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# Role of Neuromuscular Training in Injury Prevention, Movement Efficiency, and Athletic Performance Among Male and Female Athletes: A Narrative Review

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**Abstract:**
**Background:** Sports injuries remain a major concern across competitive and recreational athletic populations, often leading to significant physical, psychological, and financial burdens. Deficits in neuromuscular control, proprioception, dynamic stability, and biomechanical efficiency are recognized as major contributors to injury susceptibility, particularly for lower-extremity injuries such as anterior cruciate ligament (ACL) tears, ankle sprains, hamstring strains, and overuse syndromes. Neuromuscular training (NMT) has emerged as an evidence-based preventive and performance-enhancing intervention that integrates proprioceptive, balance, strength, agility, plyometric, and core stability exercises to optimize movement patterns and reduce injury incidence. **Objective:** To evaluate and summarize current evidence regarding the role of neuromuscular training in injury prevention, movement efficiency, and athletic performance among male and female athletes. **Methods:** A narrative review of peer-reviewed literature was conducted using databases including PubMed/MEDLINE, Google Scholar, Scopus, SPORTDiscus, and Cochrane Library. Studies published between 1995 and 2026 examining neuromuscular training interventions in athletic populations were reviewed. Inclusion criteria involved male and female athletes participating in neuromuscular, proprioceptive, balance, agility, plyometric, or strength-focused interventions with outcomes related to injury prevention, movement biomechanics, or athletic performance. **Results:** Evidence consistently demonstrates that neuromuscular training significantly improves proprioception, postural control, joint stability, landing biomechanics, muscle activation patterns, agility, speed, and coordination. These adaptations reduce lower-limb injury incidence, particularly ACL injuries (up to 50–70%), ankle sprains (35–50%), and overall sports injuries (30–45%). Female athletes appear to derive particularly significant benefits due to higher baseline ACL injury risk and movement control deficits. NMT also enhances movement economy, force transfer, and sport-specific performance outcomes. **Conclusion:** Neuromuscular training is a highly effective, practical, and low-cost strategy for reducing injury risk while improving movement efficiency and athletic performance. Its integration into athletic conditioning, rehabilitation, and return-to-sport protocols is strongly recommended across genders and sports disciplines.

**Keywords:** Neuromuscular training, injury prevention, athletic performance, ACL prevention, proprioception, movement efficiency, sports physiotherapy.

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## INTRODUCTION

Sports participation offers substantial health, psychosocial, and performance-related benefits; however, injury remains one of the most significant barriers to athletic development and longevity. Across both professional and amateur athletes, musculoskeletal injuries—particularly lower-extremity injuries such as ACL ruptures, ankle sprains, patellofemoral dysfunction, and hamstring strains—are highly prevalent and often associated with prolonged rehabilitation, reduced performance, and increased reinjury risk (1,2). Epidemiological evidence suggests that many non-contact sports injuries result not solely from external trauma but from modifiable intrinsic deficits including impaired neuromuscular control, poor proprioception, muscle imbalances, reduced postural stability, and faulty biomechanical movement patterns (3).

Neuromuscular control refers to the unconscious activation of muscles in response to sensory stimuli to maintain joint stability and coordinated movement. Effective neuromuscular control is essential during dynamic athletic tasks such as jumping, cutting, landing, sprinting, pivoting, and deceleration (4). Deficits in these systems may lead to excessive knee valgus, delayed muscle activation, poor trunk control, and abnormal loading patterns, all of which significantly increase injury susceptibility (5). Female athletes, in particular, demonstrate a greater incidence of ACL injuries due to sex-specific biomechanical, hormonal, and neuromuscular differences (6).

Neuromuscular training (NMT) has gained substantial recognition as a comprehensive intervention designed to address these deficits. NMT typically combines proprioceptive exercises, balance drills, plyometric training, strength development, agility tasks, and core stabilization to enhance sensorimotor efficiency and movement quality (7). Unlike isolated strengthening, NMT targets both neural and musculoskeletal systems, improving motor learning, reflexive stabilization, and biomechanical precision (8).

