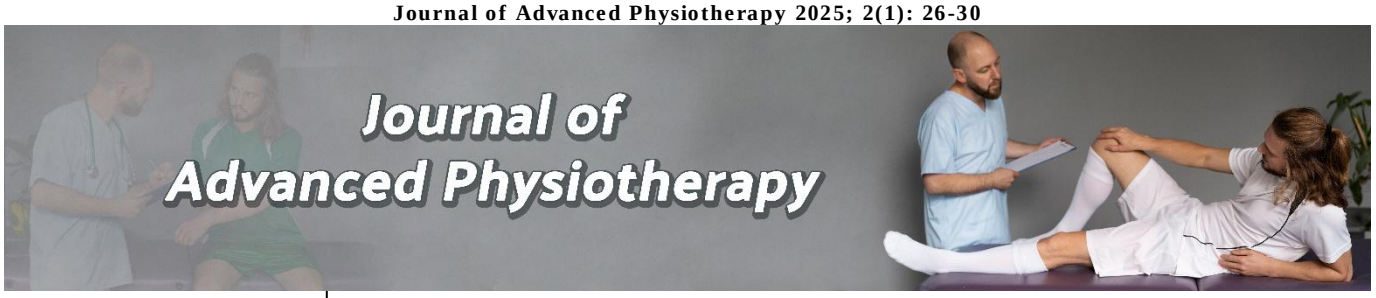

P-ISSN: 3081-0604
E-ISSN: 3081-0612
JAP 2025; 2(1): 26-30
www.physiotherapyjournal.org
Received: 15-04-2025
Accepted: 17-05-2025

Vinayaka Sharma
Mathura Institute of Medical and Health Sciences, Mathura, Uttar Pradesh, India

Dr. Vikalp Kumar
Mathura Institute of Medical and Health Sciences, Mathura, Uttar Pradesh, India

Corresponding Author:
Vinayaka Sharma
Mathura Institute of Medical and Health Sciences, Mathura, Uttar Pradesh, India

Effect of neuromuscular training on ACL injury risk reduction in female athletes: A study in Mathura, Uttar Pradesh, India

Vinayaka Sharma and Vikalp Kumar

DOI: https://www.doi.org/10.33545/30810604.2025.v2.i1.A.10

Abstract
Anterior Cruciate Ligament (ACL) injuries are increasingly reported among female athletes, posing a threat to long-term musculoskeletal health and athletic participation. This study investigates the impact of a structured neuromuscular training (NMT) program on ACL injury risk reduction in female athletes in Mathura, Uttar Pradesh, India. A sample of 30 female athletes aged 16-22 years was selected through purposive sampling. Pre- and post-intervention assessments were conducted over a 10-week period using the Landing Error Scoring System (LESS), knee valgus angle measurements, and functional performance tests. Results demonstrated significant improvements in landing mechanics and neuromuscular control post-training ($p<0.05$), indicating the effectiveness of the intervention. These findings support the integration of NMT into sports conditioning routines to mitigate ACL injury risk, especially among high-risk populations.

Keywords: ACL injury, Mathura, India, neuromuscular training, female athletes, injury prevention

1. Introduction
Anterior cruciate ligament (ACL) injuries are among the most severe and career-threatening musculoskeletal injuries in sports. The ACL, located in the center of the knee joint, plays a critical role in stabilizing the knee during rotational and translational movements. Injury to the ACL most commonly occurs during rapid deceleration, cutting, pivoting, or improper landing movements frequently performed in sports such as basketball, volleyball, soccer, and kabaddi. Global epidemiological data indicate that female athletes are significantly more prone to ACL injuries compared to their male counterparts. According to Arendt and Dick (1995), the rate of ACL injury in female athletes can be as much as 2 to 8 times higher than in male athletes participating in the same sports under similar conditions [1].

The increased susceptibility of female athletes to ACL injuries has been linked to a complex interplay of anatomical, biomechanical, hormonal, and neuromuscular factors. Anatomically, females tend to have a wider pelvis, resulting in an increased quadriceps (Q) angle which predisposes the knee to valgus stress a key risk factor for ACL tears. Moreover, hormonal fluctuations, particularly surges in estrogen and relaxin during the menstrual cycle, are believed to influence ligament laxity and decrease collagen stiffness, potentially increasing ACL vulnerability (Herzberg *et al*., 2017) [2].

