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SYSTEMATIC REVIEW

Effect of Injury Prevention Programs that Include the Nordic Hamstring Exercise on Hamstring Injury Rates in Soccer Players: A Systematic Review and Meta-Analysis

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Abstract

Background Hamstring injuries are among the most common non-contact injuries in sports. The Nordic hamstring (NH) exercise has been shown to decrease risk by increasing eccentric hamstring strength.

Objective The purpose of this systematic review and meta-analysis was to investigate the effectiveness of the injury prevention programs that included the NH exercise on reducing hamstring injury rates while factoring in athlete workload.

Methods Two researchers independently searched for eligible studies using the following databases: the Cochrane Central Register of Controlled Trials via OvidSP, AMED (Allied and Complementary Medicine) via OvidSP, EMBASE, PubMed, MEDLINE, SPORTDiscus, Web of Science, CINAHL and AusSportMed, from inception to December 2015. The keyword domains used during the search were Nordic, hamstring, injury prevention programs, sports and variations of these keywords. The initial search resulted in 3242 articles which were filtered to five articles that met the inclusion criteria. The main inclusion criteria were randomized controlled trials or interventional studies on use of an injury prevention program that included the NH exercise while the primary outcome was hamstring injury rate. Extracted data were subjected to meta-analysis using a random effects model.

Results The pooled results based on total injuries per 1000 h of exposure showed that programs that included the NH exercise had a statistically significant reduction in hamstring injury risk ratio [IRR] of 0.490 (95 % confidence interval [CI] 0.291–0.827, $p = 0.008$). Teams using injury prevention programs that included the NH exercise reduced hamstring injury rates up to 51 % in the long term compared with the teams that did not use any injury prevention measures.

Conclusions This systematic review and meta-analysis demonstrates that injury prevention programs that include NH exercises decrease the risk of hamstring injuries among soccer players. A protocol was registered in the International Prospective Register of Systematic Reviews, PROSPERO (CRD42015019912).

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Key Points

The aim of this systematic review and meta-analysis was to investigate the effectiveness of the injury prevention programs that included the NH exercise on reducing hamstring injury rates while factoring in athlete workload.

There is strong evidence that training programs that include the NH exercise decrease the risk of hamstring injuries by up to 51 % in the long term compared with usual warm-up or training programs.

The current evidence suggests that the NH exercise alone or in combination with injury prevention programs is effective for preventing hamstring injury.

1 Introduction

Hamstring injuries are among the most common non-contact injuries in sports [1] such as soccer [2–5], rugby [6, 7], American football [8], Australian football [9], baseball [10] and cricket [11]. The trend for hamstring injuries has been on the rise over the past decade [12], representing 12–17 % of total injuries [11]. In soccer, which is the most popular sport worldwide, hamstring injuries represent between 15 and 50 % of all muscle injuries, the highest percentage of hamstring injuries among the sports that have been assessed as a percentage of the players' numbers [13–15]. Furthermore, these injuries require extensive treatment and long rehabilitation periods (of more than a month) [5, 16–20], with a high recurrence rate of 12–33 %, even with preventive procedures [5, 17, 21]. Previous hamstring injury is the greatest risk factor for development of a future hamstring injury [13]. An injury to a soccer player causing missed days and time on the disabled list is of great concern to soccer clubs in terms of its effect on competitiveness of their teams and the financial impact associated with performance [22, 23].

The Nordic hamstring (NH) exercise was previously termed the 'Russian hamstring exercise' [24]. This is a partner exercise which can be performed easily on the pitch without special equipment. The NH exercise involves the player attempting to resist a forward-falling motion from a kneeling position, using the hamstring muscles to maximize loading in the eccentric phase. A group of scientists from the Oslo Sports Trauma Research Center (OSTRC) reported a preliminary result indicating that this exercise could possibly prevent some hamstring strains [25, 26]. Therefore, the OSTRC group developed a plan to investigate the effect of this exercise and they tested its protocol. The NH exercise produced a large increase in eccentric torque production after only 10 weeks of this training [27]. Furthermore, Arnason et al. [2] investigated the effect of eccentric strength training and flexibility training on the incidence of hamstring strains in soccer players in Iceland and Norway. The incidence of hamstring strains was 65 % lower in teams that used the eccentric training program than in teams that used flexibility training programs alone (relative risk [RR] 0.43, $p = 0.01$).

Brooks et al. [6] studied the effects of the NH exercise on the incidence and severity of hamstring strains among 546 professional rugby union players. The NH exercise group had a significantly lower hamstring injury rate and severity than the strengthening and the stretching/strengthening group. Van der Horst et al. [20] conducted a randomized controlled trial to investigate the preventive effect of the NH exercise on the incidence and severity of hamstring injuries in amateur male soccer players. The incidence of hamstring injuries was significantly reduced in the intervention group compared to the control group (odds ratio [OR] 0.282; 95 % confidence interval [CI] 0.110–0.721, $p = 0.005$). However, the randomized controlled trial conducted by Engebretsen et al. [28] did not show any benefits from targeted exercise programs that used the NH exercise. Moreover, Bahr et al. [29] surveyed the adoption and implementation of the NH exercise in European male soccer players and found that compliance was too low to expect any overall effect on acute hamstring injury rates.

