presented below.

All participants completed the study protocol, and no withdrawals were recorded in either group. The experimental group attended a mean of 23.4 ± 0.8 of the 24 planned PNF sessions, calculated as the average number of sessions attended per participant. This corresponds to an adherence rate of 97.5% ($(23.4 \div 24) \times 100$), indicating that most participants attended nearly all sessions. No adverse events or intervention-related injuries were reported during the training period. During FMS assessments, no participant reported pain, and no test was scored as 0 at either pre-test or post-test evaluations, indicating that all participants

Table 2. Descriptive statistics of the participants.

| Groups | Variables | N | Min. | Max. | \bar{X} | SD |
|--------------------|--------------------------|----|--------|--------|-----------|------|
| Control Group | Age (years) | 14 | 16.00 | 18.00 | 17.00 | 0.78 |
| | Height (cm) | 14 | 160.00 | 175.00 | 168.14 | 4.29 |
| | Weight (kg) | 14 | 52.00 | 62.00 | 56.14 | 3.15 |
| | BMI (kg/m ²) | 14 | 17.95 | 21.70 | 19.85 | 0.93 |
| Experimental Group | Age (years) | 14 | 16.00 | 18.00 | 16.85 | 0.86 |
| | Height (cm) | 14 | 163.00 | 172.00 | 167.21 | 2.77 |
| | Weight (kg) | 14 | 50.00 | 62.00 | 55.85 | 3.25 |
| | BMI (kg/m ²) | 14 | 18.36 | 21.20 | 19.96 | 0.79 |

N = number of participants; Min = minimum; Max = maximum; \bar{X} = mean; SD = standard deviation.

Table 3. Between-group comparisons of baseline FMS subtest scores.

| FMS Subtest | Control Median (IQR) | Experimental Median (IQR) | U | Z | p |
|---------------------------|----------------------|---------------------------|------|--------|-------|
| Deep Squat | 2.0 (1.0) | 2.0 (1.0) | 89.0 | -0.472 | 0.637 |
| Hurdle Step | 2.0 (0.0) | 2.0 (0.25) | 92.0 | -0.334 | 0.738 |
| In-Line Lunge | 2.0 (1.0) | 2.0 (1.0) | 93.0 | -0.265 | 0.791 |
| Shoulder Mobility | 2.5 (1.0) | 2.0 (1.0) | 91.0 | -0.372 | 0.710 |
| Active Straight Leg Raise | 3.0 (1.0) | 2.0 (1.0) | 84.0 | -0.742 | 0.458 |
| Trunk Stability Push-Up | 2.0 (1.0) | 2.0 (0.25) | 92.0 | -0.317 | 0.752 |
| Rotary Stability | 2.0 (0.5) | 2.0 (1.0) | 81.5 | -0.838 | 0.402 |

IQR = interquartile range; U = Mann-Whitney U test statistic; Z = standardized test statistic; p = significance level.

were able to perform the movements safely. The following tables summarize participant characteristics, as well as within-group and between-group comparisons of the FMS assessments.

Descriptive statistics regarding the demographic characteristics of the participants in the control and experimental groups are presented in Table 2. In the control group (n = 14), participants' ages ranged from 16 to 18 years, with a mean age of 17.00 ± 0.78 years. Height values ranged between 160.00 cm and 175.00 cm, with a mean height of 168.14 ± 4.29 cm, while body weight ranged from 52.00 kg to 62.00 kg, and the mean weight was calculated as 56.14 ± 3.15 kg. Body Mass Index (BMI) values were between 17.95 and 21.70 kg/m², with a mean BMI of 19.85 ± 0.93 kg/m².

In the experimental group (n = 14), participants' ages ranged from 16 to 18 years, with a mean age of 16.85 ± 0.86 years. The height of the participants varied between 163.00 cm and 172.00 cm, with a mean height of 167.21 ± 2.77 cm. Body weight ranged from 50.00 kg to 62.00 kg, and the mean weight was found to be 55.85 ± 3.25 kg. BMI values ranged between 18.36 and 21.20 kg/m², with a

mean BMI of 19.96 ± 0.79 kg/m².

