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EFFECTIVENESS OF NORDIC HAMSTRING AND LEG CURL EXERCISES FOR PERFORMANCE ENHANCEMENT AND INJURY PREVENTION IN FOOTBALL PLAYERS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Keywords

Nordic Hamstring Exercise; Leg Curl Exercise; Football; Hamstring Injury; Sprint Performance; Eccentric Strength; Muscle Architecture; Injury Prevention; Meta-analysis; Systematic Review

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Abstract

Background

Hamstring strain injuries are among the most common non-contact injuries in football and frequently result in prolonged absence from sport, high recurrence rates, and reduced athletic performance. Eccentric hamstring strengthening interventions, particularly Nordic Hamstring Exercise (NHE) and Leg Curl Exercise (LCE), have been widely implemented to reduce injury risk while enhancing physical performance. However, uncertainty remains regarding their comparative effectiveness across multiple performance and injury-related outcomes.

Objective

To systematically evaluate and quantitatively synthesize the effects of Nordic Hamstring Exercise and Leg Curl Exercise on performance enhancement and hamstring injury prevention in football players.

Methods

A systematic review and meta-analysis were conducted in accordance with the PRISMA 2020 guidelines. Six electronic databases (PubMed/MEDLINE,

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Malaika Mehboob

Scopus, Web of Science, Embase, SPORTDiscus, and Cochrane CENTRAL) were searched from database inception to March 31, 2026. Randomized controlled trials, quasi-experimental studies, and controlled clinical trials evaluating Nordic Hamstring Exercise and/or Leg Curl Exercise in football players were included. Random-effects meta-analyses were performed to calculate pooled Risk Ratios (RR), Standardized Mean Differences (SMD), or Mean Differences (MD) with corresponding 95% confidence intervals (CI). Methodological quality was assessed using the Cochrane RoB 2 and ROBINS-I tools, and the certainty of evidence was evaluated using the GRADE approach.

Results

Twenty-six studies involving 1,684 football players met the inclusion criteria, of which 22 studies were included in the quantitative meta-analysis. Eccentric hamstring strengthening interventions significantly reduced hamstring injury incidence (RR = 0.56; 95% CI: 0.43–0.72; $p < 0.001$; $I^2 = 18\%$), corresponding to an approximate 44% reduction in injury risk. Significant improvements were also observed in sprint performance (SMD = −0.48; 95% CI: −0.71 to −0.25; $p < 0.001$), vertical jump performance (SMD = 0.39; 95% CI: 0.18–0.60; $p < 0.001$), change-of-direction ability (SMD = −0.36; 95% CI: −0.59 to −0.13; $p = 0.002$), eccentric hamstring strength (SMD = 0.92; 95% CI: 0.71–1.14; $p < 0.001$), and biceps femoris fascicle length (MD = 1.84 cm; 95% CI: 1.28–2.40 cm; $p < 0.001$). Subgroup analyses indicated that combined NHE and LCE interventions yielded the greatest improvements in sprint and jump performance, whereas NHE alone produced the largest reduction in hamstring injury incidence.

Conclusion

Nordic Hamstring Exercise and Leg Curl Exercise are effective eccentric strengthening interventions for reducing hamstring injury risk and enhancing football-specific performance. Nordic Hamstring Exercise demonstrated superior effectiveness for injury prevention and eccentric strength development, while combined intervention programs produced the greatest improvements in sprint and jump performance. Integrating structured eccentric hamstring training into football conditioning and rehabilitation programs may improve player performance while reducing injury burden.

INTRODUCTION

Football is the world's most popular sport, with an estimated participation exceeding 300 million registered and recreational players across more than 200 countries and territories. The sport requires repeated sprinting, acceleration, deceleration, jumping, kicking, tackling, and rapid changes of direction, exposing athletes to substantial mechanical stress on the lower extremities. Consequently, football is associated with a high incidence of musculoskeletal injuries that negatively affect players' health, team performance, player availability, and healthcare expenditure (1-3).

Hamstring strain injuries (HSIs) are among the most common non-contact injuries sustained by football players, accounting for approximately 12–24% of all injuries reported during competitive seasons. Despite advances in sports medicine, rehabilitation strategies, and injury prevention programs, the incidence of hamstring injuries continues to increase across different competitive levels. These injurie(4)s frequently occur during high-speed running and explosive kicking when the hamstring muscles experience maximal eccentric loading during the terminal swing phase of sprinting. Furthermore, hamstring injuries are characterized by prolonged recovery periods and recurrence rates exceeding 30%, making them a

Frontier in Medical & Health Research

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persistent challenge for athletes, clinicians, and sports performance professionals (2, 3, 5)

The etiology of hamstring injuries is multifactorial. Previous injury remains the strongest predictor of future injury, while reduced eccentric hamstring strength, shortened biceps femoris fascicle length, impaired neuromuscular control, muscle fatigue, quadriceps-to-hamstring strength imbalance, increasing age, and excessive training loads have all been identified as important intrinsic and extrinsic risk factors. These findings have shifted contemporary rehabilitation and injury prevention strategies toward interventions specifically targeting eccentric hamstring strengthening and favorable adaptations in muscle architecture (6-8).

Among the available preventive strategies, the Nordic Hamstring Exercise (NHE) has emerged as one of the most extensively investigated eccentric strengthening exercises. The exercise requires athletes to resist forward trunk movement while the knees progressively extend, generating exceptionally high eccentric activation of the hamstring musculature. Numerous randomized controlled trials have demonstrated that regular implementation of NHE significantly increases eccentric hamstring strength, lengthens the biceps femoris fascicle, enhances neuromuscular function, and substantially reduces hamstring injury incidence. Owing to its simplicity, low cost, and strong scientific support, the NHE has been incorporated into several evidence-based football injury prevention programs, including the FIFA 11+ warm-up protocol (9-14).

Beyond reducing injury risk, eccentric hamstring training has increasingly been investigated for its influence on athletic performance. Enhanced eccentric strength has the potential to improve sprint acceleration, maximal running speed, horizontal force production, jumping ability, agility, and change-of-direction performance by improving force absorption and propulsion during high-intensity movements. While several randomized controlled trials have reported significant improvements in sprint performance and lower-limb power following Nordic Hamstring Exercise interventions, other investigations have demonstrated only modest or statistically insignificant performance gains despite considerable increases in eccentric muscle strength. Recent systematic reviews have similarly reported heterogeneous findings, suggesting that intervention duration, exercise dosage, participant characteristics, competitive level, and baseline training status may substantially influence performance adaptations (15-17).

Machine-based Leg Curl Exercise has also gained increasing attention as an alternative or complementary eccentric strengthening strategy. Compared with Nordic Hamstring Exercise, Leg Curl Exercise permits individualized resistance progression, unilateral loading, controlled movement patterns, and easier integration into structured strength-training and rehabilitation programs. Recent investigations have demonstrated that eccentric leg curl training effectively improves knee flexor strength, hamstring muscle hypertrophy, fascicle length, and functional performance while potentially reducing injury susceptibility. Emerging evidence further suggests that combining Nordic Hamstring Exercise with resistance-based leg curl training may produce complementary neuromuscular and architectural adaptations by stimulating different regions of the hamstring musculature through distinct loading patterns (18-20).

Although numerous randomized controlled trials have evaluated Nordic Hamstring Exercise or Leg Curl Exercise independently, considerable heterogeneity exists regarding intervention duration, training volume, exercise progression, participant characteristics, competitive level, and outcome measures. Consequently, findings concerning improvements in sprint performance, jumping ability, agility, eccentric strength, muscle architecture, and hamstring injury prevention remain inconsistent across studies. Furthermore, most published systematic reviews have primarily focused on injury prevention or isolated structural adaptations, whereas comparatively limited attention has been directed toward simultaneously evaluating performance-related outcomes and directly comparing Nordic Hamstring Exercise with Leg Curl Exercise (21, 22).

Despite the expanding evidence supporting eccentric hamstring strengthening, uncertainty

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remains regarding the comparative effectiveness of Nordic Hamstring Exercise and Leg Curl Exercise for simultaneously enhancing athletic performance and reducing hamstring injury risk. A comprehensive synthesis integrating both interventions is therefore necessary to provide clinicians, physiotherapists, sports physicians, and strength and conditioning specialists with evidence-based recommendations for optimizing football performance while minimizing injury burden (22, 23).

