International Journal of Innovative Research in Medical Science (IJIRMS)
Volume 10, Issue 06, June 2025,
https://doi.org/10.23958/ijirms/vol10-i06/2079

Systematic Review

Neuromuscular Rehabilitation in the Prevention of Anterior Cruciate Ligament Injury in Children and Adolescents

Manuel Pina Câmara *[1], **João Páscoa Pinheiro, MD, PhD** [1], **Pedro Figueiredo, MD, PhD** [1,2], **João Paulo Branco, MD, PhD** [1,2]

[1]Faculdade de Medicina, Universidade de Coimbra, Portugal.
[2]Serviço de Medicina Física e Reabilitação - Unidade Local de Saúde de Coimbra, Portugal.

*Corresponding author: Manuel Pina Câmara; *manuelcamara31@outlook.com*

Received: 19 April 2025; Accepted: 25 May 2025; Published: 05 June 2025

Abstract

Introduction: Knee injuries are increasingly common in the pediatric population, with anterior cruciate ligament (ACL) ruptures standing out due to their rising incidence in children and adolescents. These injuries are associated with significant clinical and functional consequences, such as the need for surgical intervention, lengthy rehabilitation, low return-to-sport rates, high re-injury risk, and early-onset osteoarthritis. They may also impact school performance. This study aims to evaluate the effectiveness of neuromuscular training (NMT) programs in preventing ACL injuries in young populations and to identify the most effective protocols, components, and contributing factors. ***Methods:*** A systematic review was conducted following PRISMA guidelines using PubMed, Embase, and Web of Science, covering studies from 2014 to 2024. The selection followed the PICO framework, focusing on individuals under 18 years old receiving neuromuscular or proprioceptive training, compared to control groups or studies analyzing biomechanical risk factors. Only peer-reviewed articles in English or Portuguese were included. Two independent reviewers screened studies, extracted data, and assessed quality. Outcomes evaluated were ACL injury incidence and biomechanical risk factors. ***Results:*** Of the 64 initially identified articles, 9 met the inclusion criteria3 systematic reviews and 6 original studies. The systematic reviews highlighted significant reductions in ACL injury rates and emphasized the influence of sport type and external factors. The original studies reported improvements in neuromuscular and biomechanical control following NMT protocols. ***Conclusions:*** NMT was shown to be effective, particularly when introduced early in youth. Key factors for successful implementation include exercise variety, sensory feedback, and professional supervision. Additionally, unstructured play may contribute to natural protective adaptations. Future research should refine and personalize preventive strategies.

Keywords: ***Neuromuscular training, Proprioception, Anterior Cruciate Ligament injury, Children, Adolescents, Prevention.***

1. Introduction

Knee injuries are becoming an increasing type of injury in paediatric age where ACL injuries stand out, with knee ligament injury being the most common in this population [1-3]. In addition, ACL injury has increased in prevalence in children and adolescents compared to adulthood [4].

ACL injury has both short, and long-term consequences. Initially, almost 80% is followed by reconstructive surgery that later leads to a long period of rehabilitation, requiring an average of 1 year leave [1,5]. Although 82% return to sports, only 55% of athletes return to competitive sports, and most do not reach their previous performance levels [4-6]. In addition, there is a risk of approximately 10% of new ACL injury, reaching 20% in athletes who resume sport at the same competitive level [5]. On the other hand, in the long term, the patient's prognosis is poor, since there is a 4-fold increase in the risk of arthrosis [4,5,7].

In addition, in these age groups, most or all of the population will be in some student group, and, consequently, in which academic success can be influenced by several factors, an injury with such an impact as that of the ACL is associated with a decrease in school performance [4].

Consequently, it is of enormous importance to find prevention methods in this at-risk population.

An injury with such a high incidence has numerous risk factors, which can be grouped by modifiable or non-modifiable [8], whether proprioceptive control, Body Mass Index, or agents that cannot be changed, such as age, gender or hormone levels. However, ACL injury is clearly associated with decreased neuromuscular control [9].