As presented in Table 3, between-group comparisons of baseline Functional Movement Screen (FMS) subtest scores were performed using the Mann-Whitney U test. The analyses revealed no statistically significant differences between the control and experimental groups for the deep squat (U = 89.0, Z = -0.472, p = 0.637), hurdle step (U = 92.0, Z = -0.334, p = 0.738), in-line lunge (U = 93.0, Z = -0.265, p = 0.791), shoulder mobility (U = 91.0, Z = -0.372, p = 0.710), active straight-leg raise (U = 84.0, Z = -0.742, p = 0.458), trunk stability push-up (U = 92.0, Z = -0.317, p = 0.752), and rotary stability (U = 81.5, Z = -0.838, p = 0.402) subtests (all p > 0.05).

The median and interquartile range (IQR) values were similar between groups across all FMS subtests, indicating that the control and experimental groups were comparable at baseline in terms of functional movement performance prior to the intervention.

Within-group comparisons of Functional Movement Screen (FMS) subtest scores before and after the intervention are presented in Table 4. No statistically significant pre-post differences were observed for Deep

Table 4. Within-group (pre-post) comparisons of FMS subtest scores in the control group.

| FMS Subtest | Pre Median (IQR) | Post Median (IQR) | Z | p | r |
|---------------------------|------------------|-------------------|--------|------|------|
| Deep Squat | 2 (1) | 2 (1) | 0.816 | .414 | 0.22 |
| Hurdle Step | 2 (0.25) | 2 (0.25) | 0.447 | .655 | 0.12 |
| In-Line Lunge | 2 (1) | 2.5 (1) | -1.890 | .059 | 0.50 |
| Shoulder Mobility | 2 (1) | 3 (1) | 1.732 | .083 | 0.46 |
| Active Straight-Leg Raise | 2 (0.25) | 2 (0.25) | -1.134 | .257 | 0.30 |
| Trunk Stability Push-Up | 2 (1) | 2 (1) | 0.577 | .564 | 0.15 |
| Rotary Stability | 2 (1) | 3 (1) | -1.732 | .083 | 0.46 |

IQR = interquartile range; Z = Wilcoxon signed-rank test statistic; p = significance level; r = effect size.

Table 5. Within-group (pre-post) comparison of FMS subtest scores in the experimental group.

| FMS Subtest | Pre Median (IQR) | Post Median (IQR) | Z | p | r |
|---------------------------|------------------|-------------------|-------|-------|------|
| Deep Squat | 2.00 (1.00) | 3.00 (0.25) | 2.449 | 0.014 | 0.65 |
| Hurdle Step | 2.00 (0.25) | 2.00 (1.00) | 2.111 | 0.035 | 0.56 |
| In-Line Lunge | 2.00 (1.00) | 3.00 (1.00) | 2.646 | 0.008 | 0.71 |
| Shoulder Mobility | 2.00 (1.00) | 3.00 (0.25) | 2.236 | 0.025 | 0.60 |
| Active Straight-Leg Raise | 2.00 (1.00) | 2.50 (1.00) | 0.577 | 0.564 | 0.15 |
| Trunk Stability Push-Up | 2.00 (0.25) | 2.00 (1.00) | 1.633 | 0.102 | 0.44 |
| Rotary Stability | 2.00 (1.00) | 2.00 (1.00) | 2.310 | 0.021 | 0.62 |

IQR = interquartile range; Z = Wilcoxon signed-rank test statistic; p = significance level; r = effect size.