In 2003, the Fédération Internationale de Football Association (FIFA) Medical and Research Centre (F-MARC) included the NH exercise in the development of the FIFA '11' prevention program [18, 30, 31], which was developed further and improved to form the FIFA '11+' in 2006 [32]. The '11+' comprises three sets of NH exercise: 'beginner', minimum of 3–5 repetitions, 'intermediate', minimum of 7–10 repetitions and 'advanced', minimum of 12–15 repetitions [33–36].

In 2015, Al Attar et al. [37] conducted a systematic review and meta-analysis to evaluate the efficacy of F-MARC Injury Prevention Programs for Soccer Players. The F-MARC injury prevention programs based on total injuries per 1000 h of exposure were associated with a statistically significant reduction in the lower extremity injury risk ratio [IRR] of 0.762 (95 % CI 0.621–0.935, $p = 0.009$). Additionally, the FIFA '11+' was associated with a statistically significant reduction in the lower extremity IRR of 0.612 (95 % CI 0.475–0.788, $p = 0.001$). However, this meta-analysis did not report on specific lower extremity injuries such as hamstring strains.

Several studies have evaluated the effectiveness of the NH exercise in soccer players [2, 20, 38]. However, there is a lack of agreement among studies on the effectiveness of NH exercise. Recently, Goode et al. [39] conducted a meta-analysis on the effectiveness of eccentric hamstring training on hamstring injuries in soccer and Australian football. Their study reported that eccentric hamstring training did not reduce the risk of hamstring injury [risk ratio [RR] = 0.59 (95 % CI 0.24–1.44)]. However, they pointed out that this estimate was imprecise (confidence limit ratio (CLR) = 6.0) with significant heterogeneity ($p = 0.02$). Further analysis of variables in this study showed that compliant athletes had a significant reduction in hamstring injuries [RR = 0.35 (95 % CI 0.23–0.55)]. This review also has some limitations. First, the studies evaluated combined NH exercise and other eccentric hamstring exercises. Secondly, injury rates were analysed. Finally, the review did not isolate the effects of NH exercise in soccer. For many injury epidemiologists, use of exposure time to calculate injury rates has taken precedence over simple injury incidence for evaluating the burden of injuries [2, 20, 38]. The need to evaluate the role of NH exercise in preventing soccer-related hamstring injuries, using injury rates to calculate its effectiveness, means a meta-analysis of the published literature to date is warranted.

The objective of this meta-analysis was to investigate the effectiveness of injury prevention programs that used the NH exercise for reducing hamstring injury rates while factoring in athlete workload. By expressing injury incidence rate as a proportion of exposure time, that is, the total time at risk including practice time and playing time, a better understanding of the effect of the NH exercise in terms of the workload of the athletes could be gained. The results of this study will form a framework to evaluate the efficacy of NH exercise exclusively in soccer, thereby providing evidence to include NH exercise when designing future injury prevention programs for soccer.

2 Methods

This systematic review with meta-analysis was based upon the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [40]. A protocol was registered in the International Prospective Register of Systematic Reviews, PROSPERO (CRD420 15019912).

2.1 Search Strategy

From October 2015 to December 2015, two investigators independently searched for eligible studies, a systematic literature search covering the period from January 1985 to December 2015 was performed using various electronic databases: the Cochrane Central Register of Controlled Trials via OvidSP, AMED (Allied and Complementary Medicine) via OvidSP, PubMed, SPORTDiscus, MEDLINE, CINAHL, EMBASE, AusSportMed and Web of Science. The following terms were used to perform the electronic searches: (Russian leg curl F-MARC) OR (Russian lean FIFA) OR (Russian ham curl FIFA 11) OR (kneeling Russian hamstring curl FIFA 11 +) OR (Nordic ham curl The 11+) OR (Nordic hamstrings warm-up program) OR (Nordic hamstrings lower Warm-Up Exercise) OR (Nordic leg curl Injury prevention program) OR (Nordic reverse curl neuromuscular training) OR (glute-ham curl Soccer/football warm up program) OR (body-weight leg curl Injury prevention) OR (natural hamstring curl Athletes) OR (bodyweight hamstring curl) AND (sport injuries) OR (Athletic Injuries).

2.2 Criteria for the Included Studies

Cluster-randomized controlled trials, randomized controlled trials or prospective cohort studies of sports injury prevention programs that included the NH exercise and hamstring strain injury rates were included. Only studies in the English language were included. The only studies that met the inclusion criteria were studies conducted on soccer players. Studies were not excluded on the basis of sex, skill level or age group. Only studies in which players were engaged in injury prevention programs that included the NH exercise and compared this with 'usual' or 'different' or 'no program' were included. The outcome measures were hamstring injury rates in the control group versus the intervention group.

2.3 Criteria for the Excluded Studies

Studies were excluded if they (1) did not report player exposure hours or injury rates; (2) used protective equipment as part of the intervention; (3) were observational or cross-sectional studies, case reports or case series; (4) had multiple exposure groups and were primarily designed to assess the uptake and adherence of an intervention program; and (5) reported only performance or physical measurements and not hamstring injury rates.

2.4 Data Collection, Extraction and Analysis

2.4.1 Inclusion Procedure

Duplicates were disregarded from the two searches; articles were excluded if they did not meet the inclusion criteria. A third reviewer facilitated group consensus when disagreements were noted. Once an initial list of studies was identified, reference lists of articles were searched for potential additional studies.

