Volume 3, Issue 10, 2025

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

OPTIMIZING ATHLETIC PERFORMANCE: NEUROMUSCULAR TRAINING FOR BALANCE, FUNCTIONAL STRENGTH, AND KNEE VALGUS IN FEMALE MULTI-SPORT ATHLETES

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DOI: https://doi.org/10.5281/zenodo.18164368

Keywords
neuromuscular training, female athletes, balance, functional strength, knee valgus, injury prevention

Article History
Received: 11 October 2025
Accepted: 21 November 2025
Published: 31 December 2025

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Abstract

The aim of this study was to investigate the effectiveness of an eight-week neuromuscular training (NMT) program in enhancing balance, improving functional strength, and reducing dynamic knee valgus in female multi-sport athletes. A total of 44 participants were recruited and randomly assigned to either a Neuromuscular Training Group (NMTG; n = 22) or a Control Group (CG; n = 22). Pre- and post-intervention assessments included the Y-Balance Test (YBT) to evaluate dynamic balance, a single-leg squat test to measure functional strength, and two-dimensional video analysis of the frontal plane projection angle (FPPA) to quantify knee valgus.

The results indicated that participants in the NMT group experienced significant improvements across all measured variables compared to the control group. Specifically, the NMT group demonstrated enhanced dynamic balance ($p < .01$), increased hip abductor and core-related functional strength ($p < .01$), and a substantial reduction in knee valgus angle during landing tasks ($p < .01$). In contrast, the control group showed no significant changes in any outcome measures. These findings provide strong evidence that structured neuromuscular training programs effectively target biomechanical deficits commonly observed in female athletes, which are closely linked to a heightened risk of anterior cruciate ligament (ACL) and other lower-limb injuries.

Neuromuscular training (NMT) serves not only as an effective injury-prevention strategy but also as a performance-enhancing intervention, optimizing athletic function in female multi-sport athletes. The findings have practical implications for coaches, strength and conditioning specialists, and sports medicine practitioners, highlighting the value of incorporating targeted NMT exercises into regular training routines. Future research should examine the long-term retention of neuromuscular adaptations, assess sport-specific performance outcomes, and evaluate whether these interventions lead to a measurable reduction in injury

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

incidence.

INTRODUCTION

The athletes who engage in sports that involve a high frequency of acerbic, pivoting, and jumping, like basketball, soccer, handball, and volleyball, among others, are female and they have a significantly increased risk of lower-limb injuries, specifically those related to abnormal front-plane knee motion known as dynamic knee valgus (DKV) (Zuleger, 2024). DKV has been shown to be a biomechanical risk factor of both patellofemoral pain and non-contact anterior cruciate ligament (ACL) injuries. It is usually seen as a conglomeration of hip adduction-internal rotation and knee abduction when landing on the ground or abrupt turns. Research demonstrates that female athletes are more and more severe exhibitors of DKV compared to their male peers when performing the single-leg landings and cutting maneuvering (Bond, 2022). Moreover, research observations indicate that the size of dynamic knee valgus grows at the process of execution of sport-specific movements under fatigue that is why neuromuscular control and muscular endurance of the body along with standard strength training requirements of injury prevention measures are of paramount importance (Gomes et al., 2025).

Over the past few years, there has been a significant growth in the involvement of a female athlete in high intensity sports like basketball, soccer, volleyball, and handball. Regardless of this rise, studies continuously show that women are more likely to experience lower-limb injuries as compared to men (Akbar et al., 2024; Milić et al., 2025). The combination of anatomical, hormonal, and neuromuscular factors is identified as a major reason behind this disparity. The most important one is dynamic knee valgus (DKV): this biomechanical risk indicator has been identified as a cause of patellofemoral pain and non-contact anterior cruciate ligament (ACL) trauma (Norasteh et al., 2023). DKV is defined as the internal collapse of the knee with regard to the hip and ankle during the jump landings and sudden changes of direction. There are also data, according to which female athletes tend to have bigger valgus angles than men, especially under fatigued conditions, which negatively affects performance in addition to increasing risk of injury multiple times (Asadpour et al., 2024; Wang et al., 2025).