Table 6. Between-group comparisons of FMS subtest change scores (Δ post-pre) following PNF training.

| FMS Subtest | Control Median Δ (IQR) | Experimental Median Δ (IQR) | HL Median Difference (95% CI) | Z | p | r |
|---------------------------|-------------------------------|------------------------------------|-------------------------------|--------|-------|------|
| Deep Squat | 0 (1) | 0 (1) | 0 (-1 to 0) | -1.153 | 0.249 | 0.22 |
| Hurdle Step | 0 (0.25) | 1 (1) | -1 (-1 to 0) | -1.804 | 0.071 | 0.34 |
| In-Line Lunge | 0 (1) | 0.5 (1) | -1 (-1 to 0) | -3.153 | 0.002 | 0.60 |
| Shoulder Mobility | 0 (0.25) | 0 (1) | 0 (0 to 0) | -0.822 | 0.411 | 0.16 |
| Active Straight-Leg Raise | 0 (0.25) | 0 (0) | 0 (0 to 0) | -1.150 | 0.250 | 0.22 |
| Trunk Stability Push-Up | 0 (0) | 0 (1) | 0 (-1 to 0) | -1.093 | 0.275 | 0.21 |
| Rotary Stability | 0 (0.25) | 1 (1) | -1 (-1 to 0) | -2.977 | 0.003 | 0.56 |

Median (IQR) = median and interquartile range; Z = standardized test statistic; r = effect size (Z / \sqrt{N}); HL = Hodges-Lehmann median difference; CI = confidence interval.

Values are presented as median (interquartile range, IQR). Δ post-pre indicates the change score calculated as post-intervention minus pre-intervention values. Median (IQR) = median and interquartile range; Z = standardized test statistic; r = effect size (Z / \sqrt{N}); HL = Hodges-Lehmann median difference; CI = confidence interval. HL median difference was calculated as Control group - Experimental group; therefore, negative HL values indicate greater improvement in the experimental (PNF) group.

Squat (median [IQR]: 2 [1] vs. 2 [1], $Z = 0.816$, $p = .414$), Hurdle Step (2 [0.25] vs. 2 [0.25], $Z = 0.447$, $p = .655$), Active Straight-Leg Raise (2 [0.25] vs. 2 [0.25], $Z = -1.134$, $p = .257$), or Trunk Stability Push-Up (2 [1] vs. 2 [1], $Z = 0.577$, $p = .564$).

For In-Line Lunge, the median score increased from 2 (IQR = 1) to 2.5 (IQR = 1), approaching statistical significance ($Z = -1.890$, $p = .059$) with a large effect size ($r = 0.50$). Similarly, improvements were observed in Shoulder Mobility (2 [1] vs. 3 [1], $Z = 1.732$, $p = 0.083$) and Rotary Stability (2 [1] vs. 3 [1], $Z = -1.732$, $p = 0.083$), both demonstrating moderate-to-large effect sizes ($r = 0.46$), despite not reaching statistical significance.

Within-group analyses of the experimental group revealed significant improvements in several Functional Movement Screen (FMS) subtests following the PNF training intervention (Table 5). Median Deep Squat scores increased from 2.00 (IQR = 1.00) to 3.00 (IQR = 0.25), representing a statistically significant improvement with a large effect size ($Z = 2.449$, $p = 0.014$, $r = 0.65$). Similarly, significant improvements were observed in the Hurdle Step [median: 2.00 (IQR = 0.25) to 2.00 (IQR = 1.00); $Z = 2.111$, $p = 0.035$, $r = 0.56$] and In-Line Lunge [median: 2.00 (IQR = 1.00) to 3.00 (IQR = 1.00); $Z = 2.646$, $p = 0.008$, $r = 0.71$], both demonstrating medium-to-large effect sizes.

Shoulder Mobility also showed a significant post-intervention increase, with median scores rising from 2.00 (IQR = 1.00) to 3.00 (IQR = 0.25) ($Z = 2.236$, $p = 0.025$, $r = 0.60$). Rotary Stability scores demonstrated a significant improvement as well ($Z = 2.310$, $p = 0.021$), accompanied by a large effect size ($r = 0.62$).

In contrast, no statistically significant changes were detected in Active Straight-Leg Raise [median: 2.00 (IQR = 1.00) to 2.50 (IQR = 1.00); $Z = 0.577$, $p = 0.564$, $r = 0.15$] or Trunk Stability Push-Up [median: 2.00 (IQR = 0.25) to 2.00 (IQR = 1.00); $Z = 1.633$, $p = 0.102$, $r = 0.44$], despite small-to-moderate effect sizes.