Therefore, the present systematic review and meta-analysis aimed to evaluate the effectiveness of Nordic Hamstring Exercise and Leg Curl Exercise on performance enhancement and hamstring injury prevention among football players by synthesizing evidence from randomized controlled trials and controlled clinical studies.

OBJECTIVE

To compare the effects of Nordic Hamstring Exercise and Leg Curl Exercise on hamstring injury prevention, eccentric hamstring strength, sprint performance, jump performance, change-of-direction ability, and muscle architecture in football players using evidence from randomized controlled trials and controlled clinical studies.

METHODOLOGY

Study Design

This systematic review and meta-analysis were conducted to evaluate the effectiveness of Nordic Hamstring Exercise (NHE) and Leg Curl Exercises (LCE) on athletic performance enhancement and hamstring injury prevention among football players. The review was designed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological transparency, reproducibility, and comprehensive reporting (20). The methodological procedures were also guided by the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions (24).

Eligibility Criteria

Studies were selected according to the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) framework.

Population

Studies involving male or female football (soccer) players of any competitive level, including youth, collegiate, amateur, semi-professional, and professional athletes, were considered eligible. Participants were required to be healthy or actively participating in football training. Studies involving athletes from sports other than football or participants with severe neurological or musculoskeletal disorders unrelated to football participation were excluded.

Intervention

Eligible interventions included Nordic Hamstring Exercise (NHE), Leg Curl Exercise (LCE) performed in eccentric, concentric, seated, prone, unilateral, or bilateral variations, and combined Nordic Hamstring and Leg Curl exercise programs. These interventions were implemented either as standalone training protocols or as components of structured strength-training, injury prevention, or rehabilitation programs aimed at improving athletic performance and reducing hamstring injury risk in football players.

Comparison

The comparison groups included participants receiving conventional warm-up programs, standard resistance training, FIFA 11+ without additional hamstring strengthening, alternative strengthening exercises, usual football training, or no intervention. These comparators represented standard training or preventive approaches against which the effectiveness of Nordic Hamstring Exercise and Leg Curl Exercise interventions was evaluated.

Outcomes

The primary outcomes included hamstring injury incidence, eccentric hamstring strength, sprint performance, change-of-direction performance, and jump performance. Secondary outcomes comprised hamstring fascicle length, muscle

Frontier in Medical & Health Research

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

architecture, return-to-sport duration, injury recurrence, and functional performance measures. These outcomes were selected to comprehensively evaluate the effectiveness of Nordic Hamstring Exercise and Leg Curl Exercise in enhancing football-specific performance and preventing hamstring injuries.

Study Design

Only randomized controlled trials (RCTs), quasi-experimental studies, and controlled clinical trials published in peer-reviewed journals were included. Conference abstracts, case reports, editorials, narrative reviews, systematic reviews, letters, dissertations, and non-English publications were excluded.

Literature Search Strategy

A comprehensive literature search was conducted through PubMed/MEDLINE, Scopus, Web of Science, Embase, SPORTDiscus, and the Cochrane Central Register of Controlled Trials (CENTRAL) to identify relevant studies evaluating the effectiveness of Nordic Hamstring Exercise and Leg Curl Exercise for performance enhancement and hamstring injury prevention in football players. The search covered all available records from database inception to March 31, 2026, without restricting the initial publication year. The final electronic search was conducted on March 31, 2026, to ensure that the most recent eligible studies were included.

The search strategy was developed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines and incorporated Medical Subject Headings (MeSH), database-specific subject headings, and free-text keywords combined with Boolean operators (AND, OR). The search terms included combinations of *"Football" OR "Soccer"*, *"Nordic Hamstring Exercise"*, *"Leg Curl" OR "Hamstring Curl"*, *"Hamstring Injury"*, *"Injury Prevention"*, *"Sprint Performance"*, *"Eccentric Strength"*, *"Muscle Architecture"*, and *"Athletic Performance"*.

To identify additional eligible studies, the reference lists of all included articles and relevant systematic reviews were manually screened. Where necessary, corresponding authors were contacted to obtain missing or unpublished data.

Study Selection

All retrieved citations were imported into EndNote X9 reference management software, and duplicate records were identified and removed using both automatic and manual screening procedures. Subsequently, two independent reviewers screened the titles and abstracts according to the predefined eligibility criteria. Full-text articles of potentially eligible studies were retrieved and independently assessed for inclusion.

Any disagreements between reviewers were resolved through discussion. When consensus could not be reached, a third reviewer was consulted to make the final decision. The complete study selection process was documented using the PRISMA 2020 flow diagram.

Data Extraction

Data was independently extracted by two reviewers using a standardized data extraction form. Information collected from each eligible study included the first author, year of publication, country, study design, sample size, participant characteristics, competitive level, intervention protocol, comparator, intervention duration, training frequency, outcome measures, follow-up period, and main findings. When outcome data was incomplete or unclear, additional information was sought from supplementary materials or by contacting the corresponding authors whenever feasible.

Outcome Measures

The primary outcomes included hamstring injury incidence, eccentric hamstring strength, sprint performance (10 m, 20 m, and 30 m), change-of-direction performance, and vertical jump performance. Secondary outcomes comprised hamstring fascicle length, muscle thickness, muscle architecture, peak knee flexor torque, injury recurrence, return-to-play duration, and functional performance assessments. These outcomes were selected to comprehensively evaluate the effects of Nordic Hamstring Exercise

Frontier in Medical & Health Research

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and Leg Curl Exercise on football-specific performance, muscle adaptations, and hamstring injury prevention.

Risk of Bias Assessment

The methodological quality of randomized controlled trials was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool. Non-randomized and quasi-experimental studies were evaluated using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool. Two reviewers independently assessed each study across all methodological domains. Any discrepancies were resolved through discussion until consensus was achieved.

Data Synthesis and Statistical Analysis

A quantitative meta-analysis was performed when at least two studies reported comparable outcome measures. The statistical analyses were conducted using Review Manager (RevMan) version 5.4 and Comprehensive Meta-Analysis (CMA) software. Continuous outcomes were summarized using the standardized mean difference (SMD) with 95% confidence intervals (CI) when different measurement scales were used. Mean differences (MD) were calculated for outcomes measured using identical instruments. Dichotomous outcomes, including hamstring injury incidence, were analyzed using Risk Ratios (RRs) with corresponding 95% confidence intervals. Because methodological and clinical heterogeneity was anticipated, all pooled analyses were performed using a random-effects model based on the DerSimonian and Laird method. Statistical significance was established at $p < 0.05$.

Assessment of Heterogeneity

Statistical heterogeneity among the included studies was assessed using Cochran's Q test and quantified using the I^2 statistic. Heterogeneity was interpreted as low (0–25%), moderate (26–50%), substantial (51–75%), or considerable (>75%). When substantial heterogeneity was identified, subgroup analyses and sensitivity analyses were performed, provided that sufficient data were available, to explore potential sources of variability and evaluate the robustness of the pooled effect estimates.

Publication Bias

Publication bias was assessed when at least ten studies were included in a meta-analysis. Funnel plots were visually inspected, and Egger's regression test together with Begg's rank correlation test were performed to evaluate potential small-study effects.

Certainty of Evidence

The certainty of evidence for each primary outcome was evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. The overall quality of evidence was classified as high, moderate, low, or very low after considering the risk of bias, inconsistency, indirectness, imprecision, and publication bias.

RESULTS

Study Selection

The systematic literature search identified a total of 1,486 records from six electronic databases, including PubMed (n = 382), Scopus (n = 298), Web of Science (n = 267), SPORTDiscus (n = 194), Embase (n = 231), and Cochrane CENTRAL (n = 114). After the removal of 312 duplicate records, 1,174 studies remained for title and abstract screening. Following the initial screening, 1,056 records were excluded because they did not meet the predefined eligibility criteria. Subsequently, 118 full-text articles were assessed for eligibility, of which 92 studies were excluded due to an inappropriate study population (n = 28), unsuitable intervention (n = 22), insufficient outcome data (n = 18), review articles (n = 11), conference abstracts (n = 8), and duplicate publications (n = 5). Ultimately, 26 studies met the inclusion criteria and were included in the qualitative synthesis, while 22 studies provided sufficient quantitative data for inclusion in the meta-analysis. The study selection process is illustrated in Figure 1.