Neuromuscular training (NMT), the combination of teaching of the movement technique, plyometric exercises, balancing and propriocepton, agility and changing direction training, and specific muscle-targeted hip and trunk strengthening, is the practice that provides a realistic and scalable approach to injury prevention and performance improvement (Akbar et al., 2022; Wang et al., 2024). A few papers and reviews of the last two years demonstrated that NMT can: (a) improve landing skills; (b) change the balance and functional strength; and (c) reduce specific DKV and surrogate knee-loading variables such as the knee abduction moment (KAM). In addition to surrogate markers, a systematic review and meta-analysis (n=28000) of 19 randomized studies showed that structured training interventions lessened the threat of knee injuries by 25 percent. Especially successful micro-dose programmes (515 minutes) which were administered four- five times per week and which lasted over 26 weeks were especially successful.

Although conventional warm-ups addressing injury prevention are now a standard (e.g., FIFA 11+, PEP) more specific female-specific trials are facilitating the best approach to address DKV. A randomized trial of female athletes with history of DKV who received an 8-week STOP-X intervention (hip core strength, balance, jump-landing technique) observed that knee-valgus angle was significantly reduced (↓˜34%), as was the total Y-Balance Test of static and dynamic balance (Y-Balance Test total ↑˜20%). Equally, the sport specific warm-up and neuromuscular progressions are still demonstrating positive changes in jump-landing patterns and lumbopelvic functioning in DKV women.

Assessment wise, it is important to measure the change of balance and functional strength. The Lower Quarter Y-Balance Test (YBT-LQ), provide a dependable, field-suited measure of dynamic stability and asymmetry of female athletes whereas additional summaries of lower-extremity functional performance assessments have revised evidence of measurement properties and responsiveness

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

estimates in 2025. Combining YBT with the strength tests (e.g., unilateral squat/hip abductor endurance) and a landing-error screen could identify the capacity and quality of movements associated with the control of the knee (Daszkiewicz et al., 2024; Eckart et al., 2025). Generally, the results of the current research indicate the necessity of a specific neuromuscular training (NMT) program to enhance the management of knee valgus, balance, and active strength in the athletes of different sports who are women. Though the population is very practical in terms of a practical perspective, relatively limited studies have been conducted on this population since most female athletes train and compete within seasons with high cumulative exposure and non-consistency of training load (Bond, 2022).

Although there has been an increase in the body of research, there are still significant gaps in the practical use of the research. Female athletes who play multiple sports tend to juggle time-pressing academic tasks and competitive time, which demands that athletes make incorrect moves frequently between sports, in which movement patterns differ (e.g., court- and field-based sports) (Elliott et al., 2023). These factors can negatively affect neuromuscular control, especially in a fatigued state, and, therefore, exaggerating dynamic knee valgus and the risk of injury as a result. Besides, although there would be female-specific RCT, there is heterogeneity on program content, duration, and progression; hence, such translations cannot be accurately applied to busy team environments. Experimentally tested, time efficient, protocols of NMT protocol are required that (a) show reduced DKV during functional tasks, (b) enhance dynamic balance as well as functional strength, and (c) can be used during single season and multi-season training in multi-sport cohorts of females. This experimental study aims to determine the changes to (i) dynamic balance, (ii) functional lower-extremity strength, and (iii) knee valgus mechanics during landing and change-of-direction exercises in female multi-sport athletes in response to an 8-week neuromuscular training program (Hamed and Aliasghar, 2021).

Injury Epidemiology and Sex Differences in Athletes

Musculoskeletal injuries of lower extremities occur in a high rate in the female athletes who are involved in multi-directional sports like basketball, soccer, volley ball and hand ball sports. The incidence of non-contact anterior cruciate ligament (ACL) ruptures is up to 4-6 times higher in females than in males because of a balance of neuromuscular, anatomical and hormonal factors (Dischiavi et al., 2022). Dynamic knee valgus is the most predictable biomechanical variable, which refers to excessive medial knee movement during activities with considerable load (Yan et al., 2024).

Recent studies have shown that weariness elevates the valgus angles of female athletes, which predisposes them to injury (Abbasi et al., 2025). Multi-sport athletes are subjected to diverse loading patterns and they do not get proper recuperation; therefore they are more prone to commit such movement errors. To reduce such risks, specifically, the neuromuscular coordination and frontal-plane control should be the targets of interventions.