Neuromuscular training is already recognized as a strong component of reducing the risk of injury [10]. In short, neuromuscular training aims to develop essential components such as motor coordination, joint stability during dynamic movement, generate rapid and optimized muscle activation and at the same time reduce the impact on joint areas [1], of which are crucial for performing movements and preventing injuries. In this way, it enhances the body's ability to respond more efficiently to stimuli. Regarding the knee, some types of training can include balance, plyometrics, strength and postural control exercises. The main objective would be to improve or change certain risk behaviors/movements that are already universally recognized as factors that increase the risk of ACL injury, such as increased valgus movement of the knee [6,9,11], presence of asymmetrical load movements, decreased knee or hip flexion [12], decreased chorus stability, heel landing, decreased hip abduction force [13].

Thus, the aim of this study is to present the impact of neuromuscular training, which belongs to the group of modifiable parameters [8], in a training applied to the paediatric population, and finally compare with recent systematic reviews.

2. Methods

This systematic review was conducted in accordance with the PRISMA guidelines and structured using the PICO framework to ensure transparency, reproducibility, and clinical relevance of the included studies. The methodology was implemented through several stages: definition of eligibility criteria, development of a search strategy, selection of relevant studies, and subsequent data extraction and evaluation of the level of evidence.

2.1. Eligibility Criteria

Eligibility criteria were established using the PICO framework and additional considerations:

- Population (P): Children and adolescents (under 18 years of age).
- Intervention (I): Neuromuscular and proprioceptive training programs.
- Comparison (C): Control groups or studies analyzing biomechanical risk factors [3].
- Outcomes (O): Incidence of anterior cruciate ligament (ACL) injuries and/or biomechanical risk factors associated with injury prevention.

2.2. Search Strategy

Firstly, the databases to be used for the literature search were defined. Subsequently, the strategy combined Medical Subject Headings (MeSH), EMTREE terms, and keywords using the Boolean operators AND and OR, ensuring both breadth and precision in identifying relevant studies. Based on this approach, three search equations were developed to maximise the comprehensiveness and quality of the search process.

2.2.1. Databases Searched

The following electronic databases were searched for studies published between 2014 and 2024:

- PubMed
- Embase
- Web of Science

2.2.2. Search String

The search terms were categorized into three main groups: ACL injury prevention, neuromuscular/proprioceptive training, and the target population (children and adolescents) for each of the databases. A representative search string for PubMed, Web of Science and Embase was structured as in table 1.

Table 1: Search String

PubMed	Web of Science	Embase
("Anterior Cruciate Ligament Injuries/prevention and control" OR "anterior cruciate ligament injury prevention" OR "ACL injury prevention") AND ("Child" OR "Adolescent" OR "pediatric" OR child OR adolescent) AND ("Proprioception" OR "proprioceptive training" OR "neuromuscular training")	"Anterior Cruciate Ligament injur*" OR "ACL injur*" OR "ACL tear*" OR "ACL rupture*" OR "ACL sprain*" OR "knee ligament injur*" (Topic) and child* OR adolescent* OR pediatric* (Topic) and Proprioception* OR "proprioceptive training" OR "neuromuscular training" (Topic) and prevent* OR "injury prevention" OR "risk reduction" OR "Injury protection" OR "Injury prophylaxis" (All Fields)	'child'/exp OR 'adolescent'/exp OR 'pediatric'/exp) AND ('neuromuscular training'/exp OR 'proprioception'/exp OR 'proprioceptive training'/exp) AND 'anterior cruciate ligament injury'/exp/dm_pc

2.2.3. Grey Literature

Grey literature sources such as clinical trial registries, conference abstracts, and dissertations were not included, in order to focus on peer-reviewed, high-quality research.

2.3. Study Selection

The selection process was carried out in multiple phases to ensure methodological rigour. Initially there was a screening process using inclusion and exclusion criteria and then full-text evaluations were performed.

2.3.1. Screening Process

Two independent reviewers conducted the initial screening of studies based on title and abstract, according to the established inclusion criteria.