2.4.2 Data Extraction

Two investigators independently extracted data from the selected full-text articles. Outcome data elements extracted from each study were number of hamstring injuries (or injury rates), exposure hours, duration of follow-up and compliance rate.

2.4.3 Administration

Endnote version X7 (Thomson Reuters, Philadelphia, PA, USA) was used for storage, collation and screening of studies. Primary outcome results from individual studies were extracted and collated in Excel (Microsoft Corp) prior to preparation and transfer into Comprehensive Meta-Analysis software, version 2 (CMA.V2) (Biostat, Inc., Englewood, NJ, USA).

2.4.4 Meta-Analysis

Extracted data were entered and analyzsd using CMA.V2 for the meta-analysis. The injury incidence rate refers to the number of incident injuries divided by the total time-at-risk and multiplied by 1000 as this accommodates variations in the exposure time of individual athletes [41]. IRR was calculated using the formula: IRR = injury incidence rate in intervention group/injury rate in the control group. An IRR < 1 indicates a positive intervention effect, for example, an IRR of 0.30 represents a 70 % reduction. The individual injury rates and IRR along with CI are reflected in Fig. 1. The CMA software used for analysis outputs log IRRs, standard errors and variance. In this meta-analysis an invariance random-effects model was used, with the assumption that studies drew on diverse populations and contexts, included different doses of exercise and tested the NH exercise in a variety of ways. Our analysis also factors in the sample size and CI for each study. For example the IRR for raw numbers 0.358/0.688 was 0.549. However, the IRR for the pooled estimate when study sample size and CI were taken into account changed to 0.49 after meta-analysis (Fig. 1).

2.4.5 Publication Bias

Standard funnel plots were used to detect signs of publication bias. The Egger test [42] was then applied to confirm asymmetry, and the 'trim and fill' [43] method was conducted to indicate whether the overall IRR estimate required adjustments based on missing studies.

2.5 Methodological Quality Assessment

Two investigators independently assessed the methodological quality of each study. The quality criteria and risk of bias were evaluated according to 12 criteria as recommended by Furlan et al. [44]. Each item was scored as (+ = 1 point, − or ? = 0 points). Any study that scored higher than 60 % of the 12 criteria was considered high quality or 'low risk of bias'. Table 1 shows quality scores for all the studies.

2.6 Definitions of Injury and Athlete Workload

2.6.1 Hamstring Injury

A hamstring injury was defined as an injury that causes a player to be unable to completely participate in the following match or training session. This was in accordance with the consensus statement of sports epidemiologists [45].

2.6.2 Athlete Workload

Athlete workload was defined as the number of active hours spent in either training or matches by athletes during the course of the study.

Study	Statistics for each study			
	Risk ratio	Lower limit	Upper limit	p-Value
Soligard et al. [46]	0.611	0.286	1.307	0.204
Engebretsen et al. [28]	1.310	0.538	3.187	0.552
Grooms et al. [33]	0.119	0.023	0.619	0.011
van der Horst et al. [20]	0.456	0.234	0.886	0.021
Silvers-Granelli et al. [47]	0.363	0.246	0.536	0.000
	0.490	0.291	0.827	0.008

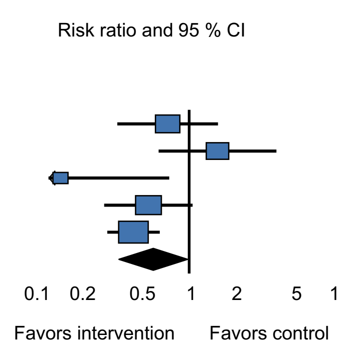

Fig. 1 Forest plot illustrating the effect of the Nordic hamstring exercise vs. controls on overall injury risk ratio

Table 1 Methodological quality scores of the included studies

Criterion	Soligard et al. [46]	Engebretsen et al. [28]	Grooms et al. [33]	van der Horst et al. [20]	Silvers-Granelli et al. [47]
Adequate randomization	+	+	–	+	+
Allocation concealment	+	–	+	+	+
Blinding patients	–	–	–	+	+
Blinding caregiver	–	–	+	+	+
Blinding/outcome assessors	–	–	+	+	+
Incomplete outcome data addressed/drop-outs	+	+	+	+	+
Incomplete outcome data/intention-to-treat (ITT) analysis	+	+	+	+	+
Free of suggestions of selective outcome reporting	+	+	+	+	+
Similar baseline characteristics	+	+	+	+	+
Co-interventions avoided or similar	+	+	+	–	–
Compliance acceptable in all groups	+	–	+	+	+
Similar timing of outcome assessment	+	+	–	+	+
Score maximum	12	12	12	12	12
Study score	9	7	9	11	11
Percentage	75	58.3	75	91.6	91.6

'+' = Yes, '–' = No. For each question only 'Yes' received a point. No points were awarded for 'No'

3 Results

3.1 Trial Flow

The database search yielded 3242 articles. After removal of duplicates, 1789 articles were screened on the basis of the title and abstract. This step left 43 full-text records, of which 28 were excluded because they did not meet the inclusion criteria. Fifteen articles were therefore chosen for detailed evaluation and review, of which ten articles were excluded because the exposure hours were not mentioned, the injury prevention programs did not use the NH exercise or only abstracts were available (i.e. the abstracts were from conference posters or free paper presentations and no full articles were published). Thus, a total of five studies were included in the current analysis. Figure 2 provides a schematic representation of the systematic steps involved in screening articles for inclusion using the PRISMA flow diagram method.