Between-group comparisons of Functional Movement Screen (FMS) subtest change scores (Δ post-pre) are presented in Table 6. The experimental group demonstrated significantly greater improvements than the control group in the In-Line Lunge ($Z = -3.153$, $p = 0.002$, $r = 0.60$) and Rotary Stability subtests ($Z = -2.977$, $p = 0.003$, $r = 0.56$), both reflecting large effect sizes.

For the Hurdle Step subtest, a trend toward greater improvement was observed in the experimental group compared with the control group; however, this difference did not reach statistical significance ($Z = -1.804$, $p = 0.071$), despite a moderate effect size ($r = 0.34$).

No statistically significant between-group differences were identified for Deep Squat, Shoulder Mobility, Active Straight-Leg Raise, or Trunk Stability Push-Up change scores (all $p > 0.05$), and effect sizes for these outcomes were small to moderate ($r = 0.16$ – 0.22). Hodges-Lehmann median difference estimates (calculated as Control – Experimental, where negative values indicate greater improvement in the experimental group) and their 95%

confidence intervals indicated distributional shifts favoring the experimental group primarily for the In-Line Lunge and Rotary Stability subtests, while other subtests did not demonstrate clear between-group differences.

Discussion

In this study, the effects of Proprioceptive Neuromuscular Facilitation (PNF) stretching exercises on functional movement skills in female basketball players were examined in detail. The fact that the experimental and control groups had similar baseline demographic characteristics (Table 2 and 3) ensured equality of initial conditions between the groups and allowed the effects of the applied PNF training to be evaluated more objectively. This is important because it demonstrates that the differences observed in the findings emerged primarily as a result of the PNF protocol rather than pre-existing group differences.

The findings revealed that PNF applications had a statistically significant effect on selected components of functional movement performance, with primary evidence derived from between-group comparisons. While no significant changes were observed in the control group measurements (Table 4), notable improvements were recorded in many functional movement tests in the experimental group following PNF exercises (Table 5). In particular, the significant increases observed in the Hurdle Step, Deep Squat, Rotary Stability, Shoulder Mobility, and In-Line Lunge tests within the experimental group support the potential influence of PNF on movement control, muscle coordination, and balance mechanisms, while between-group evidence was limited to selected FMS subtests. These results indicate that PNF methods not only improve flexibility but also enhance athletes' kinesthetic awareness and movement efficiency.

On the other hand, the absence of significant changes in the control group suggests that within the duration and scope of the present pilot study, routine training alone may not have been associated with measurable changes in functional movement, rather than indicating that routine training is insufficient *per se*, although this interpretation should be considered supportive rather than confirmatory. This finding suggests that the effectiveness of PNF depends on continuity and systematic application, and that sporadic or inconsistent use may be insufficient to elicit the expected physiological adaptations.

In addition, the significant improvements observed in the Deep Squat, Rotary Stability, and Shoulder Mobility tests indicate that PNF stretching techniques influence multiple components of musculoskeletal performance (Table 5). These developments demonstrate that when the dynamic and static positions commonly used in training are combined with the PNF method, a higher level of adaptation is achieved in terms of muscle stretch tolerance, joint range of motion, and coordination. Therefore, this method not only enhances muscle flexibility but also may enhance neuromuscular

communication between the central nervous system and the musculature, thereby contributing to motor learning.

One of the most remarkable findings of the study was the high effect size observed in the In-Line Lunge test within the experimental group ($r = 0.71$) (Table 5). This result suggests that PNF exercises are a highly effective method for improving dynamic balance, agility, proprioceptive awareness, and muscle control. Since the Hurdle Step test reflects a complex movement pattern requiring synchronization of lower-extremity muscles and maintenance of trunk stability, the significant improvement in this test demonstrates the potential impact of PNF on functional neuromuscular control.

When the between-group comparisons of FMS change scores (Δ post-pre) following the intervention are examined, the differences tended to favor the experimental group, although statistically significant differences were observed only for selected FMS components. In particular, significant between-group differences were evident in the In-Line Lunge and Rotary Stability tests (Table 6). These findings support the influence of PNF exercises on movement control, dynamic balance, and neuromuscular coordination, especially in tasks requiring multiplanar stability and controlled lower-extremity function. The effect size values observed for these outcomes, ranging from moderate to large, indicate that PNF interventions can elicit meaningful improvements in specific functional movement patterns even within relatively short training periods (Table 6).