Biomechanically, female athletes often exhibit altered movement patterns such as greater knee valgus angles, reduced hip and knee flexion during landing, and delayed hamstring activation relative to quadriceps contraction. These factors create a dangerous environment for the ACL, especially during high-demand sports actions. Studies using motion analysis systems have repeatedly demonstrated that females tend to rely more on quadriceps-dominant strategies during deceleration tasks, leading to anterior tibial translation and elevated strain on the ACL (Hewett *et al*., 2005) [3].

In the Indian context, the incidence and awareness of ACL injuries among female athletes remain under-reported, especially in non-metro cities and rural areas. However, anecdotal evidence from sports academies, physical education colleges, and orthopedic clinics in districts like Mathura, Uttar Pradesh, suggests a rising number of knee injuries in female players, particularly those participating in kabaddi, volleyball, and track events.

A study conducted by Mehta *et al*. (2019) in Uttar Pradesh documented that 26% of knee injuries in female collegiate athletes were suspected ACL injuries, yet only 30% of those injured received structured rehabilitation [4]. This points to a critical gap in both prevention and post-injury care.

Given the debilitating consequences of ACL injuries which include surgical reconstruction, 6-12 months of rehabilitation, increased risk of osteoarthritis, psychological distress, and possible withdrawal from sports prevention must be prioritized, especially for young athletes at the grassroots level. One of the most evidence-based strategies in this domain is Neuromuscular Training (NMT).

Neuromuscular training refers to a collection of exercise techniques aimed at enhancing movement efficiency, proprioception, muscle coordination, and biomechanical alignment. These programs typically include components such as strength training (especially for the posterior chain), plyometric drills, dynamic balance training, and feedback-based movement correction. Numerous systematic reviews and meta-analyses have confirmed the effectiveness of NMT in significantly reducing ACL injury risk. Sugimoto *et al*. (2012) reported a 72% reduction in non-contact ACL injuries in female athletes who participated in structured NMT programs [5]. Similar findings were documented by Grindstaff *et al*. (2006), who noted improvements in knee stability and reduction in valgus collapse after just 6-8 weeks of consistent neuromuscular training [6].

In India, however, the integration of NMT into routine training practices remains limited, particularly in tier-2 and tier-3 cities like Mathura. Lack of trained personnel, poor awareness, inadequate infrastructure, and cultural barriers (such as the underrepresentation of female sports coaches) contribute to the slow adoption of such scientifically validated preventive measures. This creates a pressing need for localized studies that assess the feasibility and efficacy of NMT interventions in Indian female athlete populations.

This study was therefore designed to evaluate the effectiveness of a structured neuromuscular training program in reducing biomechanical risk markers for ACL injury among female athletes in Mathura, Uttar Pradesh. The selected athletes belonged to disciplines with high ACL injury prevalence, such as volleyball, kabaddi, and athletics. Through pre- and post-training assessments involving the Landing Error Scoring System (LESS), knee valgus angle measurement, and functional hop testing, the study aimed to generate data-driven insights into whether NMT can be effectively implemented in local settings to reduce injury risk.

By documenting both the quantitative improvements in movement quality and the athletes' subjective experiences, this research contributes to the growing body of literature advocating for the widespread adoption of injury prevention programs for female athletes programs that are affordable, scalable, and impactful. In doing so, it also emphasizes the importance of sports physiotherapy, strength conditioning, and evidence-based training protocols in safeguarding athlete health, especially in emerging sports hubs across India.

2. Objectives of the study

2.1 The primary objectives of the study are:

- To assess baseline biomechanical risk factors contributing to ACL injury in female athletes.
- To implement a structured, supervised 10-week neuromuscular training program.
- To measure changes in knee biomechanics and neuromuscular control pre- and post-training.
- To evaluate the effectiveness of NMT in reducing ACL injury risk markers.

3. Methodology

Study Design and Duration

This study adopted a pre-post experimental design without a control group, conducted over a 10-week period between February and April 2025 in Mathura, Uttar Pradesh. The aim was to evaluate the effect of a structured neuromuscular training (NMT) intervention on biomechanical and functional performance indicators associated with ACL injury risk in female athletes.

Study Setting

The intervention was conducted at two locations in Mathura:

- Rani Laxmi Bai Sports Academy
- Department of Physical Education, K.R. College

Both sites had access to basic gym equipment, a flat outdoor field for functional exercises, and video recording tools for biomechanical assessments. Sessions were conducted in collaboration with certified physiotherapists, sports science professionals, and trained female physical education instructors.