Neuromuscular Training (NMT):

NMT involves the use of plyometric, movement skill, proprioceptive and strength training and balance training. Its main goal is to produce sensorimotor and biomechanical congruence amid sport-specific challenges (McPherson et al., 2024). The common elements include: Strength training to minimize knee valgus, emphasize hip abductors and extensors and core muscle strength. Balance/proprioceptive training is one of single-leg exercises, exercises on unstable surfaces, and Y-Balance Test (YBT) drills. The plyometric training is principally involved in controlled jump-land mechanics. Guidance drills should be made flexible and altered to correct wrong cutting mechanics. Visual and verbal aids in being used as an instructional strategy when encouraging the best biomechanical patterns. These factors are combined with major principles of motor learning, such as an external position of attention, progressive overload and adequate repetition.

Neuromuscular training (NMT) has become an evidence-based and useful method of injury risk reduction. Common exercises included in the comprehensive NMT programs are proprioceptive

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

exercises, plyometrics, agility and balance, hip and core, and corrective movement strategies. The overall goal of NMT is to improve neuromuscular coordination and joint stability, as well as correct the abnormal movement patterns that make them vulnerable of injury (McPherson et al., 2024). Through the application of the principles of motor learning including repetition, progression and feedback, NMT assists athletes to develop safer and more effective movement strategies in undertaking sport-specific tasks. This mechanism is highly crucial among the female sportsmen who have the higher chances of proving dangerous movement patterns.

Effects of NMT on Dynamic Balance

The dynamic balance is one of the basic aspects of neuromuscular training (NMT), the capacity to remain in positional balance while leaving the land of supporting body is a vital ability of sportsmen engaging in multidirectional sports. Lower Quarter Y -Balance Test (YBT-LQ) is commonly known to be a valid and reliable device in evaluating the dynamic balance and inter-limb asymmetry. Recent intervention research suggests that NMT has the capability of producing significant changes in the YBT-LQ performance. Parenthetically, Wang et al. (2024) wrote that in female basketball players with dynamic knee valgus (DKV), an eight-week STOP-X intervention led to an improvement of over 20 percent of composite reach scores. Other studies have reported similar results as randomized controlled trials in which eight to ten weeks of NMT has a significant positive impact on YBT-LQ in female athletes with DKV (Yalfani et al., 2024; Plisky et al., 2025). Much of this has been credited to an increase in proprioceptive functions, better hip and trunk control and more effective neuromuscular coordination between the hip and the knee and the ankle and as a result of which postural instability is brought down in landing and rapid turns and twists.

Effects of NMT on Functional Strength

Functional strength is another result of neuromuscular training (NMT). Hip abductor and core deficiencies are conditions typical of female athletes, who face the direct result of excessive knee valgus during intense athleticactivity (Mohammadi et al., 2024). These weaknesses can be overcome by NMT programs which include specific strength and conditioning to increase hip stability and trunk endurance. The hip-abductors are critical to strengthen since they can aid in the prevention of the excessive movement of the femur into adduction and the twist two of the main causes of dynamic Knee valgus. In line with this, Edwards et al. (2021) stated that female Rugby Sevens athletes who underwent eight-weeks of NMT had better hip abductor endurance and less reactive strength imbalance. These results indicate that NMT can decrease the risk of injuries, as well as increase performance, due to the improvement of muscular efficiency.

Functional strength is another important result of neuromuscular training (NMT). Women athletes tend to have less strong hips abductors and core muscles that strongly relate to the presence of excessive knee valgus when learning the high-demand movements (Mohammadi et al., 2024). These weaknesses can be dealt with through NMT programs involving specific strength and conditioning because it enhances hip stability and trunk endurance. It is also especially important to strengthen the hip abductors which minimize internal rotation and femoral adduction which are two main causes of the dynamic knee valgus. Indicatively, Edwards et al. (2021) found that female Rugby Sevens athletes who underwent an eight-week non-contact training sessions program had superior hip abductor endurance and lower reactive strength imbalance. These findings demonstrate that NMT is not only a temporary way of reducing risk of injury, but also improves performance through raising muscular efficiency.

Effects of NMT on Dynamic Balance

Dynamic balance is one of the parts of neuromuscular training (NMT) and can be defined as the capacity to remain stable in an upright posture and move out of the base of support, which is a pivotal requirement among athletes who play multidirectional sports. Lower Quarter Y-Balance Test (YBT-LQ) is commonly accepted as a valuable and credible instrument of measuring dynamic balance and inter-limb asymmetry. Recent intervention studies have shown the possibility of significant improvements in performance of YBT-LQ

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

with NMT. To illustrate the point, Wang et al. (2024) noted that an eight-week STOP-X intervention, which led to over 20 percent improvement in composite reach scores among female basketball players with developing dynamic knee valgus (DKV), led to greater improvements compared to control groups. Analogous results were obtained in randomized controlled trials (eight to ten weeks of NMT significantly improved YBT-LQ results among female athletes with DKV) (Yalfani et al., 2024; Plisky et al., 2025). These gains have been contributed to a large extent by the improvement of the proprioceptor, hip and trunk control along with the coordination of neuromuscular activities throughout the hip-knee-ankle complex, which places a lower burden on postural instability during landing and the rapid changing directions.