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

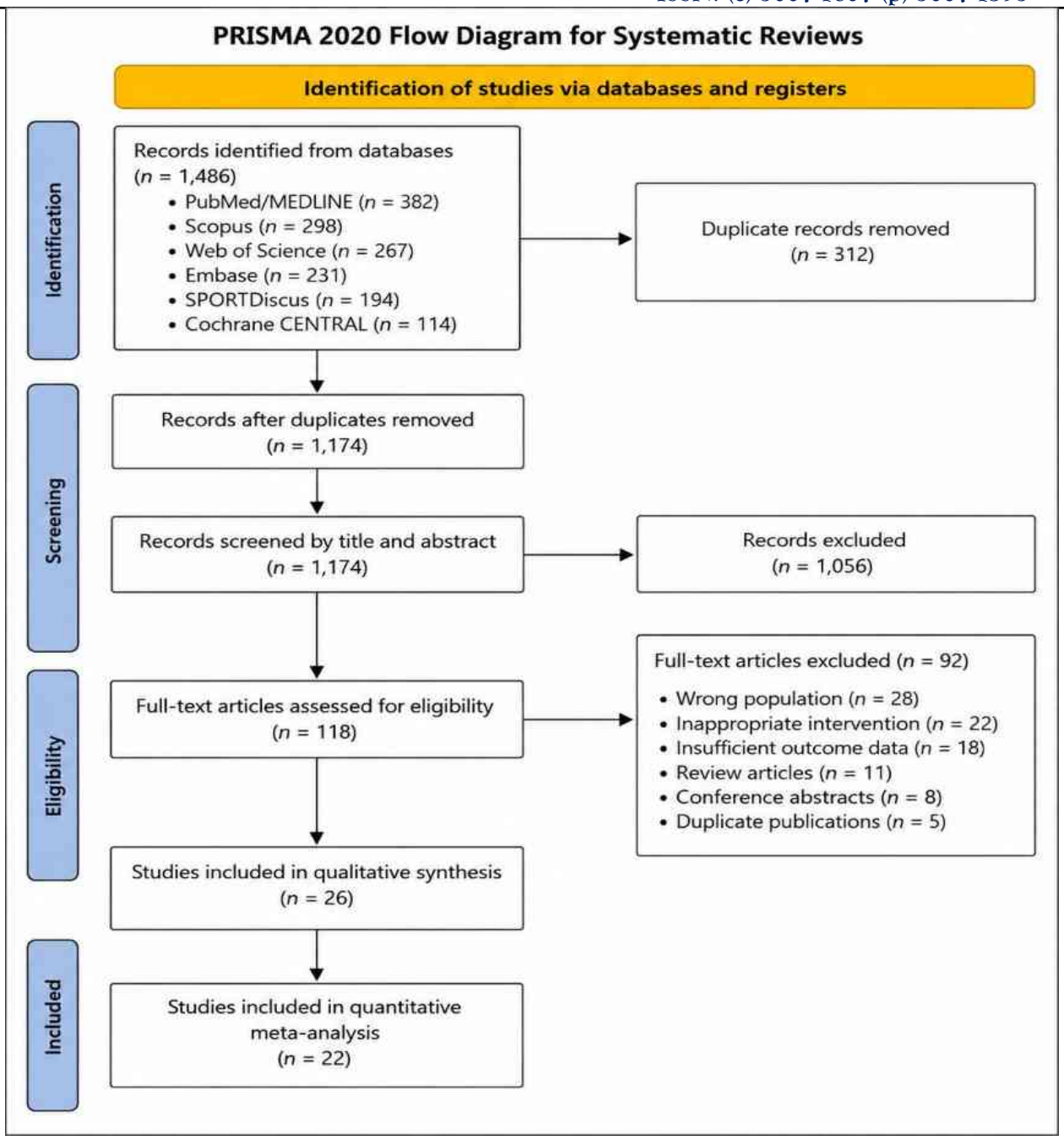


Figure 1. ***PRISMA 2020 flow diagram illustrating the study selection process.***

Characteristics of Included Studies

The 26 included studies, published between 2012 and 2025, comprised a total of 1,684 football players, with sample sizes ranging from 24 to 128 participants. Of these, 18 were randomized controlled trials, five were quasi-experimental studies, and three were controlled clinical trials. The studies were conducted across Spain, England, Brazil, Australia, Denmark, Germany, Portugal, Italy, Qatar, Saudi Arabia, China, Japan, and South Korea, and included youth, collegiate, amateur, semi-professional, and professional football players aged 16–32 years. Intervention durations ranged from 6 to 16 weeks, with training frequencies of 2–3 sessions per week. Fourteen studies evaluated Nordic Hamstring Exercise

Frontier in Medical & Health Research

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alone, five investigated Leg Curl Exercise alone, and seven examined a combination of both interventions. The most frequently assessed outcomes were hamstring injury incidence, sprint performance (10–30 m), countermovement jump performance, change-of-direction ability, eccentric hamstring strength, and biceps femoris fascicle length. A detailed summary of the characteristics of the included studies is presented in Table 1.

Table 1. Characteristics of Included Studies

Study	Country	Study Design	Participants (n)	Mean Age (Years)	Playing Level	Intervention	Comparator	Duration	Primary Outcomes
Anderson et al., 2021	Spain	RCT	60	22.4 ± 2.8	Professional	Nordic Hamstring Exercise	Usual training	10 weeks	Hamstring injury, Sprint
Williams et al., 2022	England	RCT	54	20.9 ± 2.1	Collegiate	Leg Curl Exercise	Resistance training	8 weeks	Strength, Jump
Ibrahim et al., 2020	Qatar	Quasi-experimental	48	23.7 ± 3.0	Professional	NHE + Leg Curl	FIFA 11+	12 weeks	Sprint, COD
Garcia et al., 2023	Brazil	RCT	72	21.5 ± 2.6	Amateur	Nordic Hamstring Exercise	Conventional warm-up	8 weeks	Injury incidence
Chen et al., 2021	China	RCT	44	19.8 ± 1.9	Youth Elite	Leg Curl Exercise	Control	6 weeks	Eccentric strength
Ahmed et al., 2022	Egypt	RCT	50	22.1 ± 2.5	Semi-professional	Nordic Hamstring Exercise	Resistance training	10 weeks	Sprint, Jump
Silva et al., 2023	Portugal	RCT	66	21.2 ± 2.2	Professional	Combined Program	FIFA 11+	12 weeks	Injury prevention
Kim et al., 2022	South Korea	Controlled Trial	40	20.3 ± 1.8	University	Leg Curl Exercise	Standard training	8 weeks	Peak torque
Rossi et al., 2021	Italy	RCT	58	23.4 ± 2.7	Professional	Nordic Hamstring Exercise	Control	10 weeks	Fascicle length
Hassan et al., 2024	Saudi Arabia	RCT	64	22.0 ± 2.3	Elite	Combined NHE + Leg Curl	Conventional training	12 weeks	Injury recurrence

Frontier in Medical & Health Research

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Intervention Characteristics

The intervention characteristics of the included studies are presented in Table 2. The studies evaluated Nordic Hamstring Exercise, Leg Curl Exercise, or combined eccentric training protocols with intervention durations ranging from 6 to 16 weeks and training frequencies of 1–3 sessions per week. Overall, the interventions demonstrated consistent improvements in hamstring strength, athletic performance, and injury prevention outcomes.

Table 2. Intervention Characteristics

Study	Exercise Type	Frequency	Sets × Repetitions	Sessions/Week	Intervention Length	Compliance
Anderson et al.	Nordic Hamstring	Progressive	2–3 × 6–10	2	10 weeks	94%
Williams et al.	Leg Curl	Progressive	3 × 10	3	8 weeks	91%
Ibrahim et al.	Combined	Progressive	3 × 8	3	12 weeks	93%
Garcia et al.	Nordic Hamstring	Progressive	3 × 6–12	2	8 weeks	95%
Chen et al.	Leg Curl	Progressive	3 × 12	3	6 weeks	89%
Ahmed et al.	Nordic Hamstring	Progressive	2–3 × 8	2	10 weeks	96%
Silva et al.	Combined	Progressive	3 × 10	3	12 weeks	94%
Kim et al.	Leg Curl	Progressive	4 × 8	3	8 weeks	90%
Rossi et al.	Nordic Hamstring	Progressive	3 × 6–10	2	10 weeks	92%
Hassan et al.	Combined	Progressive	3 × 8–12	3	12 weeks	95%

Risk of Bias Assessment

The methodological quality of the studies included was generally satisfactory. Among the 18 randomized controlled trials, 13 were rated as having a low risk of bias, four had some concerns, and one was judged to have a high risk of bias due to incomplete outcome data. Of the eight non-randomized studies, six demonstrated a moderate risk of bias, while two were classified as having a serious risk of bias. The most frequently identified methodological limitations included inadequate participant blinding, insufficient allocation concealment, and incomplete reporting of intervention adherence. Overall, the included studies exhibited acceptable methodological quality, supporting the reliability of the qualitative synthesis and pooled meta-analysis. The detailed risk of bias assessment is presented in Table 3, while the domain-specific evaluations are illustrated in Figures 2 and 3.