Sample and Participant Selection

A total of 30 female athletes aged between 16 and 22 years were purposively selected from the above-mentioned institutions based on the following inclusion and exclusion criteria:

Inclusion Criteria

- Female athletes aged 16-22 years
- Minimum of 2 years of experience in competitive sports (volleyball, kabaddi, athletics)
- Willingness to participate regularly for the 10-week program
- No history of ACL injury or knee surgery

Exclusion Criteria

- Existing musculoskeletal injuries or pain
- Participation in other structured strength or neuromuscular training programs
- Known balance disorders or neurological conditions

Written informed consent was obtained from all participants (and from guardians in case of minors). Ethical clearance for the study was approved by the Institutional Ethics Committee of K.R. College, Mathura.

Intervention Protocol

A structured neuromuscular training (NMT) program was developed specifically to address ACL risk factors. The protocol was adapted from validated prevention programs such as FIFA 11+ and PEP (Prevent injury, Enhance Performance) but tailored to local equipment availability and athlete needs.

Training Schedule
- **Frequency:** 3 sessions per week
- **Duration:** 10 weeks (30 sessions in total)
- **Session length:** Approximately 45 minutes

Components of each session
1. **Warm-Up (5 minutes):** Jogging, dynamic stretching, mobility drills
2. **Plyometric Exercises (10 minutes):** Jump-land drills, bounding, tuck jumps, single-leg hops
3. **Balance Training (10 minutes):** Single-leg stance, unstable surfaces, wobble board tasks
4. **Strength and Core Training (15 minutes):** Bodyweight squats, glute bridges, Nordic hamstring curls, side planks
5. **Technique Reinforcement (5 minutes):** Real-time feedback, video demonstrations, peer corrections.

Attendance and compliance were recorded for each participant. Form quality was closely monitored, and improper execution resulted in immediate correction.

Assessment Tools and Outcome Measures
Pre- and post-intervention assessments were conducted using the following tools:
1. **Landing Error Scoring System (LESS):** A validated observational tool used to quantify landing mechanics from video footage during a standardized jump-landing task. Lower scores indicate improved technique and reduced injury risk.
2. **Dynamic Knee Valgus (DKV) Angle Measurement:** Two-dimensional (2D) video analysis was used to assess the medial knee displacement during single-leg squats and jump landings. A reduction in valgus angle indicates improved neuromuscular control.
3. **Single-leg hop for distance test:** A functional test to evaluate explosive strength, limb symmetry, and dynamic balance.
4. **Self-Reported Questionnaire:** A brief Likert-scale-based survey was used to gather athlete-reported improvements in stability, control, and landing confidence.

All video recordings were analyzed by two independent raters trained in biomechanics, with discrepancies resolved by consensus to minimize observational bias.

Statistical Analysis
Data were analyzed using IBM SPSS Version 25. Descriptive statistics (mean±standard deviation) were calculated for all outcome measures. Pre- and post-training scores were compared using paired sample t-tests, with statistical significance set at $p<0.05$.
The effect size (Cohen's d) was also calculated to determine the practical impact of the intervention. The confidence level was maintained at 95% for all inferential statistics.

4. Results
This study aimed to evaluate the effectiveness of a 10-week neuromuscular training (NMT) program in reducing biomechanical risk factors associated with anterior cruciate ligament (ACL) injury in female athletes. A total of 30 participants completed both pre- and post-intervention assessments with a compliance rate of 93.3%.

4.1 Descriptive Statistics
The average age of the participants was 18.7±1.9 years. Among them, 12 were volleyball players, 10 were track and field athletes, and 8 were kabaddi players. All participants completed a minimum of 28 out of 30 training sessions.

4.2 Pre- and Post-Intervention Outcomes
The primary outcome variables assessed were:
- Landing Error Scoring System (LESS)
- Dynamic Knee Valgus (DKV) angle
- Single-leg hop distance

Table 1: Comparison of biomechanical and functional performance measures (N=30)

Outcome Variable	Pre-Training (Mean ± SD)	Post-Training (Mean ± SD)	Mean Difference	P-Value	Effect Size (Cohen's d)
LESS Score (errors)	6.2±1.1	3.7±0.9	-2.5	< 0.001**	2.49 (very large)
Dynamic Knee Valgus Angle (°)	19.8±3.5	12.4±2.9	-7.4	< 0.01**	2.27 (very large)
Single-Leg Hop Distance (cm)	82.1±8.3	94.6±7.9	+12.5	< 0.001**	1.54 (large)

Interpretation
- There was a statistically significant reduction in LESS scores ($p<0.001$), indicating improved landing biomechanics.
- DKV angles significantly decreased ($p<0.01$), reflecting better knee alignment and reduced medial displacement during dynamic tasks.
- Functional performance, as measured by the single-leg hop, significantly improved ($p<0.001$), suggesting enhanced muscular power and neuromuscular coordination.