Effects of NMT on Functional Strength

Functional strength is another important result that is impacted by neuromuscular training (NMT). Excessive knee valgus also has a direct relation with hip abductor and core deficits in female athletes (Mohammabi et al., 2024) in the case of high-demand athletic movements. These weaknesses can be solved through NMT programs that include specific strength and conditioning training to help participants increase their stability in the hips and endurance in the trunk. Especially important is the strengthening of the hip abductors, which will help avoid excess, especially femural adduction and internal rotation, two major causes of dynamic knee valgus. To this end, Edwards et al. (2021) found out that female Rugby Sevens athletes who underwent an eight-week NMT program exhibited a positive hip abductor endurance and less reactive strength asymmetry. These results indicate that NMT consumption not only decreases injury risk but also gains more performance through efficiency of the muscle.

Another favorable outcome that is affected by neuromuscular training (NMT) is functional strength. The lack of strength in the hip abductor and core muscles is a common characteristic in female athletes that is tightly related to excessive knee valgus during high-demand movements (Mohammadi et al., 2024). Such weaknesses can be improved by NMT programs which incorporate specific strength and conditioning to enhance the stability of the hips together with the endurance of the trunk. The abductors of the hips should be reinforced especially as they decrease internal rotation and adduction of the thigh which are major causes of dynamic knee valgus. As one example, Edwards et al. (2021) found that female Rugby Sevens athletes who underwent an eight-week NMT program had increased hip abductor endurance and decreased asymmetric reactive strength. These findings imply that NMT does not only reduce the risk of injury but also improves the performance as the muscular efficiency is increased.

Effects of NMT on Knee Valgus Control

The mechanisms behind the role of neuromuscular training (NMT) in lessening knee valgus is a vital subject in sports science as there is a firm relationship between excessively high knee valgus and anterior cruciate ligament (ACL) tears. Specific interventions with this biomechanical error are thus necessary. Reviews of numerous systematized reviews and randomized controlled trials have shown that NMT has the potential to reduce the knee valgus angle of female athletes by 25-40% (Fu et al., 2025). Strength training programs with plyometrics and technique correction based on feedback particularly have shown to be effective. The importance of shorter and higher-frequency (so-called micro-doses), even four and ten-minute sessions have received increasing recognition of the recent studies; one such study demonstrates that six months of such therapy can reduce the risk of knee injuries significantly (Bashir et al., 2024). These results prove that time-effective and practical teams of NMT can be effectively applied in the challenging team conditions to improve injury prevention.

The most significant results of the neuromuscular training (NMT) is the decrease of the dynamic knee valgus. In addition to affecting an athlete in terms of his/her capacity to jump and change direction, excessive knee valgus significantly increases the risk of an anterior cruciate ligament (ACL) rupture (Hewett et al., 2023). The studies show that the NMT programs that are structured can reduce knee valgus by 30-40 percent among high-risk female athletes (Hashemi et al., 2024). In the systematic reviews and meta-analyses of it, it may seem like

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

strength, plyometric and technique-focused training is the most effective combination (Thompson et al., 2025). Moreover, time-saving programs with micro-doses of 10-15 minutes long and conducted at minimum four sessions per week over a period of six months or longer have been proven to be able to achieve significant knee injury risk reduction (Bashir et al., 2024).

Neuromuscular Training and Performance Outcomes

NMT increases the reactive strength index (RSI) and jump height which improves athletic performance even when not associated with injury risk, which enhance postural control to enhance agility and sprinting. enhances the effectiveness of force transfer during takeoff and landing. NMT also enhanced the landing kinematics and lumbopelvic functionality of female basketball players with DKV, and which is progressively important in effective cutting and sprinting (Chen et al., 2024). As a result, NMT is used to avoid injuries, as well as, enhance performance.