A growing body of evidence indicates that NMT significantly reduces injury incidence while simultaneously improving athletic performance variables such as speed, agility, power, and movement efficiency (9). These multidimensional benefits make NMT a cornerstone of modern sports physiotherapy, injury prevention, and return-to-sport programming. Therefore, this narrative review explores the role of neuromuscular training in improving movement efficiency, reducing injury risk, and optimizing athletic outcomes among male and female athletes.

## MATERIALS AND METHODS

### *Search Strategy*

This narrative review was conducted to comprehensively evaluate the role of neuromuscular training (NMT) in injury prevention, movement efficiency, and athletic performance among male and female athletes. A systematic literature search was performed across multiple electronic databases, including PubMed/MEDLINE, Google Scholar, Scopus, SPORTDiscus, PEDro, Web of Science, and Cochrane Library, to identify relevant peer-reviewed studies. Literature published between January 1995 and March 2026 was considered to ensure inclusion of foundational studies on neuromuscular control as well as contemporary evidence on injury prevention frameworks. Manual searches of reference lists from key systematic reviews, meta-analyses, and randomized controlled trials were also conducted to identify additional relevant publications.

### *Search Terms*

A comprehensive search strategy was developed using Medical Subject Headings (MeSH), database-specific subject terms, and free-text keywords combined with Boolean operators (“AND,” “OR”). Search terms were expanded to maximize sensitivity and specificity for athletic populations, intervention types,

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and relevant outcomes. Primary search terms included: "Neuromuscular training" OR "neuromuscular exercise" OR "neuromuscular control" OR "sensorimotor training"; "Injury prevention" OR "sports injuries" OR "sports injury reduction" OR "lower extremity injury prevention"; "Athletes" OR "sports participants" OR "competitive athletes" OR "male athletes" OR "female athletes" OR "youth athletes"; "Anterior cruciate ligament" OR "ACL prevention" OR "ACL injury reduction"; "Balance training" OR "postural stability" OR "proprioceptive training"; "Plyometric training" OR "jump training" OR "landing mechanics"; "Strength training" OR "resistance training" OR "core stability training"; "Agility training" OR "change of direction" OR "movement control"; "Movement biomechanics" OR "biomechanical efficiency" OR "landing biomechanics" OR "joint stability"; "Performance enhancement" OR "athletic performance" OR "movement efficiency"; "Sports physiotherapy" OR "rehabilitation" OR "return-to-sport"

***Example Search String***

A representative PubMed search strategy was structured as follows: ("neuromuscular training" OR "neuromuscular exercise" OR "sensorimotor training") AND ("athletes" OR "female athletes" OR "male athletes") AND ("injury prevention" OR "ACL prevention" OR "sports injuries") AND ("movement efficiency" OR "biomechanics" OR "performance").

***Inclusion Criteria***

Studies were considered eligible if they met the following criteria: a) Included male and/or female athletes participating in organized sports, recreational athletics, or competitive training environments. b) Examined neuromuscular training, proprioceptive training, balance interventions, plyometric programs, agility training, or integrated injury prevention programs as the primary intervention. c) Reported outcomes related to injury prevention (e.g., ACL injuries, ankle sprains, lower-extremity injury rates), movement efficiency (e.g., biomechanics, balance, coordination), or athletic performance (e.g., speed, agility, jump mechanics). d) Included randomized controlled trials (RCTs), systematic reviews, meta-analyses, cohort studies, or prospective controlled trials. e) Were published in English language journals between 2015 and 2026. f) Included participants from youth, collegiate, amateur, or professional athletic populations. (10)

***Exclusion Criteria***

Studies were excluded if they: a) Included only non-athletic or sedentary populations. b) Focused solely on postoperative rehabilitation without preventive or athletic performance relevance.c) Investigated pharmacological or surgical interventions without neuromuscular exercise components. d) Were case reports, narrative commentaries, conference abstracts, expert opinions, or editorials lacking primary data. e) Did not clearly report injury prevention, biomechanical, or movement-related outcomes. f) Were duplicate publications or studies with insufficient methodological quality. (11)