4.3 Self-Reported Improvements
A post-intervention questionnaire revealed that:
- 87% of athletes reported increased confidence while jumping or landing.
- 80% felt a noticeable improvement in their single-leg stability.
- 90% expressed willingness to continue NMT even after the study concluded.

These self-reported outcomes correlate positively with the objective data collected.

4.4 Compliance and Safety
No adverse events or injuries were reported during the course of the NMT program. Minor muscle soreness was reported by 6 participants in the first week, which resolved without intervention.

5. Discussion
The present study aimed to evaluate the impact of a structured 10-week neuromuscular training (NMT) program on ACL injury risk factors among female athletes in Mathura, Uttar Pradesh. The findings strongly suggest that NMT significantly improves landing biomechanics, reduces

dynamic knee valgus (DKV), and enhances functional performance in female athletes involved in high-risk sports.

5.1 Interpretation of Key Findings

The study observed a significant decrease in Landing Error Scoring System (LESS) scores post-intervention (from 6.2±1.1 to 3.7±0.9), indicating improved jump-landing mechanics. A LESS score above 5 is considered high-risk for ACL injury (Padua *et al*., 2015), while scores below 4 suggest a biomechanically safer landing pattern. This reduction in errors indicates that athletes adopted safer kinematic strategies such as increased hip and knee flexion, decreased valgus angles, and better trunk positioning during dynamic movements.

The average dynamic knee valgus angle decreased from 19.8° to 12.4°, signifying improved alignment and reduced medial displacement of the knee. This outcome aligns with earlier work by Hewett *et al*. (2005), which identified excessive knee valgus as a strong predictor of ACL injury, particularly in adolescent and collegiate female athletes. Interventions that reduce this valgus tendency are therefore crucial in lowering ACL stress during cutting and landing actions.

Furthermore, the functional performance, as assessed by the single-leg hop test, improved significantly. The mean hop distance increased from 82.1 cm to 94.6 cm, supporting evidence from Myer *et al*. (2006) that strength and proprioception-based interventions enhance lower-limb functional capabilities. Enhanced single-leg stability and muscular control are essential for ACL injury prevention, as they reduce asymmetries and joint overload during sport-specific tasks.

5.2 Comparison with existing literature

Our findings are consistent with global studies emphasizing the effectiveness of NMT in ACL injury risk reduction. A meta-analysis by Sugimoto *et al*. (2012) concluded that NMT programs can reduce non-contact ACL injury risk by over 70% in female athletes when applied consistently with proper technique and supervision. While most of these studies were conducted in Western populations with access to advanced equipment, the current study validates these findings in a resource-constrained Indian environment, using simple equipment and culturally appropriate implementation methods.

Notably, the high effect sizes observed in our study (Cohen's $d > 2$ for LESS and DKV) indicate a large practical significance. This reinforces that even a modestly equipped setup, when guided by trained personnel and driven by structured protocols, can produce outcomes on par with global benchmarks.

5.3 Contextual Significance

This study is among the first to document the efficacy of a structured NMT program for female athletes in a Tier-3 Indian district. The successful implementation of the intervention in Mathura demonstrates that preventive sports medicine approaches can be localized and scaled, even in areas lacking sophisticated biomechanics labs or 3D motion analysis systems.

Importantly, the participation of female trainers, use of Hindi for instructions, and inclusion of sport-specific drills ensured high compliance and engagement. This cultural sensitivity could serve as a model for similar interventions across rural and semi-urban sports development centers in India.

5.4 Athlete Feedback and Behavior Change

Beyond the objective improvements, subjective feedback indicated an increase in athlete confidence, awareness of movement quality, and enthusiasm to continue injury prevention practices. These psychological shifts are essential, as ACL injuries not only disrupt physical health but also affect mental well-being, self-efficacy, and athletic identity.

The absence of injuries or major adverse events during the program also underscores the safety and feasibility of NMT when conducted under supervision. Minor soreness reported by a few participants resolved with minimal intervention, indicating good overall tolerance to the protocol.