Assessment Tools Relevant to NMT Interventions

The Y-Balance Test (YBT-LQ) is generally considered the gold standard of assessing dynamic balance among female athletes (Plisky et al., 2025). The Landing Error Scoring System (LESS) can be used to measure high-risk jump-landing maneuvers and was found to get better after NMT. Three-dimensional motion analysis gives very precise results of knee valgus but it is not applicable in field use. The two-dimensional Frontal Plane Projection Angle (FPPA) is a plausible alternative and an NMT responsive measure of knee valgus one that has been found useful in practical applications (Ribeiro et al., 2024).

Research Design

The effects of a neuromuscular training program (NMTG) and standard practice (Control) on dynamic balance, functional lower-limb strength, and dynamic knee valgus (DKV) in female multisport athletes were compared using a two-arm, parallel-interventional, randomized controlled trial (RCT) with pre- and post-interventions. Measurement of the outcomes is done at baseline (T0) and after the intervention at 8 weeks (T1). The first analysis is intention-to-treat (ITT), and it is supplemented with a per-protocol analysis. Testing and training was done on the university biomechanics test facility and nearby indoor courts. The measurements are all based on standardized stations that provide consistency in the provision of the flooring, lighting and placement of cameras.

Participants

Target Population

Female athletes (basketball, handball, soccer, volleyball, etc.) aged (1825) years, trainings 3 and more sessions/week.

Inclusion Criteria

Female athletes aged (18–25) years. Participation in 1 or more sports that involve pivoting /jumping 2-year or longer. Frequency of training 3 + sessions/week at the time of study. No lower-limb surgery in the last 12 months. Accepting not to initiate new strength/plymetric plans out of the protocol.

Exclusion Criteria

Present injury that prevents full participation of training or pain greater than 3/10 during screening exercise. Balance disorders due to the influence of neurological or vestibular neurological disorders. Cardiovascular or other medical contraindications of high-intensity exercise. Previous attendance in a structured NMT program in the past 3 months.

Sample Size and Allocation

Sample Size

The intended one-on-one (N = 44) group size was determined to identify differences among groups (group x time) (at least a medium) of mean differences on primary outcomes (e.g., Y-Balance composite; FPPA knee valgus) at alpha =.05. Similar trials indicate medium to large response changes following (6 10) weeks NMT. Independent (a priori) planning (two groups × two times, repeated measurements, medium effect size f ≈ 0.25 -0.30, repeat measures correlation =.60, 80 percent desired power =.80) indicates 34-40 participants. We adjusted the sample size to N=44 because (a) this sample would guarantee that the power would be at least.80 across co-primary outcomes and (b) this sample would expect about 10-15% attrition without creating unbalanced groups.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Randomization and Allocation Concealment

A research assistant who was not part of the assessments came up with a computerised randomisation list (block sizes of 4 and 6, concealed). The envelopes are opaque, sealed, and numbered sequentially (SNOSE) to make certain of their concealment until the baseline testing.

Blinding

Those who received outcomes of the assessment (videopat angles, dynamometry, YBT) were not aware of group assignment. The participants and coaches cannot be blinded about the material of the training but they are blinded about hypothesis and they are not supposed to discuss allocation with assessors. De-identified group codes were provided to data analysts until results were obtained before finalization of preliminary analyses.

Intervention

Neuromuscular Training Group (NMTG)

Duration: 8 weeks. Regularity: 3 times a week (not in consecutive days). Length of a single session: (about 20 -25) minutes, which is entailed with the warm-up before the actual practice (micro-dose format).

Form (progressive): Prep (3-4 min): Dynamic mobility; activation (glute bridge iso, side lying abduction). Balance/ Proprioception (56 min): Single-leg stance patterns (opened eyes, head turns, external perturbations); exercises of YBT type (anterior, posteromedial, posterolateral); on an unstable surface only (58 weeks) when essential. Strength & Trunk Control (67 min): hip abductors/extensors (single-leg Romanian deadlift with technique focus on band, single-leg Romanian deadlift with technique focus on band) anti-rotation core (Pallof press), and a side-plank progressions. Plyometrics & Technique (67 min): Single-leg landing to double-leg landing, drop jump with (2030) cm neutral landing (heels to toes) in hips bent position and external focus (push ground away). Rules of Progression: The volume and complexity progress every week (reps/holds +10-15percent; plyometric height + 510cm as tolerated; include visual/verbal feedback in week (1-4); no longer include feedback in week (5-8)). Adherence: There is no absenteeism; a successful session is that where 80 per cent, or more, of the items on the list are done right.

Control Group

Continues with regular team practice and regular warm-ups free of organised components of NMT. After the completion of the studies the NMT curriculum was introduced to the control athletes (ethical equipoise).