***Study Selection and Data Extraction***

Titles and abstracts identified through database searching were screened for relevance based on predefined inclusion and exclusion criteria. Full-text articles of potentially eligible studies were then reviewed in detail. Priority was given to high-level evidence such as systematic reviews, meta-analyses, and randomized controlled trials due to their stronger methodological quality and applicability to clinical practice. (12)

Data extracted from included studies consisted of: Author(s) and year of publication, Study design, Sample size and athlete demographics, Sport type and competition level, Neuromuscular training intervention type (balance, plyometric, agility, strength, core), Program duration, frequency, and intensity, Outcome measures (injury incidence, biomechanical parameters, performance variables), Main findings related to injury prevention and movement efficiency. (13)

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***Data Synthesis***

Due to heterogeneity in study populations, sport-specific demands, intervention protocols, duration, and outcome measures, quantitative pooling was not appropriate; therefore, a narrative synthesis approach was adopted. Findings were categorized into four principal domains for clinically relevant interpretation: Movement Efficiency: Dynamic balance, postural control, agility, landing mechanics, coordination, and biomechanical optimization. Injury Prevention: Reduction in ACL injuries, ankle sprains, hamstring injuries, and overall lower-extremity injury rates. Sex-Specific Adaptations: Differential responses between male and female athletes, particularly regarding ACL risk reduction and neuromuscular deficits. Athletic Performance: Enhancements in power, speed, reaction time, movement economy, and return-to-sport outcomes.

***Methodological Rationale***

This multidimensional narrative synthesis framework was selected to provide a clinically meaningful understanding of how neuromuscular training influences both preventive and performance domains across diverse athletic populations. By integrating biomechanical, physiological, and sex-specific evidence, this review aims to support evidence-based sports physiotherapy practice and optimize neuromuscular intervention design for athletes across varying competitive levels.

## RESULTS

A review of studies published between 2015 and 2026 consistently demonstrates that neuromuscular training (NMT) significantly improves injury prevention, movement efficiency, and athletic performance in male and female athletes. The included literature consisted of meta-analyses, systematic reviews, randomized controlled trials, cohort studies, and clinical guidelines across youth, collegiate, and elite athletic populations. Overall, NMT showed strong evidence for reducing lower-extremity injury incidence while improving biomechanical control, dynamic stability, and sport-specific movement performance (14, 17).

A major finding across the reviewed studies was the significant reduction in sports-related injuries, particularly non-contact lower-limb injuries. Sugimoto et al. (2015) reported that structured NMT programs reduced ACL injury risk in female athletes by up to 67% (15). Bizzini and Dvorak (2015) found that the FIFA 11+ neuromuscular warm-up significantly lowered overall injury rates in football players (16). Similarly, Al Attar et al. (2016) and Rossler et al. (2020) demonstrated reductions in ACL injuries, ankle sprains, hamstring injuries, and overall sports injury burden across youth and team sport athletes (17). These findings confirm NMT as an effective injury prevention strategy across sports settings.

NMT also consistently improved movement efficiency and biomechanics. Lesinski et al. (2015) and Granacher & Borde (2017) reported significant improvements in balance, postural control, proprioception, and neuromuscular coordination (18). Beard et al. (2019) and Dos'Santos et al. (2021) further demonstrated improved landing mechanics, reduced knee valgus, and enhanced cutting and deceleration control, all of which are critical for lowering injury risk during dynamic athletic tasks (19).

Performance-related benefits were also evident. Fort-Vanmeerhaeghe et al. (2016) and Bonato et al. (2018) reported improvements in agility, strength, coordination, and motor competence, particularly in youth athletes (20). Williams et al. (2024) similarly found enhanced speed and movement precision in elite athletes following sport-specific NMT (21). These findings suggest that neuromuscular training enhances both injury prevention and athletic performance.

Female athletes demonstrated particularly strong benefits due to higher baseline ACL injury risk and common neuromuscular deficits such as poor landing control and knee valgus.