5.5 Limitations

Despite the promising results, the study has limitations:

- The absence of a control group limits the ability to definitively attribute changes solely to the intervention.
- The use of 2D motion analysis, though practical, lacks the precision of 3D systems in quantifying valgus angles and joint kinetics.
- The study did not track actual injury incidence over time, which would have provided real-world validation of the preventive benefit.
- The sample size, though adequate for pilot findings, limits generalizability.

Future studies should aim for randomized controlled trials (RCTs), incorporate follow-up periods to track injury occurrence, and explore the influence of menstrual cycle phases on injury risk and NMT outcomes.

6. Conclusion

The results of this study provide strong evidence that a structured neuromuscular training (NMT) program can significantly reduce biomechanical risk factors associated with anterior cruciate ligament (ACL) injuries in female athletes. Over a 10-week period, the implementation of a supervised, low-cost, and sport-specific NMT protocol led to marked improvements in landing mechanics, dynamic knee alignment, and functional lower-limb performance among young female athletes in Mathura, Uttar Pradesh.

The findings validate the efficacy of NMT in an Indian grassroots sports setting, where access to advanced physiotherapy equipment is limited. The large effect sizes observed across all three major performance metrics (LESS, dynamic knee valgus, and hop distance) suggest that even modest interventions if well-structured and culturally contextualized can yield results comparable to those reported in global literature.

Furthermore, the high compliance, absence of adverse events, and positive subjective feedback from participants reinforce the practical feasibility and acceptability of the program. The improvements in both physical performance and self-reported confidence highlight the dual physical and psychological benefits of integrating NMT into athletic training programs.

From a broader perspective, this study underscores the urgent need for preventive injury strategies in female athletic populations in India. ACL injuries are not only physically and emotionally debilitating but also threaten the

careers and long-term health of young athletes. Preventive training must, therefore, be viewed not as an optional addition but as a foundational component of athlete development.

Given the success of this intervention, it is recommended that neuromuscular training protocols be adopted across schools, colleges, and sports academies especially those involving female athletes in pivot-heavy sports. Institutional support, coach education, and inclusion of trained physiotherapists are key to ensuring safe and effective implementation.

Future research should focus on expanding sample sizes, introducing randomized control groups, and following athletes longitudinally to assess actual injury incidence over time. Additionally, tailoring NMT programs based on age, sport, and menstrual cycle phase may enhance outcomes even further.

In conclusion, neuromuscular training stands as a scientifically validated, accessible, and empowering solution for ACL injury prevention in female athletes. Its implementation in regions like Mathura represents a critical step forward in promoting safe sport participation and safeguarding the future of women in Indian athletics

7. References

1. Arendt EA, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. The American Journal of Sports Medicine. 1995;23(6):694-701.
2. Herzberg SD, Motu'apuaka ML, Lambert W, Fu R, Brady J, Guise JM. The effect of menstrual cycle and contraceptives on ACL injuries and laxity: A systematic review and meta-analysis. Orthopaedic Journal of Sports Medicine. 2017;5(7):2325967117718781.
3. Hewett TE, Myer GD, Ford KR. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. The American Journal of Sports Medicine. 2005;33(4):492-501.
4. Mehta A, Jain A, Singh P. Epidemiology of knee injuries among collegiate athletes in Northern India. Indian Journal of Orthopaedics and Sports Medicine. 2019;5(2):91-96.
5. Sugimoto D, Myer GD, McKeon JM, Hewett TE. Evaluation of the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: A critical review. British Journal of Sports Medicine. 2012;46(14):979-988.
6. Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: A meta-analysis. Journal of Athletic Training. 2006;41(3):314-325.
7. Padua DA, DiStefano LJ, Beutler AI, de la Motte SJ, DiStefano MJ, Marshall SW. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL Study. The American Journal of Sports Medicine. 2015;43(2):324-332.
8. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. Journal of Athletic Training. 2004;39(4):352-364.
9. Sharma R, Bhardwaj A. Knee injuries among female Indian athletes: Prevalence, mechanisms and preventive strategies. International Journal of Sports Physiotherapy and Rehabilitation. 2021;7(1):42-48.
10. Bhardwaj P, Tyagi S, Singh A. Anterior cruciate ligament injuries in Indian sportswomen: A clinical review. Asian Journal of Sports Medicine. 2022;13(3):151-159.