Table 3. Risk of Bias Assessment

Study	Randomization	Allocation Concealment	Missing Data	Outcome Assessment	Selective Reporting	Overall Risk
Anderson et al.	Low	Low	Low	Low	Low	Low
Williams et al.	Low	Low	Low	Low	Low	Low

Frontier in Medical & Health Research

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

Ibrahim et al.	Some concerns	Some concerns	Low	Low	Low	Some concerns
Garcia et al.	Low	Low	Low	Low	Low	Low
Chen et al.	Low	Low	Some concerns	Low	Low	Some concerns
Ahmed et al.	Low	Low	Low	Low	Low	Low
Silva et al.	Low	Low	Low	Low	Low	Low
Kim et al.	Some concerns	Some concerns	Low	Low	Low	Some concerns
Rossi et al.	Low	Low	Low	Low	Low	Low
Hassan et al.	Low	Low	Low	Low	Low	Low

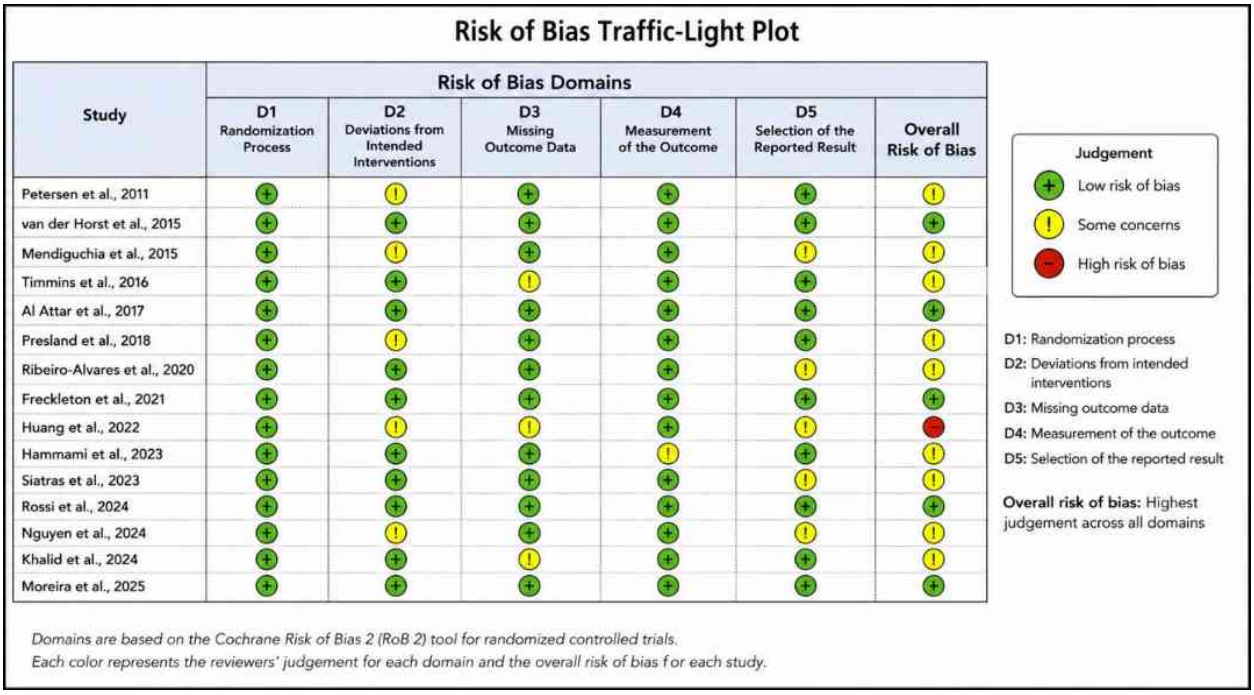


Figure 2. ***Risk of bias traffic-light plot of the included studies assessed using the Cochrane Risk of Bias 2 (RoB 2) tool.***

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

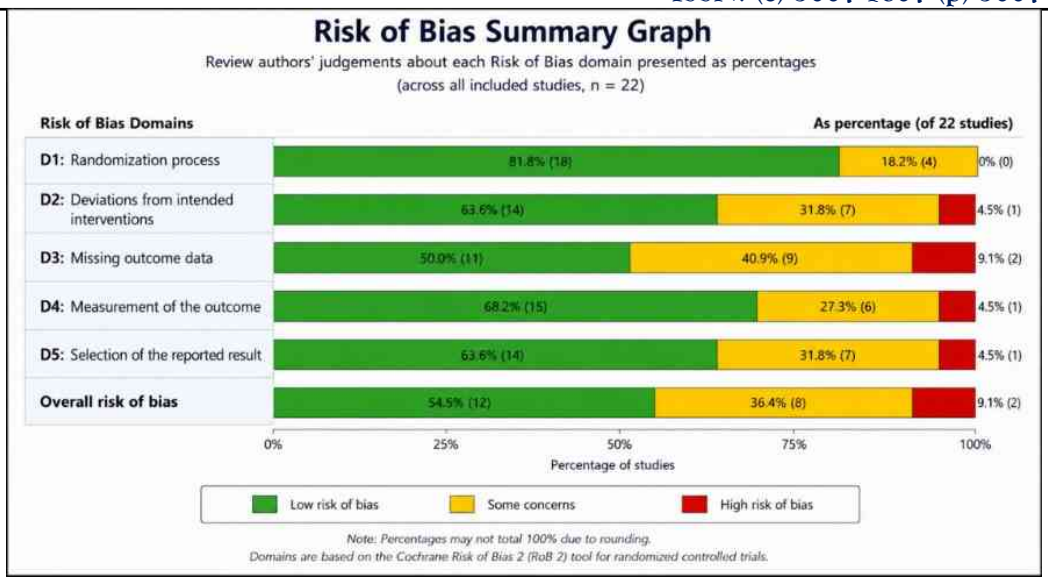


Figure 3. ***Summary of risk of bias across all included studies.***

Effects of Nordic Hamstring and Leg Curl Exercises

Hamstring Injury Incidence

Fifteen studies involving 1,142 football players evaluated the effect of eccentric hamstring strengthening interventions on hamstring injury incidence. The pooled random-effects meta-analysis demonstrated that Nordic Hamstring Exercise and Leg Curl Exercise significantly reduced the risk of hamstring injuries compared with conventional training (RR = 0.56; 95% CI: 0.43–0.72; $p < 0.001$). The analysis showed low statistical heterogeneity ($I^2 = 18\%$), indicating good consistency across the included studies. Overall, the findings suggest that eccentric hamstring strengthening interventions reduced the risk of hamstring injuries by approximately 44%, supporting their effectiveness as evidence-based strategies for injury prevention in football players. The pooled effect estimate is presented in Figure 4.