3.2 Study Characteristics

Four studies were cluster randomized controlled trials [20, 28, 46, 47] and one was a cohort study [33]. Two studies were conducted in Norway [28, 46], one in The Netherlands [20] and two in the USA [33, 47]. Four studies included male participants [20, 28, 33, 47] and one study included female participants [46]. Two studies included collegiate soccer players, aged 18–25 years [33, 47], one study included youth soccer players, aged 13–17 years [46], one study included soccer teams played in the Norwegian First, Second, and top of the Third Division, aged 17–35 years [28] and one study included amateur soccer players, aged 18–40 years [20]. Three studies used the '11+' [33, 46, 47], comprising of three sets of NH exercise: 'beginner', minimum of 3–5 repetitions, 'intermediate', minimum of 7–10 repetitions and 'advanced', minimum of 12–15 repetitions. One study used only the NH exercise [20] comprising 2–3 sets of NH exercise, with repetitions per set gradually increasing over the season from a minimum of 5–6 repetitions at the start of the season to 8–10 repetitions toward the end of the season. One study used targeted exercise programs including the NH exercise [28] in the intervention groups, comprising 1–3 sets of NH exercise, with repetitions per set gradually increasing over 10 weeks; minimum of five repetitions at the start of intervention period to 8–12 repetitions toward the end of intervention period. The duration of the programs ranged from 10 weeks to 8 months. Four studies used their usual warm-up programs [20, 28, 46, 47] and one used a traditional dynamic warm-up program [33] in control groups. Grooms et al. [33] evaluated one American collegiate soccer team for two seasons and only lower extremity injuries were recorded. Season one was compared with season two in this meta-analysis. Table 2 summarises the characteristics of the five included studies and Table 3 shows the injury rates and hours of exposure for intervention and control groups.

3.3 Pooled Injury Estimates

Pooled data of 4455 individuals, 315,992 exposure hours and 166 hamstring injuries were collected from the five included studies. The pooled IRR of the intervention and

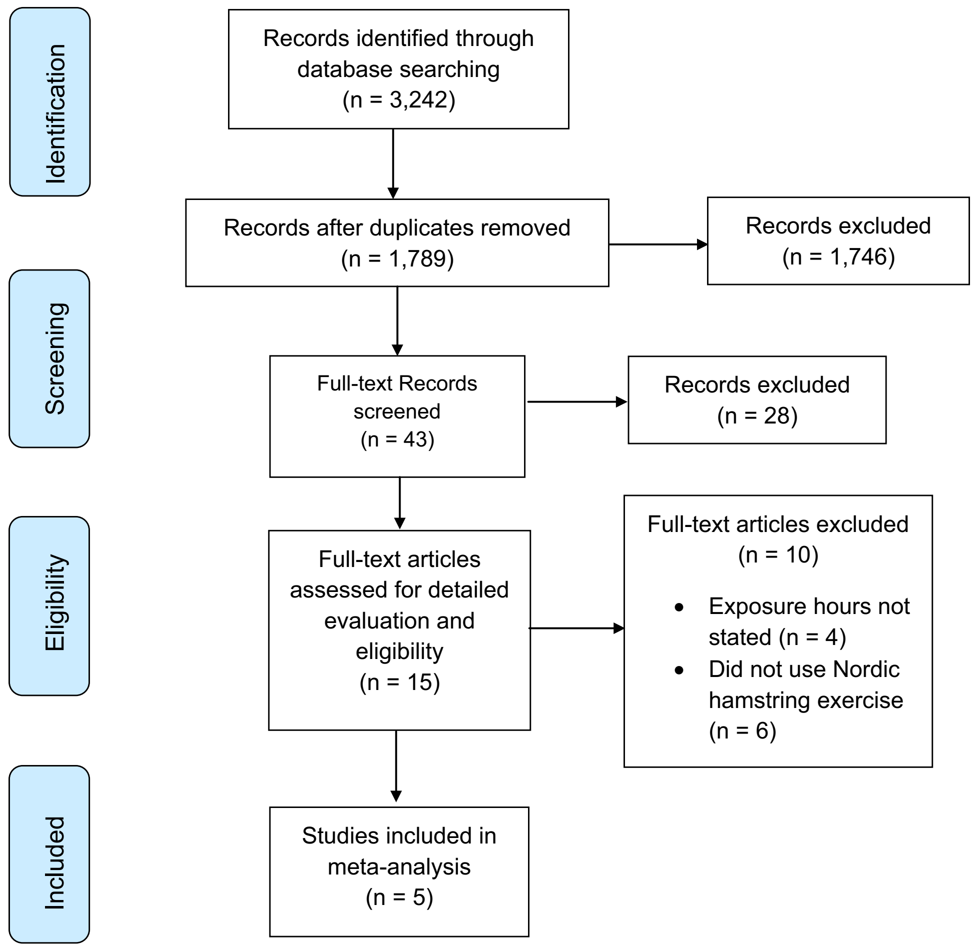

Fig. 2 Flowchart for review and triage of articles

control groups were 0.359 and 0.689 injuries per 1000 h of exposure, respectively (Table 3).