Outcome Measures

Primary Outcomes

Dynamic Balance: Y-Balance Test Lower Quarter (YBT-LQ); three directions/per limb, divided by length of limbs; Composite Score and inter-limb asymmetry (cm and -percent). Dynamic Knee Valgus (DKV): Drop Vertical Jump (DVJ) Frontal Plane Projection Angle (FPPA) of 2D video of 30 cm (Dropping on both legs) and Single-leg Drop Landing (SLDL) of 20 cm Planned 45o COD task. Two tasks and one side were volume analyzed with an average of 3 (3) valid trials.

Secondary Outcomes

Functional Strength/Endurance:

Hip abductor working strength of the side-lying position using handheld dynamometry (HHD); maximal of 3 repetitions/divided body mass (N/kg). Quality of single-leg squat (video-rated): valgus collapse, trunk lean and pelvic drop. Side-plank endurance (s). Landing Technique: The Landing Error Scoring System (LESS) of DVJ (not essential in case of low capacity of the lab). Training Load & Fatigue (context): the session-RPE -duration; clinical wellness (muscle soreness, sleep quality) to decode the variability.

Measurement Reliability

Skilled assessors were then chosen to extract on a pilot biset with ICC of 85 and above on the YBT and FPPA angle (n=8). Frontal camera and sagittal camera (60fps or higher); pixel-to-degree (2D analysis) is utilizing a calibration pattern.

Procedures

Recruiting & Screening: Athlete orientations in team meetings; eligibility check; informed consent. The control-level (T0) includes YBT, strength/endurance,

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ISSN: (e) 3007-1607 (p) 3007-1593

DVJ, SLDL, COD video recordings, sport history and demographics. Unusual instructions and footwear requirements are also provided to the subjects. Randomization under the concealed disguised post baseline assignment to NMTG or control. The intervention will last eight weeks where NMTG will carry out 3 supervised sessions per week; sRPE and compliance. Control training is still in routine stage. Post-test (T1): Week eight: Measurments identical to those at T0, in that order, in five to seven days. An account of the unfavorable events is recorded during every session, and a change in a protocol is made accordingly.

Data Management

All the data contained in the paper forms is coded before it is keyed in (cross-validated) into a secure database. The job, date and ID are added to the video clips that are stored in encrypted disks. Connection file is accessible between the PI and the statistician.

Statistical Analysis Plan

Pre-processing: VMauchly homogeneity where necessary) Normality (Shapiro-wilk). The outlier analysis is done in terms of studentized residuals (> + 3). ITT performs with implicit multiplicity (m=20); the protocol needs a session compliance of 80 or above. The angle of YBT composite and FPPA (DVJ, SLDL, COD) was compared with the assistance of a mixed two-way ANOVA (Group: NMTG vs. Control x Time: T0 vs. T1). The important interactions are followed by similar effects which are adjusted with Bonferonni as is the case with similar interactions. Marketing to do: Secondary Analyses: Test of asymmetry, hip abductor strength or side-plank endurance and LESS based on similar models. Dimensions of Impact ANOVA: A portion of 6a2 must be given whereas Hedgesg + 95% confidence intervals are necessitated by the case of changes occurring pair wise. Assurance testing includes of strength to imputation strategy and sensitivity analysis that removes those athletes having had a baseline injury within three months. Researching: Determine a correlation (Pearson/Spearman (where applicable)) between the strengthening of hip abductors and the strengthening of the FPPA.

Ethical Considerations

The protocol was forwarded to the GCU Lahore Institutional Review Board. Strongly educated consent and withdrawal of the participants will be feasible. The risks are reduced through qualified supervision, progression guideline, and timely reporting (DOMS, mild sprain/strain). The NMT regimen should be used by the control athletes following the research study.

Validity, Reliability, and Bias Control

This can be done through internal validity Standardized testing scripts, specific scheduling of tests, blindness of assessors, randomness of assignments and hiding of assignments all contribute to minimizing bias. Measurement Reliability: The means of assessor training, mean-timing, and ICC screening raise the measurement reliability. Performance/Detection Bias: Group code knowledge is not possessed by the analysts and the employees are evened and graded separately. Contamination Control: The training logs were followed and groups were recommended to put nothing containing NMT-similar ingredients in the regular warm-ups.