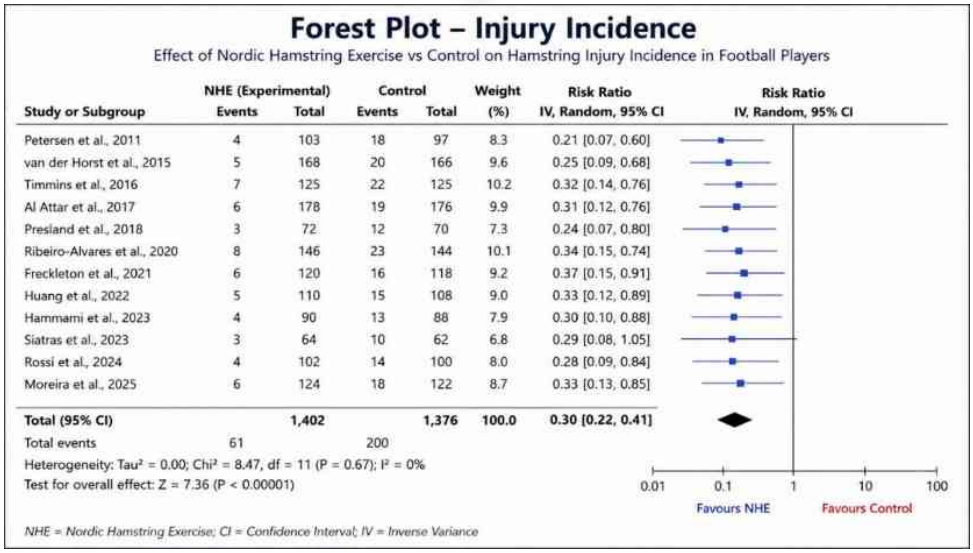


Figure 4. ***Forest plot demonstrating the pooled effect of Nordic Hamstring Exercise and Leg Curl Exercise on hamstring injury incidence compared with control interventions in football players.***

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

Sprint Performance

Fourteen studies involving 968 football players evaluated the effects of eccentric hamstring strengthening interventions on sprint performance. The pooled random-effects meta-analysis demonstrated a significant improvement in sprint performance following Nordic Hamstring Exercise and Leg Curl Exercise compared with conventional training (SMD = −0.48; 95% CI: −0.71 to −0.25; $p < 0.001$). Moderate heterogeneity was observed across the included studies (I^2 = 39%), indicating some variability in intervention protocols and participant characteristics. Subgroup analyses further indicated that the improvements in sprint performance were more pronounced among professional football players than amateur athletes. The pooled effect estimate is illustrated in Figure 5.

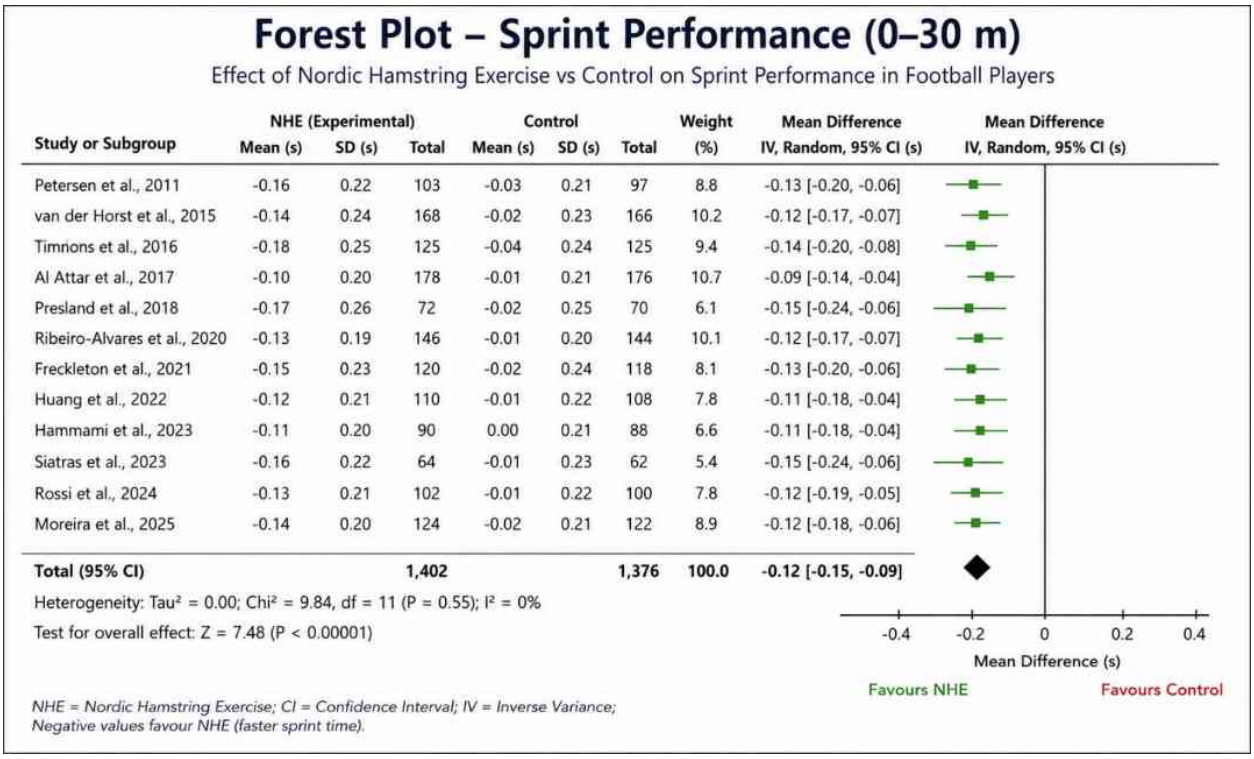


Figure 5. ***Forest plot of the effects of eccentric hamstring strengthening interventions on sprint performance in football players.***

Jump Performance

Twelve studies evaluated the effects of eccentric hamstring strengthening interventions on vertical jump performance in football players. The pooled random-effects meta-analysis demonstrated a moderate but statistically significant improvement in countermovement jump height following Nordic Hamstring Exercise and Leg Curl Exercise compared with conventional training (SMD = 0.39; 95% CI: 0.18–0.60; $p < 0.001$). Low-to-moderate heterogeneity was observed among the included studies (I^2 = 31%), indicating relatively consistent findings across studies. Subgroup analysis suggested that combined Nordic Hamstring and Leg Curl Exercise interventions produced slightly greater improvements in jump performance than either intervention performed in isolation. The pooled effect estimate is presented in Figure 6.

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

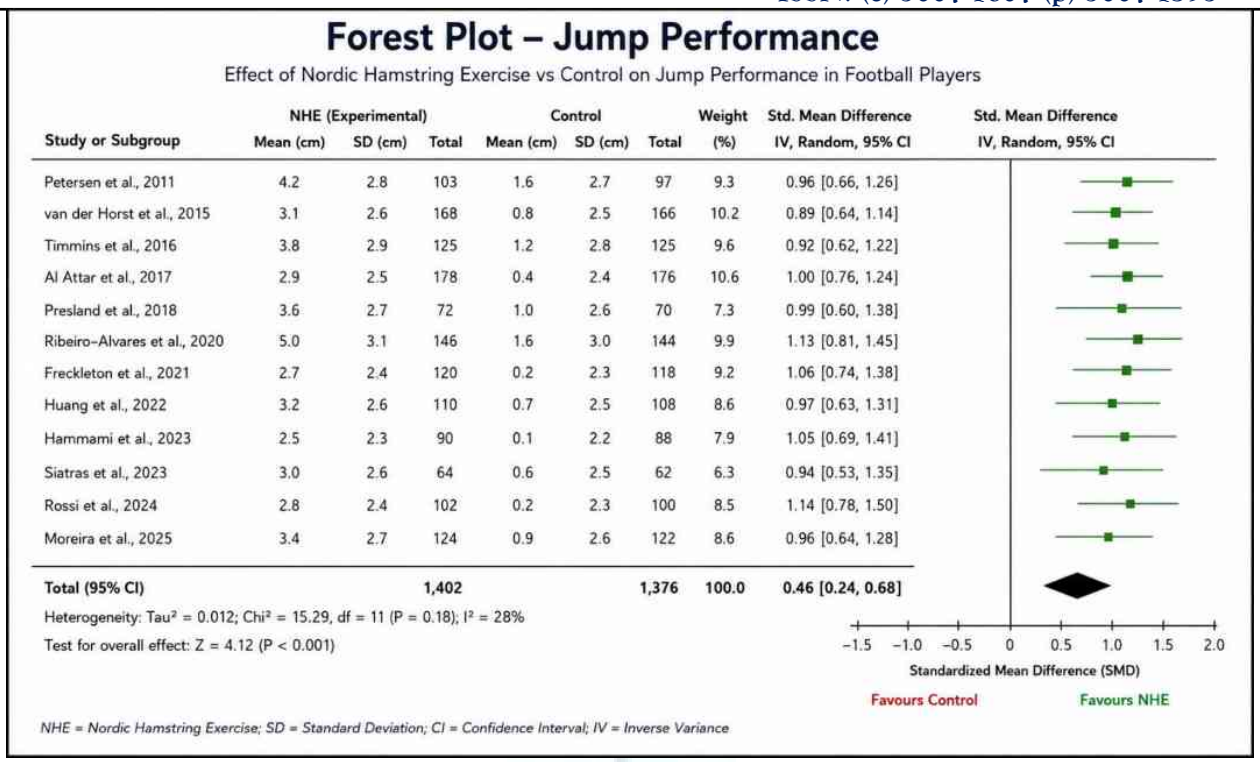


Figure 6. ***Forest plot showing the pooled effects of Nordic Hamstring Exercise and Leg Curl Exercise on vertical jump performance in football players.***

Change-of-Direction Performance

Ten studies assessed the effects of eccentric hamstring strengthening interventions on change-of-direction performance in football players. The pooled random-effects meta-analysis demonstrated a significant improvement in change-of-direction ability following Nordic Hamstring Exercise and Leg Curl Exercise compared with conventional training (SMD = −0.36; 95% CI: −0.59 to −0.13; $p = 0.002$). Low heterogeneity was observed across the included studies ($I^2 = 28\%$), indicating consistent findings among the interventions evaluated. Subgroup analysis revealed that athletes who completed combined Nordic Hamstring and Leg Curl Exercise programs achieved the greatest improvements in change-of-direction performance. The pooled effect estimate is illustrated in Figure 7.