3.4 Meta-Analysis Results

3.4.1 Reduction in Hamstring Injuries

The pooled results showed 51 % overall injury reduction per 1000 h of exposure in the NH exercise injury prevention program group compared to the control group (IRR 0.490 (95 % CI 0.291–0.827), $p = 0.008$) (Fig. 1).

3.4.2 Publication Bias Results

Inspection of funnel plots showed slight asymmetry, suggesting that a bias may not be present (Fig. 3). The Egger test [42] confirmed symmetry (intercept = 0.59, SE = 1.93, $p = 0.77$). The 'trim and fill' procedure of Duval and Tweedie [43] did not adjust the overall IRR and reported it as 0.49 (95 % CI 0.29–0.83; $n = 0$ imputed studies), indicating that no adjustment to the overall point estimate was warranted.

4 Discussion

This is the first meta-analysis that specifically examined the effects of injury prevention programs that include the NH exercise in prevention of hamstring injuries among soccer players. This meta-analysis, which included four cluster randomized controlled trials [20, 28, 46, 47] and one cohort study [33], provided strong evidence that the NH exercise alone or in combination with injury prevention programs is effective in reducing the risk of hamstring injuries for soccer players.

A meta-analysis by Goode et al. [39] that included four studies, reported no significant effect of different techniques of eccentric hamstring training in reducing the risk of hamstring injury. However, they showed that when the compliance for eccentric training is high then hamstring injury rate reduction is significant. There were several methodological differences between the meta-analysis by Goode et al. [39] and our study. First, it included studies from sports other than soccer, that did not meet our inclusion criteria, e.g. Australian football. Second, they included eccentric exercises in addition to the NH exercise, i.e. 'Yo-Yo' flywheel ergometer. Finally, their outcome was number of injuries rather than injury rates and did not consider exposure time. By considering exposure time the bias of workload-related risk factors is removed. The general consensus among injury epidemiologists is that injury incidence rate is a more meaningful and informative unit than raw injury numbers [41, 45]. This has been further elaborated in the work by Al Attar et al. [37] and Soomro et al. [19], who proposed that an athlete's playing time exposure can be a major factor influencing their injury risk. The more time athletes spend in match and training conditions, the more they are predisposed to injury risk factors such as fatigue, collisions, falls and workload [1, 48, 49].

The study by van der Horst et al. [20] revealed that when compliance rates are high (91 %) the NH exercise is beneficial in decreasing hamstring injury rate. On the other hand, little benefit is achieved when compliance rates are low as in the randomised controlled trial by Engebretsen et al. (21 %) [28]. Compliance with eccentric hamstring strengthening significantly decreased hamstring injury risk by 65 % [39]. Compliance with sport injury prevention interventions is very important and can significantly affect study results [50]. Based on these results there is a need for greater compliance with the NH exercise. Nevertheless, compliance seems to be greater when the NH exercise is included in a specific injury prevention program such as the '11+' [18, 31, 33–35, 46].

Only the cluster-randomized controlled trial by Petersen et al. [38] reported new and recurrent hamstring strains separately. In that study the NH exercise decreased the overall rate of injuries, both new and recurrent acute hamstring injuries, in Danish male soccer players. Also, the injury rate was 71 % lower when players were using the NH exercise as part of their training compared with their usual training program. The effect was even greater for players with a prior history of hamstring strains, with an 86 % reduction in injury rate compared with usual training program.

We could not run a separate analysis based on sex differences as there was only one study involving female participants [46] that met the criteria for inclusion. Understanding sex differences in the implementation of the NH exercise may be of interest because females have a significantly lower peak torque to body mass ratio for the quadriceps and hamstrings than males [51]. The meta-analysis by Al Attar et al. [37] on F-MARC injury prevention programs showed that injury rate reduction was greater among the male players with a significant reduction in injury risk for lower extremity injury; in the female players, lower extremity injury reduction did not reach significance. A cluster-randomized controlled trial to investigate the preventive effect of the NH exercise on hamstring injuries in female players is needed.

Table 2 Characteristics and moderators of the included studies

Study	Location	Sex	Age (years)	Study design	Compliance (%)	Duration	Level/sport	Type of exercise in intervention group	Type of exercise in control group	Frequency (no. per week)	Quality score
Soligard et al. [46]	Norway	F	13–17	Cluster-randomized controlled trial	77	8 months	Youth soccer	FIFA 11 + including NH exercise	Usual	3	9
Engebretsen et al. [28]	Norway	M	17–35	Randomized controlled trial	21	10 weeks	1st, 2nd, 3rd Division soccer	Targeted exercise programs including NH exercise	Usual	2–3	7
Grooms et al. [33]	USA	M	18–25	Cohort study	100	12 weeks	Collegiate soccer	FIFA '11+' including NH exercise	Traditional dynamic warm-up	5–6	9
van der Horst et al. [20]	Netherlands	M	18–40	Cluster-randomized controlled trial	91	13 weeks	Amateur soccer	NH exercise	Usual	1–2	11
Silvers-Granelli et al. [47]	USA	M	18–25	Cluster-randomized controlled trial	73	6 months	Collegiate soccer	FIFA 11 + including NH exercise	Usual	3	11

NH exercise Nordic hamstring exercise, *F* female, *FIFA '11+'* Fédération Internationale de Football Association Medical and Research Centre (F-MARC) injury prevention program, *M* male