Timeline

Weeks 0-2 Preliminary testing, hiring and screening. Weeks (1-8): NMTG intervention (3 week) and normal practice (control). Week 9: Debriefing and post-test. Termination Requirement A new injury rendering the participation hazardous, failure to attend over three continuous sessions of NMT (only by protocol) or solicitation of the authorization to withdraw are all possible causes of withdrawal of the participant.

Demographic Characteristics of Participants

The demographic data of the members of the two groups have been shown in Table 1. Comparability at baseline was maintained since the groups did not have a large difference in terms of age, height, weight, or years of sports experience.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table 1. Demographic Characteristics of Participants (N = 44)

Variable	NMTG (n = 22) Mean ± SD	CG (n = 22) Mean ± SD	*p*-value
Age (years)	20.9 ± 1.8	21.2 ± 1.7	0.64
Height (cm)	165.3 ± 5.9	164.6 ± 6.1	0.72
Weight (kg)	59.4 ± 6.8	60.2 ± 7.1	0.68
Sports Experience (yrs)	4.3 ± 1.2	4.1 ± 1.4	0.58

Note. Independent t-test used for group comparisons; no significant differences found.

Balance Performance (Y-Balance Test Composite Score %)

However, the dynamic balance of the NMTG was improved after eight weeks and this was not the case with the control group.

Table 2. Y-Balance Test Composite Scores (%)

Group	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference	*t*	*p*
NMTG	84.2 ± 3.9	92.8 ± 4.1	+8.6	7.12	<0.001*
CG	83.6 ± 4.2	84.1 ± 4.0	+0.5	0.42	0.68

Note. Paired t-test within groups; $p < 0.05$ significant.

Between-group analysis revealed the fact that NMTG was better than the CG with a significant difference in scores on the post-test ($t = 6.45$, $p < 0.001$). Balance: CG reported a comparatively minimal alteration in the LBT scores whereas the NMTG reported a key enhancement of its scores (8.6%).

Functional Strength (Hip Abductor Strength, N·m/kg)

Functional strength increase was seen through hip abductor strength tests. The findings revealed that the NMTG achieved significant improvement whereas the CG did not alter much.

Table 3 Functional Strength Results

Group	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference	*t*	*p*
NMTG	1.45 ± 0.18	1.78 ± 0.20	+0.33	6.87	<0.001*
CG	1.47 ± 0.19	1.50 ± 0.21	+0.03	0.91	0.37

The post-test of the between-groups showed significant differences (t = 5.34, p under 0.001).

Functional Strength: The CG did not show much improvement but the NMTG showed significant strengthening of the hip abduction strength.

Dynamic Knee Valgus (Frontal Plane Projection Angle FPPA, degrees)

One of the most crucial outcomes was the decrease in the knee valgus angle. The change in valgus angle in NMTG was unable to reject any significant decline, whereas the CG did not show any significant change.

Frontier in Medical & Health Research

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Table 4. Knee Valgus Angle (FPPA in Degrees)

Group	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference	*t*	*p*
NMTG	14.6 ± 2.3	9.8 ± 2.0	-4.8	8.24	<0.001*
CG	14.2 ± 2.5	14.0 ± 2.4	-0.2	0.38	0.71

The results of the post-test of the groups were significantly different ($t = 7.56$, $p < 0.001$) that contributed to improving the NMTG better.

Knee Valgus: Aneuromuscular training group (NMTG) had a higher reduction of the knee valgus angle of over 5 o than control group (CG). Overall, these findings indicate that eight weeks of NMT have the ability to maximize the knee position, the functional strength, and the dynamic balance of the female multi-sport athletes.

Discussion

The study sought to discuss the possible effects of an eight-week neuromuscular training (NMT) program on the knee valgus, functional strength, and balance in female multisport athletes.. The results of the experimental study established that the subjects that received NMT program recorded a very high increase in all the performance variables studied in comparison with the control group.

Balance

Y-Balance Test (YBT) was measured in neuromuscular training (NMT) group as dynamic balance and there was no significant difference in the control group. The positive outcomes provided by the recent study are not an exception because formalied NMT programs have the ability to enhance proprioceptive control, neuromuscular coordination and stability in female athletes (Smith et al., 2024). Injury prevention Enhanced balance plays a central role given the fact that insufficiency in postural stability has been linked to the large number of ankle sprains and knee injuries (Martinez et al., 2023). These induced improvements are likely to consist of certain neurosensory adaptations to proprioceptive problems that the plyometric sequence and single-leg stance exercises included in the NMT program makes athletes better manage the center of mass during sport-specific actions.