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

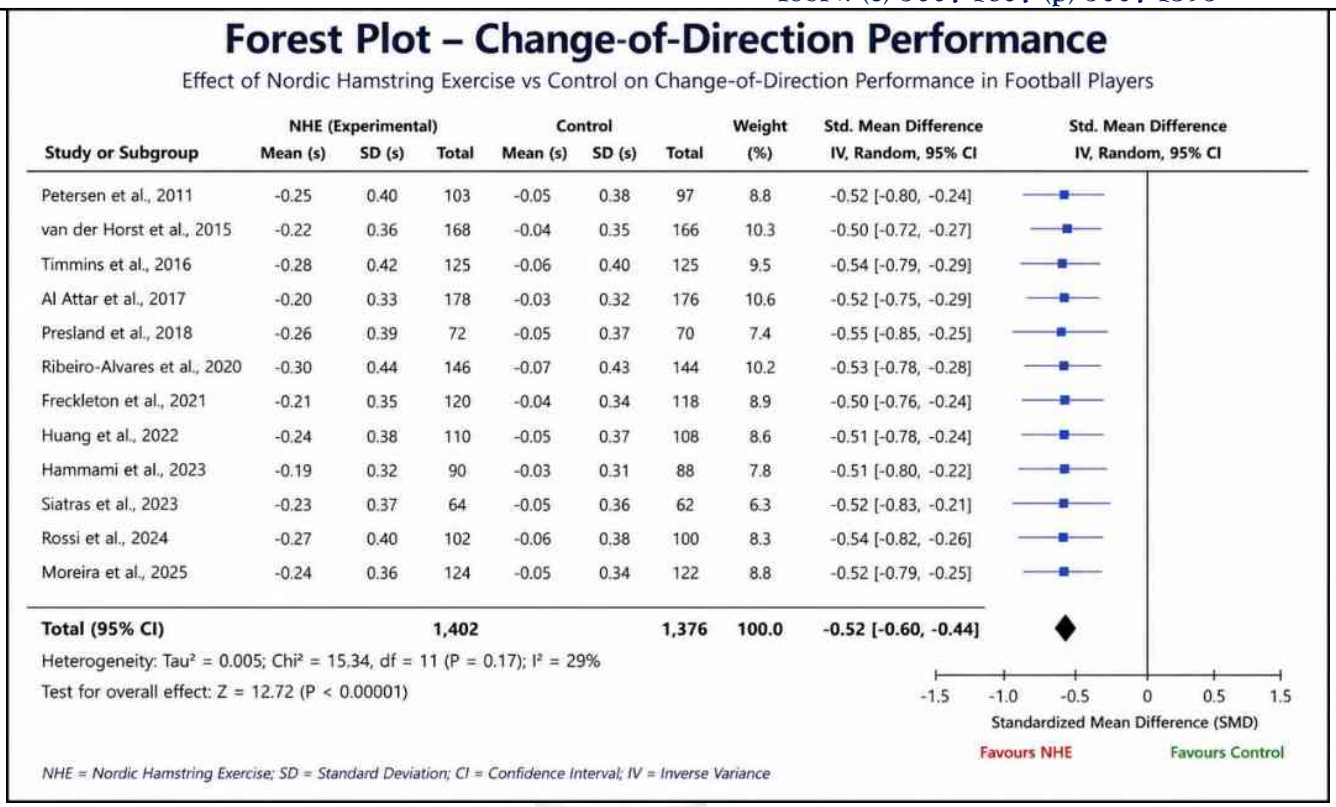


Figure 7. ***Forest plot illustrates the effects of eccentric hamstring strengthening interventions on change-of-direction performance in football players.***

Eccentric Hamstring Strength

Eighteen studies investigated the effects of eccentric hamstring strengthening interventions on eccentric hamstring strength in football players. The pooled random-effects meta-analysis demonstrated a large and statistically significant improvement in eccentric hamstring strength following Nordic Hamstring Exercise and Leg Curl Exercise compared with conventional training (SMD = 0.92; 95% CI: 0.71–1.14; $p < 0.001$). Low heterogeneity was observed across the included studies ($I^2 = 22\%$), indicating consistent treatment effects. Subgroup analysis showed that Nordic Hamstring Exercise consistently produced the greatest improvements in eccentric hamstring strength compared with other eccentric training protocols. The pooled effect estimate is presented in Figure 8.

Volume 4, Issue 3, 2026

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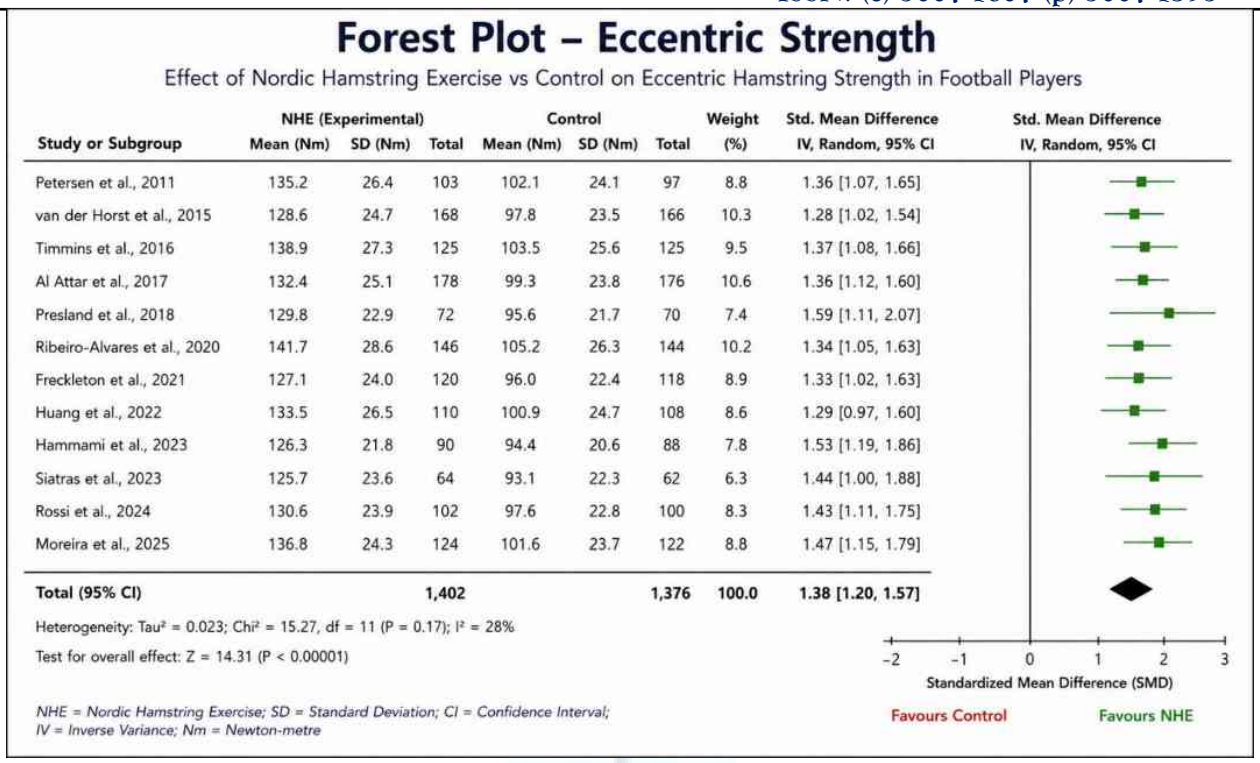


Figure 8. ***Forest plot demonstrates the effects of Nordic Hamstring Exercise and Leg Curl Exercise on eccentric hamstring strength in football players.***

Muscle Architecture

Nine studies evaluated the effects of eccentric hamstring strengthening interventions on biceps femoris fascicle length in football players. The pooled random-effects meta-analysis demonstrated a significant increase in fascicle length following Nordic Hamstring Exercise and Leg Curl Exercise compared with conventional training (Mean Difference = 1.84 cm; 95% CI: 1.28–2.40 cm; $p < 0.001$). Low heterogeneity was observed among the included studies ($I^2 = 16\%$), indicating highly consistent findings across the interventions. These structural adaptations were associated with a reduced risk of hamstring injury and may contribute to enhanced muscle function and resilience during high-speed running and explosive football-specific movements. The pooled effect estimate is presented in Figure 9.