Table 3 Injury rates per 1000 h of exposure in the intervention and control groups of the included studies

Study	Intervention subjects	Hamstring injuries	Exposure hours	Hamstring injuries per 1000 h	Control subjects	Hamstring injuries	Exposure hours	Hamstring injuries per 1000 h
Soligard et al. [46]	1055	5	49,899	0.1	837	8	45,428	0.176
Engebretsen et al. [28]	193	23	41,856	0.55	195	17	40,913	0.416
Grooms et al. [33]	41	1	2703	0.37	30	5	1605	3.115
van der Horst et al. [20]	292	11	26,426	0.416	287	25	27,724	0.902
Silvers-Granelli et al. [47]	675	16	35,226	0.454	850	55	44,212	1.244
Pooled data	2256	56	156,110	0.359	2199	110	159,882	0.689

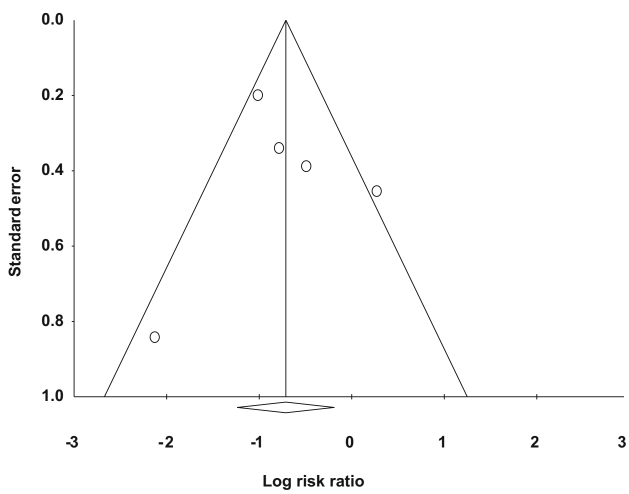

Fig. 3 Funnel plot based on study standard error and log risk ratio in assessing publication bias. Circles indicate study point estimates; imputed study estimates based on the procedure by Duval and Tweedie [43]. The diamond represents the pooled injury risk ratio (IRR) which is the summary measure of the study. The centre of the *diamond* (vertical tips) is the overall effect and the lateral tips of the *diamond* are the associated confidence intervals

The NH exercise has been implemented in other sports that have high hamstring strain rates, such as rugby [52] and Australian Football [53, 54]. However, it is currently unclear whether it would be effective in reducing hamstring injuries in these sports. Thus, similar reviews are required through a range of different sports.

4.1 Directions for Future Research

The current meta-analysis demonstrates that the NH exercise has the potential to reduce hamstring injury rates in soccer players. Therefore, teams incorporating NH exercise in their training may have a competitive advantage. Future research should focus on the implementation of the NH exercise as an injury preventive strategy in reducing hamstring injuries in soccer players. Reverse NH exercise protocols have also been proposed for preventing quadriceps injuries [55].

All of the included studies used the NH exercise as a warm-up exercise at the beginning of the training session [20, 28, 33, 46, 47]. However, the findings from Small et al. [56] indicated that performing eccentric hamstring strengthening exercises during the warm-down rather than warm-up of soccer training sessions maintains eccentric hamstring strength and preserves the functional strength ratio. Moreover, Marshall et al. [57] found that performing NH exercises in a fatigued state may help improve and/or maintain strength in a fatigued state. This is considerable evidence that a warm-down may increase muscle flexibility and thereby assist in reducing muscle injury and improving performance. Further randomized trials are needed to establish whether the NH exercise is effective in a fatigued state.

4.2 Strengths and Limitations

This research employed high methodological standards including the use of injury rate relative to hours of exposure. A limitation was that only five studies were available and all were specifically related to soccer as these were the only studies that met the inclusion criteria. There were possible effects on the incidence of hamstring strains by other exercises in the prevention programs performed in these five studies of hamstring strain incidence. It is possible that other parts of these programs (other than NH exercise) had some effect on reducing the incidence of hamstring strains.

It is crucial to assess the effect of the NH exercise in isolation. However, this is practically very difficult given the current literature. Of the studies which met our criteria, three studies used the '11+' (which includes the NH exercise) [33, 46, 47] one used the NH exercise on its own [20] and one study used a targeted exercise program that included the NH exercise [28]. Thus, the methods were designed to capture the studies that included the NH exercise in isolation or as part of a broader exercise program.

5 Conclusions

This meta-analysis provides evidence that the NH exercise alone or in combination with an injury prevention program can reduce hamstring injuries in soccer players to a great extent. This information has, until now, been questionable due to the lack of agreement among studies. This is the first meta-analysis to report the efficacy of the NH exercise in preventing hamstring injuries among soccer players. These results suggest that teams utilizing the NH exercise alone or in combination with injury prevention programs could reduce hamstring injury rates up to 51 % in the long term compared to the teams that do not. These findings can assist policy makers involved in decisions about the implementation of measures to reduce soccer injuries.

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Compliance with Ethical Standards

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Conflict of interest Wesam Saleh A. Al Attar, Najeebullah Soomro, Peter Sinclair, Evangelos Pappas and Ross Sanders declare they have no conflicts of interest with regard to the content of this review.