Inclusion Criteria

- Studies published in English or Portuguese, with full-text availability;
- Publication within the last 10 years;
- Participants under 18 years of age;
- Implementation of neuromuscular/proprioceptive training programs;
- Comparison with a control group or analysis of biomechanical risk factors;
- Outcomes focused on the incidence of ACL injury or associated risk factors.

Exclusion Criteria

- Studies involving participants with other knee injuries;
- Studies without clear reference to the target age population;
- Studies on post-injury or re-injury prevention of ACL injuries;
- Opinion articles, umbrella reviews, or articles published in non-eligible languages.

2.3.2. Full-Text Review

Full texts of the selected studies were reviewed by two independent reviewers. Any disagreements were resolved by discussion, and a third reviewer was consulted when necessary.

2.3.3. PRISMA Flow Diagram

A PRISMA flow diagram was used to illustrate all phases of the study selection process, from initial identification to final inclusion, shown in figure 1.

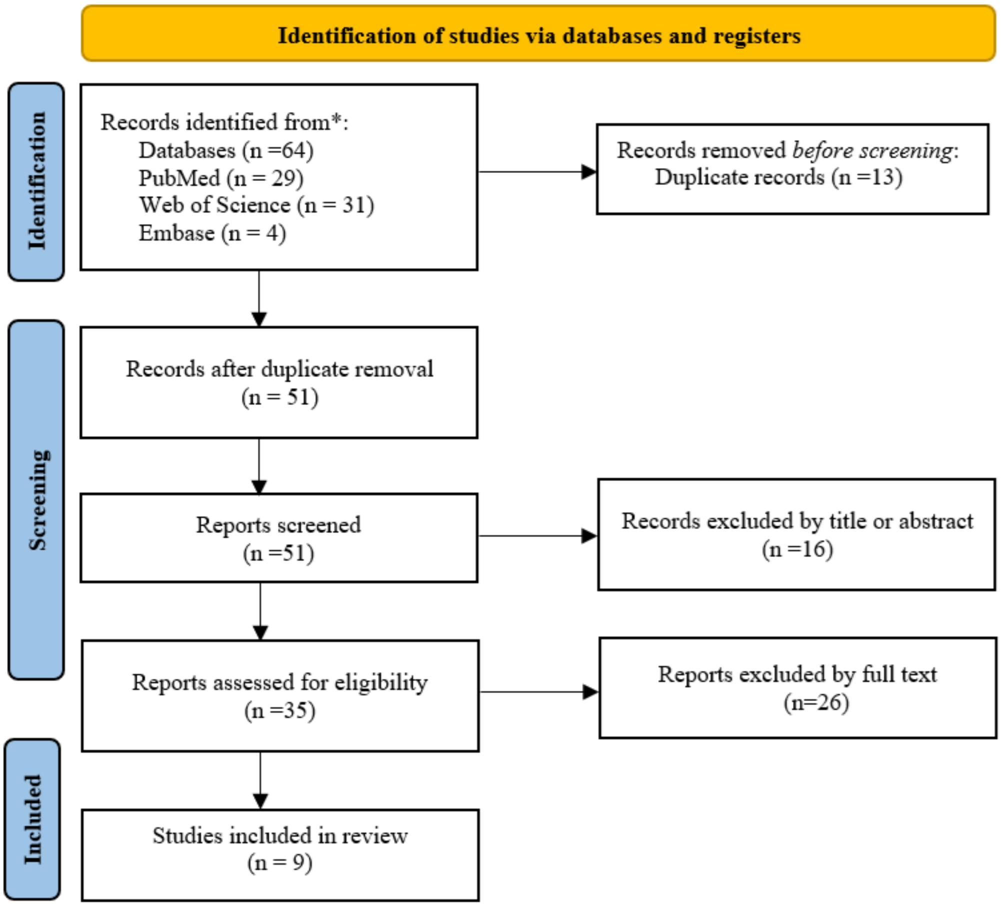

Figure 1: Search strategy and selection of studies for inclusion in the systematic review.