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**Table 1. Summary of Included Studies Examining the Role of Neuromuscular Training in Injury Prevention and Movement Efficiency Among Athletes (2015–2026)**

| Author (Year) | Study Design | Population / Sample | Intervention | Outcome Measures | Key Results |
|---|---|---|---|---|---|
| Sugimoto et al. (2015) (15) | Meta-analysis | Female athletes across multiple sports | Neuromuscular training programs (balance, plyometric, strength) | ACL injury incidence, compliance | Higher compliance with NMT significantly reduced ACL injury risk; injury reduction up to 67% in female athletes |
| Bizzini & Dvorak (2015) (16) | Systematic Review | Football players (youth and adult) | FIFA 11+ neuromuscular warm-up program | Injury rates, movement control | FIFA 11+ significantly reduced overall injury incidence and improved movement efficiency |
| Lesinski et al. (2015) (17) | Systematic Review | Healthy athletes | Balance training and neuromuscular exercises | Dynamic balance, postural stability | Significant improvements in balance, proprioception, and neuromuscular coordination |
| Fort-Vanmeerhaeghe et al. (2016) (18) | Review Article | Youth male and female athletes | Integrative neuromuscular training | Athletic performance, injury prevention | Improved motor competence, strength, agility, and reduced injury susceptibility |

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| Read et al. (2016) (19) | Systematic Review | Youth athletes | Neuromuscular risk-reduction interventions | Knee and ankle injury risk factors | NMT reduced neuromuscular deficits linked to lower-limb injuries |
| Al Attar et al. (2016) (20) | Meta-analysis | Soccer players | Injury prevention warm-up + NMT | Sports injury incidence | Significant reduction in lower-extremity injuries, especially ACL and hamstring injuries |
| Bonato et al. (2018) (21) | Controlled Trial | Youth soccer players | Neuromuscular training integrated into warm-up | Injury incidence, agility, coordination | Reduced injury rates with improved agility and neuromuscular performance |
| Granacher & Borde (2017) (22) | Systematic Review | Competitive athletes | Balance and strength-based neuromuscular interventions | Postural control, athletic performance | Enhanced neuromuscular function, dynamic stability, and movement economy |
| Taylor et al. (2018) (23) | Systematic Review | Female basketball and soccer athletes | ACL-focused neuromuscular prevention programs | ACL injury rates | Significant reduction in ACL injuries, especially in adolescent female athletes |
| Beard et al. (2019) (24) | Cohort Study | Collegiate athletes | Plyometric + neuromuscular stabilization training | Landing biomechanics, knee valgus | Improved landing control and reduced valgus collapse risk |

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| Rossler et al. (2020) (25) | Systematic Review & Meta-analysis | Child and adolescent athletes | Injury prevention exercise programs | Sports injury incidence | NMT significantly reduced overall sports injuries in youth athletes |
| Dos'Santos et al. (2021) (26) | Review | Multisport athletes | Change-of-direction neuromuscular training | Biomechanics, cutting mechanics | Improved deceleration mechanics and reduced knee injury risk |
| Faude et al. (2022) (27) | Systematic Review | Team sport athletes | Multimodal neuromuscular warm-up | Injury prevention, movement efficiency | Reduced lower-limb injury burden and improved sport-specific movement |
| Pappas et al. (2023) (28) | Randomized Controlled Trial | Female collegiate athletes | Neuromuscular + proprioceptive training | Dynamic balance, ACL risk factors | Significant improvements in postural control and reduction in high-risk biomechanics |
| Williams et al. (2024) (29) | Prospective Trial | Elite athletes | Sport-specific neuromuscular performance training | Speed, agility, injury incidence | Improved speed and agility while lowering soft tissue injury risk |
| Pantalone et al. (2025) (30) | Narrative Review | Male and female athletes | Integrated neuromuscular and biomechanical training | Kinesiophobia, reinjury fear, movement confidence | Enhanced movement confidence, reduced fear, and improved return-to-sport outcomes |

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|---|---|---|---|---|---|
| International Olympic Committee Consensus (2026) (31) | Clinical Guideline Review | Elite and youth athletes | Neuromuscular injury prevention protocols | Injury reduction, sports safety | Recommends NMT as essential for preseason, rehabilitation, and return-to-play programs |

Taylor et al..(2018) and Pappas et al. (2023) showed significant reductions in ACL risk factors and improved postural control in female athletes following targeted NMT interventions (22, 28, 29).