In light of these findings, it can be concluded that PNF exercises represent an effective method for improving selected components of functional movement skills in female basketball players, particularly those related to dynamic balance, coordination, and movement control, as demonstrated primarily by between-group differences in specific FMS subtests. Notable short-term improvements were evident in specific FMS subtests rather than across all movement patterns. Furthermore, the results suggest that the sustainability and generalization of these improvements likely depend on the regular and systematic implementation of PNF-based training protocols.

Studies investigating the effects of Proprioceptive Neuromuscular Facilitation (PNF) stretching exercises on functional movement skills in female basketball players also align with the present findings. The literature indicates that PNF contributes to functional enhancement in several key performance areas. Previous research emphasizes the positive influence of PNF applications on athletic performance^{6,19}. For example, the results obtained in the In-Line Lunge test ($z = 2.646$; $p = 0.008$; $r = 0.71$) demonstrate a high level of effectiveness of PNF. Similarly, a significant improvement was recorded in the Deep Squat test ($Z = 2.449$; $p = 0.014$; $r = 0.65$), supporting the efficiency of PNF exercises²⁰. In addition, comparable positive outcomes have been reported in the Shoulder Mobility and In-Line Lunge tests²¹.

However, no significant change was observed in the Active

Straight Leg Raise ($p = 0.564$; $r = 0.15$) and Trunk Stability Push-Up ($p = 0.102$; $r = 0.44$) tests. Nevertheless, the moderate effect size detected in the Trunk Stability Push-Up test ($r = 0.44$) suggests that the exercises produced a partial influence. This may indicate that the effects of PNF are limited in enhancing certain movement competencies⁶. These findings may imply that PNF does not consistently improve the efficiency of specific muscle groups. Therefore, the reduced level of effectiveness observed in some tests may serve as an important indication that PNF applications can produce variable outcomes among different individuals².

The literature provides substantial evidence regarding the positive effects of PNF in various sports and across different age groups. In particular, proprioceptive stretching exercises have been shown to enhance balance, speed, and coordination skills in dynamic sports such as basketball⁶. Moreover, findings indicate that PNF may not only improve athletic performance but also reduce the risk of injury²². This suggests that PNF contributes both to performance enhancement and to the protection of athletes' physical health.

The present study, which examined the effects of Proprioceptive Neuromuscular Facilitation (PNF) stretching exercises in female basketball players, demonstrated that PNF-based training led to significant improvements in specific functional movement skills. Statistically significant improvements were observed in the Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, and Rotary Stability tests ($p < 0.05$) within the experimental group, with moderate to large effect sizes ($r = 0.56-0.71$), while statistically significant between-group differences were limited to the In-Line Lunge and Rotary Stability subtests, supporting this conclusion. These findings indicate that PNF training is an effective method for enhancing selected movement skills in basketball players. Compared with traditional training methods, the primary advantage of PNF lies in its ability to improve proprioceptive awareness and neuromuscular control, thereby reinforcing body balance and overall performance^{6,23}.

Previous research has consistently supported the positive influence of PNF exercises on athletic performance. For instance, Zemková and Zapletalová reported that improvements in neuromuscular control and balance play a decisive role in overall athletic performance²⁴. This suggests that PNF may enhance not only balance-related abilities but also movement efficiency, agility, and execution of sport-specific actions. Further evidence indicates that PNF may also reduce injury risk. Naderifar et al. (2024) found that neuromuscular control training protocols can effectively lower the likelihood of sports injuries²⁵. Additional studies have reported that combining PNF techniques with other exercises can improve dynamic balance and athletic performance¹⁹.

In terms of effect size, the highest value was observed in the In-Line Lunge test ($r = 0.71$), suggesting that PNF has a strong capacity to enhance movement patterns requiring dynamic balance, lower-extremity control, and trunk

stability. This finding supports the idea that PNF plays an important role in neuromuscular coordination and motor control, resulting in clearer performance improvements among athletes²⁶. It may also be inferred that such training programs contribute to post-exercise physiological and functional adaptations, thereby promoting an enhanced athletic profile.