2.4. Data Extraction and Synthesis

Data extraction was conducted independently by two reviewers using a standardized form to ensure consistency and reliability.

2.4.1. Extracted Data

The following data were extracted from each included study:

- Study Characteristics: Authors, year of publication, country, study design.
- Population Details: Sample size, age, gender distribution.
- Intervention Details: Type, structure, duration, frequency, and components of the neuromuscular training program.
- Comparison Details: Description of control or comparison group.
- Outcome Measures: Incidence of ACL injuries, changes in biomechanical risk factors, effectiveness in injury prevention.

2.5. Evidence Classification and Ethical Issues

To address the variability in methodological quality among the selected studies, a structured evaluation of their evidentiary strength was conducted. using the Centre for Evidence-Based Medicine (CEBM) for Therapeutic Studies, which ranks evidence on a scale from level 1A (highest reliability) to level 5 (lowest). The resulting categorization of the studies is presented in Tables 1 and 2. As this review exclusively analysed data already available in the literature, it did not require ethical approval.

2.6. Study Characteristics

The characteristics of the studies included in this review are detailed in Table 3. The studies analysed were published between 2014 and 2024, including three from the United States, one from Canada, one from Spain, and one from Sweden.

Regarding methodological design, the sample includes two randomized clinical trials, two randomized controlled clinical trials, one cohort study, one retrospective cohort study, and three systematic reviews.

The number of participants in the studies ranged from 18 to 27,335. Three of the studies included only female participants, one focused on male participants both with an emphasis on football while the remaining two included adolescents of both sexes.

Various neuromuscular interventions were implemented across the different articles. Two studies used augmented neuromuscular training (aNMT), one reported the implementation of ACL injury prevention protocol (ACL-IPP), another used injury prevention exercise programme (IPEP) or IPEP, Knee Control+, and finally, one study used perturbation-based neuromuscular training as an intervention.

The retrospective study evaluated various aspects, including gender, type of sport practiced, school location (urban or rural), types of neuromuscular training (NMT) performed, and the influence of these variables on the incidence of ACL injury.

The effectiveness of the interventions was assessed using different methodologies. Three studies used the Drop Vertical Jump (DVJ), two of which assessed pKAM and one evaluated knee alignment through video analysis. This same study also included the Tuck Jump Assessment (TJA). Additionally, one study used the

Single-Leg Squat (SLS) test to assess Dynamic Knee Valgus (DKV), another analyzed the prevalence of ACL injuries in the study population, and one employed the Y-Balance Test (YBT).

Regarding the age range of participants, the average age varied between 12.51 and 16.2 years. Only one study specified that the participants were high school students, without detailing the exact age.

Three types of systematic reviews were included and are explicit in table 2. These analyzed: effective NMT programs for reducing ACL injuries in adolescent female athletes, common and effective components of these programs with the development of a checklist-style tool to assess program quality and the comparison of different NMT programs to determine which is most effective for ACL injury prevention.

3. Results

The following section presents the main result from the studies included in this systematic review.

The results are summarised in tabular format to provide a clear overview of the study characteristics, objectives, populations, interventions, and main conclusions.

Table 2: Systematic Reviews Characteristics and Conclusions

Study	Year/ Country	Study design	Main objective	Main conclusions	Sex	Level of evidence
Noyes *et al* [7]	2014- USA	Systematic review	Identify TNM programs that are effective in reducing ACL injuries.	Sportsmetrics, PEP, and KIPP have shown efficacy. Adherence to the program is crucial for success.	Female only	II
Petushek *et al* [5]	2019- USA	Systematic review and meta-analysis	Identify effective components and create a checklist to guide TNM programs.	Significant reduction in the risk of injury (OR=0.51). Greatest benefit in <18 years old and in basketball, football and handball sports. More effective exercises include lunges, nordic hamstrings, and drop landings. Qualified supervision improves results.	Female only	Ia
Willadsen *et al*[8]	2019- USA	Systematic review	Determine which types of training are most effective in preventing ACL injuries.	Plyometric, balance, and neuromuscular workouts are effective. Core training can have mixed benefits. Recommends training 2–3x per week for ≥4 weeks, with verbal feedback.	Female only	IIb