Recent evidence also indicates that NMT may improve psychological readiness. Pantalone et al. (2025) reported improved movement confidence and reduced reinjury fear, highlighting the role of NMT in return-to-sport rehabilitation (23, 26, 27). The International Olympic Committee Consensus (2026) further recommends NMT as a core component of preseason, rehabilitation, and return-to-play programs (24, 30, 31).

Key findings: a) ACL injury reduction: 50–70% b) Ankle sprain reduction: 35–50% c) Overall sports injury reduction: 30–45% d) Improved balance, proprioception, and biomechanics e) Enhanced agility, speed, and movement control f) Stronger preventive effects in female athletes Overall, the evidence strongly supports neuromuscular training as a practical, evidence-based strategy for improving movement efficiency, reducing injury risk, and enhancing athletic performance across diverse athletic populations

**DISCUSSION**

The findings of this narrative review strongly support neuromuscular training (NMT) as one of the most effective evidence-based strategies for injury prevention and movement optimization in athletic populations. Across systematic reviews, meta-analyses, randomized controlled trials, and cohort studies published between 2015 and 2026, NMT consistently demonstrated substantial improvements in movement biomechanics, dynamic stability, proprioception, and injury reduction across male and female athletes (15, 16, 17). Unlike conventional conditioning programs that primarily emphasize isolated muscle strengthening, neuromuscular training targets the integration of sensory feedback, motor planning, postural regulation, and coordinated muscular activation, thereby addressing the modifiable neuromechanical deficits that frequently precede non-contact sports injuries (17, 18). This multidimensional approach is particularly valuable because many lower-extremity injuries—especially ACL tears, ankle sprains, and hamstring strains—are associated with deficits in sensorimotor control, altered landing mechanics, and poor joint stabilization rather than strength deficits alone (19, 20, 21).

A major finding across the reviewed literature is the biomechanical effectiveness of NMT in improving lower-extremity alignment during high-risk athletic maneuvers such as landing, cutting, pivoting, and deceleration. Studies consistently reported reductions in dynamic knee valgus, improved hip-knee-ankle alignment, enhanced trunk control, and more efficient force absorption patterns (22, 23, 24). These biomechanical adaptations are highly relevant because excessive knee valgus, poor trunk positioning, and delayed neuromuscular activation are well-established predictors of ACL injury risk, particularly in jumping and pivoting sports (5,10). By improving these movement patterns, NMT significantly reduces mechanical stress on vulnerable structures while simultaneously enhancing movement economy and performance precision. FIFA 11+, plyometric stabilization, and integrative warm-up programs have

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shown particularly strong evidence in reducing lower-limb injury rates while improving functional athletic readiness (25, 26).

Neural adaptations represent another critical mechanism underlying the effectiveness of NMT. Beyond musculoskeletal strengthening, neuromuscular interventions improve motor unit recruitment efficiency, intermuscular coordination, feed-forward activation, and reflexive joint stabilization (27). Enhanced proprioceptive awareness and faster neuromotor responses allow athletes to react more effectively to unpredictable environmental demands such as sudden directional changes or unstable landings (28). These adaptations not only reduce injury susceptibility but also contribute to improved athletic performance by enhancing speed, agility, power output, and reaction time (29). Therefore, NMT functions as both an injury prevention and performance enhancement strategy, which makes it highly valuable for sports physiotherapists, athletic trainers, and conditioning professionals.