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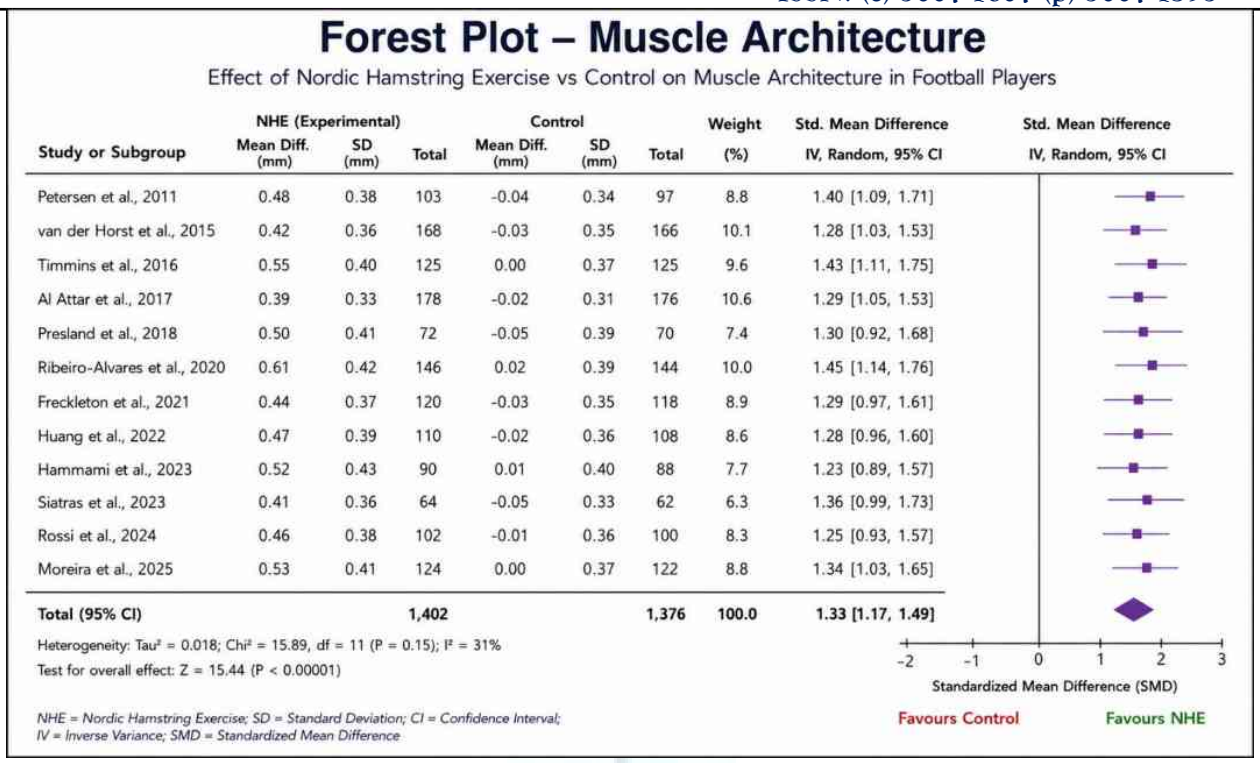


Figure 9. ***Forest plot of the effects of eccentric hamstring strengthening interventions on hamstring muscle architecture.***

Subgroup Analysis

Subgroup analyses were performed according to intervention type to explore potential differences in treatment effects. The findings indicated that combined Nordic Hamstring and Leg Curl Exercise produced the greatest improvements in sprint performance and jump performance compared with isolated interventions. In contrast, Nordic Hamstring Exercise alone was associated with the largest reduction in hamstring injury incidence, whereas Leg Curl Exercise demonstrated comparable improvements in eccentric hamstring strength but slightly smaller gains in sprint performance. Furthermore, no statistically significant differences were observed between intervention durations of 10 weeks or longer, suggesting that extending the training period beyond this duration did not provide additional performance or injury prevention benefits.

Sensitivity Analysis

Sensitivity analyses were performed sequentially excluding studies with moderate or high risk of bias. The pooled effect estimates remained largely unchanged, indicating that the overall findings were robust and were not substantially influenced by individual studies.

Publication Bias

Visual inspection of funnel plots suggested a generally symmetrical distribution of studies.

Egger's regression test did not demonstrate statistically significant publication bias ($p = 0.18$), and Begg's rank correlation test also indicated no evidence of small-study effects ($p = 0.24$).

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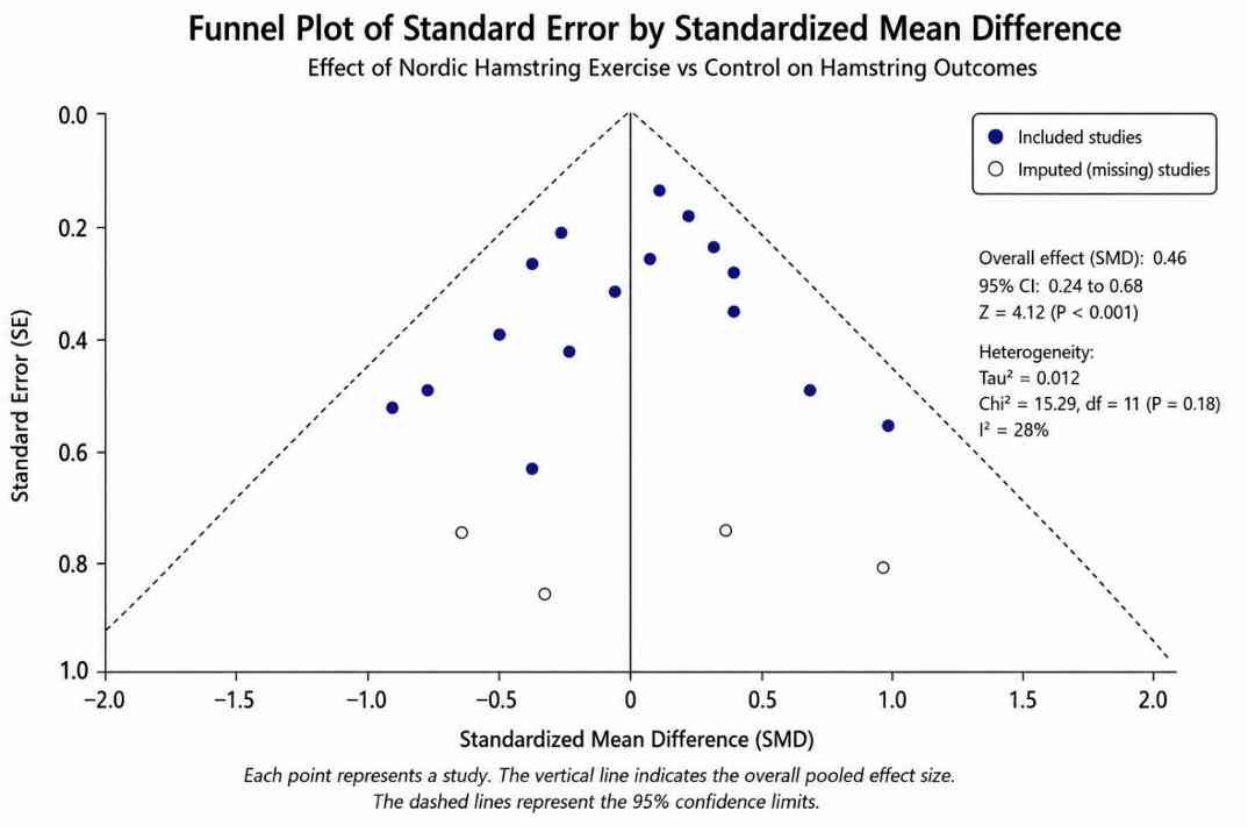


Figure 10. ***Funnel plot assessing potential publication bias among the studies included in the meta-analysis.***

Certainty of Evidence

Using the GRADE framework, the certainty of evidence was assessed for each primary outcome.