Table 3: Studies Characteristics

Study	Year/ country	Study Design	Number of participants/ Sex	Age	Intervention	Evidence level
García-Luna *et al* [11]	2020- Spain	Experimental crosseover study	18 football players- Male	12,51 ± 0,87 years	ACL-IPP (warm-up)	IIb
Lindblom *et al* [6]	2019- Sweden	Cluster-Randomized Controlled Trial	158 divided into: 4 teams of girls 4 teams of boys	14.1 ± 0.8 years- Male=47 and Female=27	IPEP or a IPEP, Knee Control +, for 8 weeks for 2/3 times a week	Ib
Murray *et al* [4]	2017- USA	Retrospective cohort study	27 335 students- Male and female	High school	-	IIb
Grooms *et al* [12]	2017- USA	Cohort Study	20 from High school- Female	Intervention and control groups: 15.7 ± 1.06 years; 16.2 ± 0.63 years	aNMT with real-time biofeedback- 6 weeks 3x per week	IIb
Diekfuss *et al* [9]	2020- USA	preliminary longitudinal investigation	30 participants- Female	Control and intervention groups: 16.2 years; 15,7	aNMT with real-time biofeedback- 6 weeks 3x per week	IV
Bulow *et al* [1]	2021- Canada	Randomized Controlled Trial	24 participants- Female	Control and intervention groups: 13.9 ± 1.1; 14.3 ± 1.5	perturbation-based neuromuscular training	Ib

Characteristics of the Neuromuscular Training and each evaluation

From the 6 articles found table 4 describes each training methodology and the evaluation that proceeded and lead to the results wich be discussed in the following chapter.

Table 4: NMT Protocols and their Evaluation Method

Intervention	Duration	Description	Evaluation
ACL-IPP	warm up- 5 min before the assessment	- Pre-workout warm-up protocol with neuromuscular and proprioceptive exercises for gluteus medius.- Exercises: *knee band squat* (10 reps), *side-steps* (10/side), *Bulgarian split* (5/leg).- Applied only to participants with moderate/severe KD.	SLS:- DKV assessment (maximum tibiofemoral angle vs. Q-angle (anatomical reference value).- Classification: mild (δ ≤ 16.2°), moderate (16.3° ≤ δ ≤ 32.4°), severe (δ ≥ 32.5°).- Pre and post-intervention assessment.

IPEP and IPEP Knee Control+	8-week program, 2-3 sessions/week (11-18 sessions).	- Exercises: single-leg squats, plank, lunges, jump/landing technique.- 4 levels of difficulty, with training partner. - IPEP Knee Control +: Advanced version of IPEP, with 6-10 levels of progressive difficulty.- No training partner.	DVJ: Analysis of knee alignment (T1, T2, T3) via video. TJA: Subjective evaluation of 10 technical criteria during repeated jumps.
aNMT	6-week program (3x/week; 18 sessions).	- Exercises: plyometrics, core, balance, *squat*, *pistol squat* (3x10/5 repetitions) with visual biofeedback.	pKAM:- Biomechanical evaluation during DVJ. RM: Analysis of brain activity *during exercises* (knee extension alone vs. *leg press* with resistance).
aNMT	6-week program (3x/week; 18 sessions).	- Exercises: plyometrics, core, balance, *squat*, *pistol squat* (3x10/5 repetitions) with visual biofeedback.	pKAM: Biomechanical evaluation during DVJ. RM: Analysis at rest, pre/post-intervention, focusing on ROIs (regions of interest).
Perturbation-based NMT	5 weeks (2x/week; 10 sessions)- Progression: initial phase (sessions 1-4), intermediate (5-7), final (8-10).	- exercises: Balance and posture using unstable platforms (Rockerboard/Rollerboard) and unpredictable stimuli (balls).	YBT: Measurement of reach in 3 directions (anterior, posteromedial, posterolateral). Normalization by leg length.