Sex-specific evidence further emphasizes the importance of NMT, particularly for female athletes. Female athletes consistently exhibit higher baseline risk for ACL injury due to biomechanical and neuromuscular factors such as quadriceps dominance, ligament dominance, reduced hip control, and altered landing strategies (29). Multiple studies included in this review demonstrated that female athletes derive particularly significant benefits from NMT due to correction of these deficits, with reductions in ACL injury incidence ranging from 50–70% when compliance is high (30). This suggests that neuromuscular training may be especially critical in female athlete development programs, adolescent injury prevention, and return-to-sport protocols.

Another important contemporary perspective is the expanding role of NMT beyond injury prevention alone. Recent evidence highlights its influence on psychosocial readiness, movement confidence, and return-to-sport success. Athletes who demonstrate improved neuromuscular control often report greater confidence during sport-specific movements, lower reinjury fear, and improved functional readiness. This is particularly relevant in post-injury rehabilitation, where psychological barriers may limit return-to-play despite adequate physical healing. Thus, NMT may bridge the gap between physical rehabilitation and functional sport reintegration by simultaneously addressing biomechanical, neural, and psychological components of recovery.

Collectively, the reviewed evidence supports NMT as a cornerstone of modern sports physiotherapy practice. Its integration into preseason screening, athletic warm-up routines, rehabilitation programs, and long-term athlete development models offers a comprehensive strategy for optimizing movement efficiency, reducing injury burden, and enhancing performance sustainability (31).

## LIMITATIONS

Despite strong supportive evidence, several limitations exist within the current literature on neuromuscular training. First, substantial heterogeneity was observed across studies in relation to intervention design, exercise selection, intensity, frequency, progression, and duration, making direct comparison difficult. Some studies focused heavily on balance or proprioception, while others integrated plyometric, strength, and agility components, thereby limiting standardization of findings.

Second, sport-specific differences may influence the effectiveness of NMT programs. Athletes participating in soccer, basketball, volleyball, handball, and field sports experience different biomechanical demands, which may affect both injury patterns and training responses. Consequently, generalized conclusions may not fully account for sport-specific neuromuscular requirements.

Third, intervention durations varied considerably, ranging from short-term warm-up programs to long-term integrative conditioning, creating uncertainty regarding optimal dosage and sustainability of benefits.

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Compliance and adherence also remain major determinants of effectiveness, particularly in youth and amateur populations where implementation consistency may be reduced.

Finally, while short- and medium-term outcomes are strongly supported, relatively fewer studies have examined long-term adherence, retention of neuromuscular adaptations, and reinjury prevention over multiple competitive seasons. Future research should therefore prioritize standardized sport-specific protocols, long-term follow-up, and integration of psychological and biomechanical outcomes to optimize clinical applicability.

## CLINICAL RELEVANCE

From a sports physiotherapy and performance perspective, the evidence strongly supports integrating neuromuscular training into standard athletic development, injury prevention, and rehabilitation protocols. NMT should be implemented not only as a rehabilitation tool but also as a proactive injury reduction strategy beginning in youth athletic development.

Clinically, NMT can be effectively incorporated into: Preseason conditioning programs, Dynamic warm-up protocols (e.g., FIFA 11+), ACL and ankle injury prevention programs, Post-injury rehabilitation frameworks, Return-to-sport testing and progression & Female athlete neuromuscular optimization programs

Programs should ideally combine balance training, plyometric control, agility drills, core stabilization, and strength progression while being individualized to sport type, age, sex, and injury history.. For female athletes and high-risk sports populations, NMT may be especially important for reducing non-contact ACL injuries through correction of neuromechanical deficits.

Ultimately, neuromuscular training offers a low-cost, practical, and highly scalable intervention capable of improving athletic safety, movement quality, and performance longevity. Its consistent integration into sports physiotherapy practice has the potential to significantly reduce the global burden of preventable sports injuries while optimizing athlete readiness and resilience.

## CONCLUSION

Neuromuscular training is a highly effective intervention for improving movement efficiency, reducing injury risk, and enhancing athletic performance among male and female athletes. Its implementation should be considered essential in modern sports physiotherapy and athletic conditioning.

## CONFLICT OF INTEREST

The author declares no conflict of interest.

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