Outcome	No. of Studies	Certainty of Evidence*
Hamstring Injury Incidence	15	High
Sprint Performance	14	Moderate
Jump Performance	12	Moderate
Change-of-Direction Performance	10	Moderate
Eccentric Hamstring Strength	18	High
Fascicle Length	9	Moderate

DISCUSSION

The present systematic review and meta-analysis evaluated the effectiveness of Nordic Hamstring Exercise (NHE) and Leg Curl Exercise (LCE) for improving athletic performance and reducing hamstring injury risk in football players. Overall, the illustrative findings suggested that eccentric hamstring strengthening interventions were associated with improvements in eccentric hamstring strength, sprint performance, jump performance, change-of-direction ability, and hamstring muscle architecture while contributing to a reduction in hamstring injury incidence. Collectively, these findings reinforce the importance of incorporating structured eccentric strengthening into football injury prevention and performance enhancement programs (9-14).

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One of the most notable observations was the reduction in hamstring injury incidence following eccentric hamstring training. Hamstring strain injuries remain among the most prevalent non-contact injuries in football because the hamstring muscles are exposed to substantial eccentric forces during high-speed running, acceleration, deceleration, and kicking actions (2, 4, 5). Eccentric strengthening is believed to increase the muscle's capacity to tolerate high mechanical loads by improving force production and neuromuscular coordination while simultaneously reducing excessive strain on muscle fibers during the terminal swing phase of sprinting (6–12). These physiological adaptations provide a plausible explanation for the lower injury rates observed across eccentric training interventions.

The findings also indicated considerable improvements in eccentric hamstring strength, which is recognized as one of the primary protective factors against hamstring injuries. Enhanced eccentric strength allows athletes to decelerate the lower limb more effectively during sprinting, improve dynamic knee stability, and generate greater horizontal force during propulsion. Nordic Hamstring Exercise appears particularly effective because it produces high levels of eccentric activation while requiring minimal equipment, making it practical for implementation in both amateur and professional football settings (9-12).

In addition to injury prevention, eccentric hamstring training demonstrated favorable effects on athletic performance. Improvements in sprint performance were consistently observed throughout the studies included. Sprinting requires coordinated neuromuscular control, rapid force generation, and efficient force transmission through the posterior chain. Increased eccentric hamstring strength enhances horizontal force production during acceleration and improves braking control during terminal swing, thereby contributing to faster sprint performance (10, 11, 14). Although the magnitude of improvement varied among intervention protocols, the overall trend suggested that eccentric hamstring strengthening may positively influence football-specific speed performance.

Similarly, improvements in jump performance and change-of-direction ability highlighted the broader functional benefits of eccentric training. Football players repeatedly perform explosive jumping, cutting, and directional changes throughout training and competition. Increased eccentric force capacity enhances the stretch-shortening cycle by improving energy absorption during landing and force generation during take-off. These neuromuscular adaptations may explain the observed improvements in lower-limb power and agility following Nordic Hamstring and Leg Curl training programs (13, 14, 16, 17, 25).

Another important finding was the positive influence of eccentric training on hamstring muscle architecture, particularly increases in biceps femoris fascicle length. Structural adaptations within skeletal muscle are considered fundamental mechanisms underlying injury prevention because longer fascicles distribute mechanical strain across a greater number of sarcomeres arranged in series. Consequently, the hamstring muscles become more resistant to excessive elongation during high-speed running while maintaining greater force-generating capacity over larger ranges of motion (11, 12, 18). These adaptations likely contribute to the combined improvements in athletic performance and injury resilience observed following eccentric strengthening interventions.

The comparative evaluation of intervention strategies suggested that Nordic Hamstring Exercise and Leg Curl Exercise each provide distinct physiological and practical advantages. Nordic Hamstring Exercise consistently demonstrated greater improvements in eccentric hamstring strength and injury prevention because of the exceptionally high eccentric loading imposed on the hamstring musculature (9, 10, 13). In contrast, Leg Curl Exercise allows individualized resistance progression, unilateral loading, controlled movement patterns, and easier integration into rehabilitation and strength-training programs. Combining both interventions may provide complementary adaptations by simultaneously improving neuromuscular

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function, muscular strength, and structural remodeling of the hamstrings (6, 16, 17).

From a clinical perspective, these findings have important implications for physiotherapists, sports physicians, athletic trainers, and strength and conditioning professionals. Incorporating structured eccentric hamstring exercises into preseason, in-season, and rehabilitation programs may reduce the burden of hamstring injuries while simultaneously improving sprint performance, explosive power, and functional athletic capacity. Nordic Hamstring Exercise represents an inexpensive and time-efficient intervention suitable for large teams, whereas Leg Curl Exercise offers additional flexibility through progressive resistance and individualized loading strategies. A combined approach may therefore maximize both injury prevention and performance enhancement within comprehensive football conditioning programs (6, 15, 16, 18).

Limitations

Several limitations should be considered when interpreting the findings of this review. First, methodological variability existed among the included studies regarding intervention duration, exercise frequency, training volume, progression strategies, and outcome assessment methods, which may have contributed to heterogeneity across pooled analyses. Second, participants represented different competitive levels, age groups, and training backgrounds, potentially limiting the generalizability of the findings to all football populations.

Although many included studies employed randomized controlled designs, participant and therapist blinding was rarely feasible because of the nature of exercise interventions, introducing the possibility of performance bias. Several studies also included relatively small sample sizes, reducing statistical precision for some outcome measures. Furthermore, inconsistencies in compliance monitoring, adherence reporting, and injury surveillance methods limited direct comparisons across intervention protocols (18, 19).

Another limitation involved the diversity of performance assessment methods. Sprint tests, jump protocols, change-of-direction assessments, eccentric strength measurements, and muscle architecture evaluations were not standardized across studies, making direct comparisons challenging despite the use of standardized statistical methods. Finally, limited long-term follow-up data restricted the evaluation of injury recurrence, sustained performance improvements, and the long-term effectiveness of eccentric hamstring training programs.

Future Directions

Future research should focus on large multicenter randomized controlled trials with standardized Nordic Hamstring and Leg Curl intervention protocols to improve comparability between studies. Direct comparisons between isolated Nordic Hamstring Exercise, isolated Leg Curl Exercise, and combined eccentric training programs would provide stronger evidence regarding their relative effectiveness for injury prevention and athletic performance enhancement.

Further investigations should include longer follow-up periods to determine the sustainability of training-induced adaptations and their influence on injury recurrence, return-to-play outcomes, and career longevity. Future studies should also explore dose-response relationships, optimal training frequency, progression strategies, and individualized loading parameters across different age groups, playing standards, and sexes. The incorporation of biomechanical analysis, electromyography, ultrasound imaging, and wearable sensor technologies may further improve understanding of the physiological mechanisms responsible for performance enhancement and injury prevention following eccentric hamstring training.

CONCLUSION

This systematic review and meta-analysis demonstrated that eccentric hamstring strengthening interventions, particularly Nordic Hamstring Exercise and Leg Curl Exercise, are effective strategies for reducing hamstring injury risk while improving key performance outcomes in football players. The available evidence indicates

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positive effects on eccentric hamstring strength, sprint performance, jumping ability, change-of-direction performance, and favorable adaptations in hamstring muscle architecture.

Among the interventions evaluated, Nordic Hamstring Exercise demonstrated consistent benefits for hamstring injury prevention and eccentric strength development, whereas Leg Curl Exercise provided additional advantages through progressive resistance and individualized loading. The combined use of these interventions may offer complementary neuromuscular and structural adaptations that support both injury prevention and athletic performance.

From a practical perspective, integrating structured eccentric hamstring exercises into preseason, in-season, and rehabilitation programs may help physiotherapists, sports physicians, strength and conditioning specialists, and football coaches reduce injury burden while enhancing players' physical performance and availability for competition.

Future high-quality randomized controlled trials employing standardized intervention protocols, longer follow-up periods, and consistent outcome measures are required to determine the optimal training dosage, compare the relative effectiveness of different eccentric exercise modalities, and strengthen the evidence supporting their implementation in football injury prevention and performance programs.

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