4. Discussion

The studies included demonstrated significant methodological heterogeneity, both in the interventions assessed and, in the outcomes, measured. Therefore, a narrative synthesis was conducted.

Grooms *et al*. and Diekfuss *et al*. found a significant reduction in pKAM following aNMT, with p-values of 0.02 and 0.03, respectively. Grooms *et al*., using fMRI during isolated knee extension-flexion, observed activation in brain areas related to proprioceptive-visual integration and motor control. Diekfuss *et al*. reported increased connectivity between the right cerebellum and thalamus, and between the supplementary motor area and contralateral thalamus key regions in movement initiation and motor regulation. Both studies concluded that reduced pKAM was associated with activation in these neural regions (p=0.036 and p=0.029).

Interestingly, there was reduced activation in the primary motor and somatosensory cortices during a multijoint leg-press, suggesting improved motor coordination and efficiency although no significant reduction in pKAM was observed in this task (p=0.38). The authors proposed that these changes reflect neuromuscular adaptations via neuroplasticity, supporting the optimization of prevention strategies by targeting specific brain regions. Real-time visual biofeedback may enhance sensorimotor integration and promote safer biomechanics. Early interventions, particularly in younger individuals with greater neuroplastic potential, appear to be especially effective.

Bullow *et al* found no significant effect of perturbation-based neuromuscular training in adolescent females compared to controls using the YBT test, though both groups improved over time, possibly due to test familiarization. Limitations included using a protocol validated for adults and small sample size. The results suggest that mere exposure to novel motor tasks may stimulate neuromuscular adaptations, reinforcing the value of varied physical experiences during adolescence. Moreover, it is recommended that, for children, less emphasis be placed on structured and highly supervised activities such as neuromuscular training and more on free, unstructured play, away from screens. This type of play fosters creativity, provides emotional release, and supports healthy motor, cognitive, and social development [14,15].

Lindblom *et al*. showed that boys had superior baseline neuromuscular control, but only girls significantly improved post-intervention, particularly in knee flexion angle during landing tasks and reduced TJA errors. These findings support the idea that individuals with greater initial neuromuscular deficits benefit most from targeted interventions. The study also highlighted the need for sex-specific and performance-level-tailored approaches and noted limitations due to the lack of a control group and biomechanical data resolution.

Garcia-Luna *et al*. demonstrated a significant and clinically relevant reduction in dynamic knee valgus (DKV) following a warm-up protocol in both limbs (p=0.007 and p=0.005; d=1.39), with no asymmetry between dominant and non-dominant legs. A negative correlation between age and pre-intervention DKV indicated higher risk in younger athletes, underscoring the need for early prevention. Moreover, the impact of ACL-IPPs may be particularly relevant in younger athletes, as interventions during this developmental stage can promote the acquisition of safer and more efficient long-term patterns. The authors also suggest incorporating these programs into warm-up routines, especially when combined with longer protocols. This approach may yield exponential benefits, particularly when using evidence-based programs with proven efficacy, such as those highlighted by García-Luna *et al*., Grooms *et al*., Diekfuss *et al*., and in the review by Noyes *et al*., which identified Sports metrics, PEP, and KIPP as the most effective protocols in this population. Despite the promising results, limitations included small sample size and the absence of power analysis.

Murray *et al*. conducted a retrospective study showing that strength and plyometric training significantly reduced ACL injury risk in male athletes. However, NMT appeared to increase injury risk in female volleyball players contradicting several other studies (e.g., Noyes, Grooms, Diekfuss, Bullow). These findings highlight the complexity of intervention outcomes depending on sex, sport, and environmental factors.