Despite these strengths, the present study has certain limitations that should be acknowledged. One limitation is that the study was not prospectively registered in a clinical trial registry, which may affect transparency and reproducibility. Future studies should ensure prospective registration to enhance methodological rigor and strengthen the evidence base. Furthermore, the relatively small sample size, the ordinal nature of FMS outcomes (which may cause ceiling effects), and the possibility of contamination from other physical activities limit the generalizability of the findings. In addition, the exploratory analysis of multiple FMS subtests may increase the risk of type I error, and the findings should therefore be interpreted with caution.

The large effect size used for sample size estimation was derived from a study conducted in a different population and exercise context. Therefore, the present study should be interpreted as a feasibility investigation, designed to explore feasibility and to provide preliminary estimates for future, adequately powered randomized controlled trials.

In conclusion, PNF stretching exercises appear to be a beneficial training strategy for improving selected components of functional movement and neuromuscular control in female basketball players. Specifically, the most robust evidence from this randomized controlled trial was observed in selected Functional Movement Screen subtests demonstrating clear between-group improvements.

The findings suggest that integrating PNF into athletes' training programs may be beneficial particularly with respect to movement control and dynamic balance, rather than global functional performance. However, individual differences must be taken into account, and future research should compare the effectiveness of PNF across different age groups, sex, and sports disciplines.

Additionally, long-term studies are needed to assess the sustainability of subtest-specific performance improvements and injury prevention outcomes, in order to generate more comprehensive data regarding the effective implementation of PNF in training programs. Although the findings suggest beneficial effects of PNF training, the relatively small sample size and the use of an effect size derived from a different population limit the generalizability of the results.

Recommendations

In line with the findings of the present study, several recommendations can be made regarding the effectiveness of PNF stretching exercises in improving functional movement skills and overall performance in female basketball players.

First, the regular integration of PNF techniques into athletes' training programs is recommended, as this may contribute to the sustainable enhancement of functional capacity, balance, and neuromuscular control.

Additionally, it is advised that PNF programs be planned in a personalized and progressive manner, taking into account individual differences such as age, physical capacity, flexibility level, and injury history. Monitoring the long-term effects of PNF is also essential for evaluating the continuity of performance gains and its potential role in injury prevention.

Future studies should conduct comparative analyses of the effects of PNF across different age groups, sex, and sports disciplines in order to provide broader insight into the method's applicability and effectiveness. It is also recommended to investigate the combined impact of PNF exercises with other training methods—such as strength, endurance, or plyometric training—on athletic performance.

Moreover, the systematic use of motor control and proprioceptive feedback assessments before and after training would allow for a more detailed evaluation of the effects of PNF. Finally, to increase the generalizability of the findings, future research should be conducted with larger sample sizes and replicated across different athletic populations.

Ethics approval

Ethics approval was obtained from the Ethics Committee of Dicle University, Social and Human Sciences (Decision No. 889195, dated 18/03/2025).

The study was conducted in accordance with the Declaration of Helsinki (1964) and its later amendments.

Consent to Participate

Written informed consent was obtained from all participants; for those under 18 years of age, consent was also obtained from a parent or legal guardian. All participants' coaches were informed about the purpose, procedures, and potential risks of the study.

Authors' Contributions

YG contributed to the conception and planning of the study, supervised the intervention, conducted the data analysis and interpretation, and drafted the main sections of the manuscript. HAA contributed to the data collection process, supported the implementation of the intervention, assisted in writing different sections of the manuscript, and critically reviewed the manuscript. Both authors read and approved the final version of the manuscript.

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This study was conducted as an original research article. AI-assisted tools were used during the writing process to correct grammatical errors and improve the flow of academic writing. This process was carried out under human supervision to ensure academic integrity. Also, we would like to express our sincere gratitude to all athletes who voluntarily participated in the study and to the coaches who provided support throughout the research process.

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