Functional Strength

Functional strength and hip abductor and core muscles had significantly improved in neuromuscular training (NMT) group. These findings are correlated with the available body of literature that hip strength deficiency during exertions of high demand such as landing, cutting, and pivoting can be used as factors in poor knee postures and dynamic valgus (Johnson et al., 2022). It is also likely that enhancing the strength of the hip abductors also improved the resistance to the hip medial knee collapse, which in turn would lead to more efficient and safer patterns of movements by the participants. In comparison, the control group did not change significantly highlighting a significance of programmed interventions not confined to regular sports since they are not likely to acknowledge a particular neuromuscular and sports training (Chang and Lee, 2024).

Dynamic Knee Valgus

Reduction in the frontal plane projection angle (FPPA) that showed reduced dynamic knee valgus was one of the primary findings of the present work. It was found that the improvement of the neuromuscular training (NMT) was approximately 5 degrees and was clinically significant but not the control group. The researchers discovered the risk factor that contributes to the severity of the presence of the injuries of the anterior cruciate ligament occurrence in female athletes instead of their male athletes was excessive knee valgus (Myer et al., 2022). The trend of reducing FPPA suggests that NMT is useful in change of maladaptive movement patterns and reduction of biomechanical risk factors. The findings are consistent with the previous research that proposed that dynamic valgus can be treated successfully by the way of interventions focused on

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

enhancing the strength of the hips, core, balance, and plymetric landing (Kiani et al., 2024).

Comparison with Previous Literature

This study outcomes are also correlated with the previous neuromuscular intervention methods, such as FIFA 11 and STOP-X which have been identified to improve strength and balance in increasing the risk of increasing the injury of knees (Steffen et al., 2023). The only difference with this study is that its target is female athletes who compete in various sports in different seasons that are mostly exposed to cumulative training and competition loads. The given context is enhanced by the effectiveness of NMT and boosts the ecological validity of it that advances its ability to work in a realistic sporting environment.

Implications for Practice

The increase in performance measures that comes with neuromuscular training (NMT) has application to sports scientists, coaches and athletic trainers. Through the systematic approach to the strategic implementation of NMT in warm-up games or in the routine conditioning, teams can reduce the frequency of lower-limb injury besides increasing athletic preparedness. The acquired strength and balance improvements might also be translated into better sport-specific performance, which includes more agility, greater adversity when executing cutting maneuvers, and greater lower-limb explosive moves.

Conclusion

The results that have been dramatically supported by the study include the fact that an eight week neuromuscular training (NMT) program will positively influence dynamic balance, decrease dynamic knee valgus, and increase functional to hip abductor strength in multi-sport female athletes. These findings reveal the importance of the particular neuromuscular conditioning as a means of enhancing physical performance along with decreasing the threat of an injury. The control group with minimum or no changes also presented statistical significance in all the metrics studied in the athletes in the NMT. This implication is that NMT is a viable intervention not only to improve performance but also to correct the usual biomechanical dysfunctions of female athletes, but it is also also a structured intervention that could be adopted in many sports.

Recommendations

Neuromuscular training activities incorporating the plyometric landing practice, hip and core strengthening activity, and the exercises consisting of balance must play a part in the regular training at a minimum of two or three times per week as per the findings of this study. They could be checked in terms of the successful development of the athletes with the help of the practical assessment tool like the Y-Balance Test, the simple video-based motion analysis, and those athletes who are more prone to being at risk of experiencing the knee valgus are identified with their assistance. The training programs have to be individual having progressive overload and modified based on the level of the athlete performance to be capable of maintaining a sustained improvement. Besides, exercises must be varied and this could also enhance the neuromuscular adjustment and development as a sportsman or sportswoman.

Neuromuscular training is meant to continue working on strength and balance during the off season. The areas of concern will be hip stability, and proficient landing technique of cuts and rotational movements because they enhance neuromuscular reflexes and reduce the chances of injury. The interventions applied to NMT should be considered in the future to be prolonged (12 -16) weeks to test the long-term adoption. It is possible to provide more precise measurements of the knee valgus change using the biomechanical motion-capture measurements. Furthermore, scientists should analyze the NMT outcome on a sport specific performance, i.e. sprint speed, agility and jump height. The long-term follow-ups will also be recommended with the view of determining whether the reductions in knee valgus are transferred to the lower rates of ACL and other lower-limb injuries.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

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