Across the systematic reviews referenced, neuromuscular training consistently emerged as an effective ACL injury prevention strategy especially in youth. Notably, studies by Grooms and Diekfuss supported the neuroplasticity link, strengthening the rationale for early NMT implementation. While some protocols (e.g., Sports metrics, PEP, KIPP) were more commonly identified as effective, the overall success seems to stem from the inclusion of diverse and engaging movement experiences. Murray *et al*.'s finding that female soccer teams in rural settings had lower injury rates (despite similar exposure levels) may suggest that varied, playful, and spontaneous motor experiences have a protective effect by enhancing neuromuscular control.

In children, promoting unstructured play especially outdoors should be a priority, as the variability inherent in spontaneous motor and play activities (through unpredictable movements and constantly changing situations) can lead to more effective neuromuscular adaptations. This type of stimulation enhances motor learning and better prepares young athletes to respond efficiently to the varied demands of sports practice [14-16]. However in adolescents, however, a more structured implementation of NMT may prove more effective, particularly in individuals with increased risk factors, given its demonstrated efficacy in injury prevention.

5. Conclusion

The studies reviewed reinforce the evidence that early NMT plays a crucial role in preventing ACL injuries in children and adolescents. Despite methodological differences and generally low levels of evidence due to previously discussed limitations, there is a consistent trend showing neuromuscular and biomechanical benefits across various training approaches. The enhanced neuroplasticity typical of this age group likely amplifies the training effects, particularly in those with more pronounced technical or neuromuscular deficits.

While the existing studies have limitations, they indicate that NMT is an effective and promising strategy for reducing ACL injury risk. At the same time, unstructured play is vital for developing proprioceptive and neuromuscular skills in children, whereas structured NMT remains essential during adolescence.

Future research should aim to isolate the effects of specific training components, include more representative populations, and investigate external factors to optimize preventive programs.

List of abbreviations

ACL: Anterior Cruciate Ligament
NMT: Neuromuscular Training
aNMT: Augmented Neuromuscular Training
ACL-IPP: Anterior Cruciate Ligament Injury Prevention Protocol
IPEP: Injury Prevention Exercise Programme
DVJ: Drop Vertical Jump
TJA: Tuck Jump Assessment
SLS: Single-Leg Squat.
DKV: Dynamic Knee Valgus
YBT: Y-Balance Test
pKAM: Peak Knee Abduction Moment
RM: Resting-state fMRI Measurement
fMRI: Functional Magnetic Resonance Imaging
ROI: Region of Interest (brain imaging context)
CEBM: Centre for Evidence-Based Medicine
PEP: Prevent, Injury and Enhance Performance Program
KIPP: Knee Injury Prevention Program
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PICO: Population, Intervention, Comparison, Outcome

Ethics approval and consent to participate

Not applicable

Data Availability

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Funding Statement

The authors confirm that no external funding was received for the research or publication of this article. All publication costs were covered by the authors.

Authors' contributions

MC and JPB selected the articles to be included in the review. MC, JPP, and JPB drafted the manuscript. MC, JPB, JPP, and PF revised and approved the final version of the manuscript.

Acknowledgments

None

6. References

[1] Bulow A, Anderson JE, Leiter JRS, *et al*. Safety and Effectiveness of a Perturbation-based Neuromuscular Training Program on Dynamic Balance in Adolescent Females: A Randomized Controlled Trial. INTERNATIONAL JOURNAL OF SPORTS PHYSICAL THERAPY 2021;16(4):1001-1015, doi:10.26603/001c.25685

[2] Sanders TL, Maradit Kremers H, Bryan AJ, *et al*. Incidence of Anterior Cruciate Ligament Tears and Reconstruction: A 21-Year Population-Based Study. The American Journal of Sports Medicine 2016;44(6):1502-1507, doi:10.1177/0363546516629944

[3] Gianotti SM, Marshall SW, Hume PA, *et al*. Incidence of anterior cruciate ligament injury and other knee ligament injuries: A national population-based study. Journal of Science and Medicine in Sport 2009;12(6):622-627, doi:10.1016/j.jsams.2008.07.005

[4] Murray JJ, Renier CM, Ahern JJ, *et al*. Neuromuscular Training Availability and Efficacy in Preventing Anterior Cruciate Ligament Injury in High School Sports: A Retrospective Cohort Study. Clin J Sport Med 2017;27(6):524-529, doi:10.1097/jsm.0000000000000398

[5] Petushek EJ, Sugimoto D, Stoolmiller M, *et al*. Evidence-Based Best-Practice Guidelines for Preventing Anterior Cruciate Ligament Injuries in Young Female Athletes: A Systematic Review and Meta-analysis. AMERICAN JOURNAL OF SPORTS MEDICINE 2019;47(7):1744-1753, doi:10.1177/0363546518782460

[6] Lindblom H, Waldén M, Carlfjord S, *et al*. Limited positive effects on jump-landing technique in girls but not in boys after 8 weeks of injury prevention exercise training in youth football. Knee Surg Sports Traumatol Arthrosc 2020;28(2):528-537, doi:10.1007/s00167-019-05721-x

[7] Noyes FR, Barber-Westin SD. Neuromuscular Retraining Intervention Programs: Do They Reduce Noncontact Anterior Cruciate Ligament Injury Rates in Adolescent Female Athletes? ARTHROSCOPY-THE JOURNAL OF ARTHROSCOPIC AND RELATED SURGERY 2014;30(2):245-255, doi:10.1016/j.arthro.2013.10.009

[8] Willadsen EM, Zahn AB, Durall CJ. What Is the Most Effective Training Approach for Preventing Noncontact ACL Injuries in High School-Aged Female Athletes? JOURNAL OF SPORT REHABILITATION 2019;28(1):94-98, doi:10.1123/jsr.2017-0055

[9] Diekfuss JA, Grooms DR, Bonnette S, *et al*. Real-time biofeedback integrated into neuromuscular training reduces high-risk knee biomechanics and increases functional brain connectivity: A preliminary longitudinal investigation. Psychophysiology 2020;57(5):e13545, doi:10.1111/psyp.13545

[10] Hübscher M, Zech A, Pfeifer K, *et al*. Neuromuscular training for sports injury prevention: a systematic review. Med Sci Sports Exerc 2010;42(3):413-21, doi:10.1249/MSS.0b013e3181b88d37

[11] García-Luna MA, Cortell-Tormo JM, García-Jaén M, *et al*. Acute Effects of ACL Injury-Prevention Warm-Up and Soccer-Specific Fatigue Protocol on Dynamic Knee Valgus in Youth Male Soccer Players. INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH 2020;17(15), doi:10.3390/ijerph17155608

[12] Grooms DR, Diekfuss JA, Slutsky-Ganesh AB, *et al*. Preliminary Report on the Train the Brain Project, Part II: Neuroplasticity of Augmented Neuromuscular Training and Improved Injury-Risk Biomechanics. J Athl Train 2022;57(9-10):911-920, doi:10.4085/1062-6050-0548.21

[13] Larwa J, Stoy C, Chafetz RS, *et al*. Stiff Landings, Core Stability, and Dynamic Knee Valgus: A Systematic Review on Documented Anterior Cruciate Ligament Ruptures in Male and Female Athletes. Int J Environ Res Public Health 2021;18(7), doi:10.3390/ijerph18073826

[14] Ginsburg KR, Communications atCo, Health atCoPAoCaF. The Importance of Play in Promoting Healthy Child Development and Maintaining Strong Parent-Child Bonds. Pediatrics 2007;119(1):182-191, doi:10.1542/peds.2006-2697

[15] Nijhof SL, Vinkers CH, van Geelen SM, *et al*. Healthy play, better coping: The importance of play for the development of children in health and disease. Neurosci Biobehav Rev 2018;95(421-429, doi:10.1016/j.neubiorev.2018.09.024

[16] Prins J, van der Wilt F, van der Veen C, *et al*. Nature play in early childhood education: A systematic review and meta ethnography of qualitative research. Front Psychol 2022;13(995164, doi:10.3389/fpsyg.2022.995164