References

1. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. Sports Med. 2012;42(3):209–26. doi:10.2165/11594800-000000000-00000.
2. Arnason A, Andersen TE, Holme I, et al. Prevention of hamstring strains in elite soccer: an intervention study. Scand J Med Sci Sports. 2008;18(1):40–8. doi:10.1111/j.1600-0838.2006.00634.x.
3. Walden M, Hagglund M, Ekstrand J. UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. Br J Sports Med. 2005;39(8):542–6. doi:10.1136/bjsm.2004.014571.
4. Woods C, Hawkins R, Hulse M, et al. The Football Association Medical Research Program: an audit of injuries in professional football-analysis of preseason injuries. Br J Sports Med. 2002;36(6):436–41; discussion 41. doi:10.1136/bjsm.36.6.436.
5. Woods C, Hawkins RD, Maltby S, et al. The Football Association Medical Research Program: an audit of injuries in professional football—analysis of hamstring injuries. Br J Sports Med. 2004;38(1):36–41. doi:10.1136/bjsm.2002.002352.
6. Brooks JH, Fuller CW, Kemp SP, et al. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. Am J Sports Med. 2006;34(8):1297–306. doi:10.1177/0363546505286022.
7. Gabbett TJ. Incidence of injury in junior and senior rugby league players. Sports Med. 2004;34(12):849–59. doi:10.2165/00007256-200434120-00004.
8. Shankar PR, Fields SK, Collins CL, et al. Epidemiology of high school and collegiate football injuries in the United States, 2005–2006. Am J Sports Med. 2007;35(8):1295–303. doi:10.1177/0363546507299745.
9. Gabbe BJ, Bennell KL, Finch CF, et al. Predictors of hamstring injury at the elite level of Australian Football. Scand J Med Sci Sports. 2006;16(1):7–13. doi:10.1111/j.1600-0838.2005.00441.x.
10. Seagrave RA, Perez L, McQueeney S, et al. Preventive effects of eccentric training on acute hamstring muscle injury in professional baseball. Orthop J Sports Med. 2014;2(6):2325967114535351. doi:10.1177/2325967114535351.
11. Orchard J, James T, Kountouris A, et al. Changes to injury profile (and recommended cricket injury definitions) based on the increased frequency of Twenty20 cricket matches. Open Access J Sports Med. 2010;1:63–76.
12. Ekstrand J, Walden M, Hagglund M. Hamstring injuries have increased by 4 % annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. Br J Sports Med. 2016;50(12):731– + . doi:10.1136/bjsports-2015-095359.
13. Engebretsen AH, Myklebust G, Holme I, et al. Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. Am J Sports Med. 2010;38(6):1147–53. doi:10.1177/0363546509358381.
14. Petersen J, Thorborg K, Nielsen MB, et al. Acute hamstring injuries in Danish elite football: a 12-month prospective registration study among 374 players. Scand J Med Sci Sports. 2010;20(4):588–92. doi:10.1111/j.1600-0838.2009.00995.x.
15. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. Scand J Med Sci Sports. 2003;13(4):244–50.
16. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011;39(6):1226–32. doi:10.1177/0363546510395879.
17. Hagglund M, Walden M, Ekstrand J. Injuries among male and female elite football players. Scand J Med Sci Sports. 2009;19(6):819–27. doi:10.1111/j.1600-0838.2008.00861.x.
18. van Beijsterveldt AM, van de Port IG, Krist MR, et al. Effectiveness of an injury prevention program for adult male amateur soccer players: a cluster-randomised controlled trial. Br J Sports Med. 2012;46(16):1114–8. doi:10.1136/bjsports-2012-091277.
19. Soomro N, Sanders R, Hackett D, et al. The efficacy of injury prevention programs in adolescent team sports: a meta-analysis. Am J Sports Med. 2015;. doi:10.1177/0363546515618372.
20. van der Horst N, Smits DW, Petersen J, et al. The preventive effect of the nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial. Am J Sports Med. 2015;43(6):1316–23. doi:10.1177/0363546515574057.
21. Hagglund M, Walden M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med. 2006;40(9):767–72. doi:10.1136/bjsm.2006.026609.
22. Arnason A, Sigurdsson SB, Gudmundsson A, et al. Physical fitness, injuries, and team performance in soccer. Med Sci Sports Exerc. 2004;36(2):278–85. doi:10.1249/01.mss.0000113478.92945.ca.
23. Gouttebarge V, Hughes Schwab BA, Vivian A, et al. Injuries, matches missed and the influence of minimum medical standards in the A-League professional football: a 5-year prospective study. Asian J Sports Med. 2016;7(1):e31385. doi:10.5812/asjsm.31385.
24. Ebben WP. Hamstring activation during lower body resistance training exercises. Int J Sport Physiol Perform. 2009;4(1):84–96.
25. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength

training with eccentric overload. Scand J Med Sci Sports Med. 2003;13(4):244–50. doi:10.1034/j.1600-0838.2003.00312.x.
26. Brockett CL, Morgan DL, Proske U. Human hamstring muscles adapt to eccentric exercise by changing optimum length. Med Sci Sports Exerc. 2001;33(5):783–90.
27. Mjolsnes R, Arnason A, Osthagen T, et al. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. Scand J Med Sci Sports. 2004;14(5):311–7. doi:10.1046/j.1600-0838.2003.367.x.
28. Engebretsen AH, Myklebust G, Holme I, et al. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. Am J Sports Med. 2008;36(6):1052–60. doi:10.1177/0363546508314432.
29. Bahr R, Thorborg K, Ekstrand J. Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: the Nordic Hamstring survey. Br J Sports Med. 2015;49(22):1466–71. doi:10.1136/bjsports-2015-094826.
30. Steffen K, Myklebust G, Olsen OE, et al. Preventing injuries in female youth football—a cluster-randomized controlled trial. Scand J Med Sci Sports. 2008;18(5):605–14. doi:10.1111/j.1600-0838.2007.00703.x.
31. Gatterer H, Ruedl G, Faulhaber M, Regele M, Burtscher M. Effects of the performance level and the FIFA "11" injury prevention program on the injury rate in Italian male amateur soccer players. J Sports Med Phys Fitness. 2012;52(1):80–4.
32. F-MARC. FIFA 11 + a complete warm-up programme. http://f-marc.com. Accessed 23 May 2016.
33. Grooms DR, Palmer T, Onate JA, et al. Soccer-specific warm-up and lower extremity injury rates in collegiate male soccer players. J Athl Train. 2013;48(6):782–9. doi:10.4085/1062-6050-48.4.08.
34. Steffen K, Emery CA, Romiti M, et al. High adherence to a neuromuscular injury prevention program (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. Br J Sports Med. 2013;47(12):794–802. doi:10.1136/bjsports-2012-091886.
35. Hammes D, Aus der Funten K, Kaiser S, et al. Injury prevention in male veteran football players—a randomised controlled trial using "FIFA 11 + ". J Sports Sci. 2015;33(9):873–81. doi:10.1080/02640414.2014.975736.
36. Owoeye OB, Akinbo SR, Tella BA, et al. Efficacy of the FIFA 11 + warm-up program in male youth football: a cluster randomised controlled trial. J Sports Sci Med. 2014;13(2):321–8.
37. Al Attar WS, Soomro N, Pappas E, et al. How effective are F-MARC injury prevention programs for soccer players? a systematic review and meta-analysis. Sports Med. 2016;46(2):205–17. doi:10.1007/s40279-015-0404-x.
38. Petersen J, Thorborg K, Nielsen MB, et al. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. Am J Sports Med. 2011;39(11):2296–303. doi:10.1177/0363546511419277.
39. Goode AP, Reiman MP, Harris L, et al. Eccentric training for prevention of hamstring injuries may depend on intervention compliance: a systematic review and meta-analysis. Br J Sports Med. 2015;49(6):349–56. doi:10.1136/bjsports-2014-093466.
40. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009. doi:10.1136/bmj.b2535.
41. Caine D, Maffulli N, Caine C. Epidemiology of injury in child and adolescent sports: injury rates, risk factors, and prevention. Clin Sports Med. 2008;27(1):19–50, vii. doi:10.1016/j.csm.2007.10.008.
42. Egger M, Davey Smith G, Schneider M, et al. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629–34.
43. Duval S, Tweedie R. Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. Biometrics. 2000;56(2):455–63.
44. Furlan AD, Pennick V, Bombardier C, et al. 2009 updated method guidelines for systematic reviews in the Cochrane Back Review Group. Spine. 2009;34(18):1929–41. doi:10.1097/BRS.0b013e3181b1c99f.
45. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Br J Sports Med. 2006;40(3):193–201. doi:10.1136/bjsm.2005.025270.
46. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. BMJ. 2008;337:a2469. doi:10.1136/bmj.a2469.
47. Silvers-Granelli H, Mandelbaum B, Adeniji O, et al. Efficacy of the FIFA 11 + injury prevention program in the collegiate male soccer player. Am J Sports Med. 2015;43(11):2628–37. doi:10.1177/0363546515602009.
48. Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. Br J Sports Med. 2014;48(8):708–12. doi:10.1136/bjsports-2013-092524.
49. Croisier JL. Factors associated with recurrent hamstring injuries. Sports Med. 2004;34(10):681–95.
50. van Reijen M, Vriend I, van Mechelen W, et al. Compliance with sport injury prevention interventions in randomised controlled trials: a systematic review. Sports Med. 2016. doi:10.1007/s40279-016-0470-8.
51. Lephart SM, Ferris CM, Riemann BL, et al. Gender differences in strength and lower extremity kinematics during landing. Clin Orthop Relat Res. 2002;401(401):162–9.
52. Bourne MN, Opar DA, Williams MD, et al. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. Am J Sports Med. 2015;43(11):2663–70. doi:10.1177/0363546515599633.
53. Opar DA, Williams MD, Timmins RG, et al. Eccentric hamstring strength and hamstring injury risk in Australian Footballers. Med Sci Sports Exerc. 2015;47(4):857–65. doi:10.1249/mss.0000000000000465.
54. Gabbe BJ, Branson R, Bennell KL. A pilot randomised controlled trial of eccentric exercise to prevent hamstring injuries in community-level Australian Football. J Sci Med Sport. 2006;9(1–2):103–9. doi:10.1016/j.jsams.2006.02.001.
55. Brughelli M, Mendiguchia J, Nosaka K, et al. Effects of eccentric exercise on optimum length of the knee flexors and extensors during the preseason in professional soccer players. Phys Ther Sport. 2010;11(2):50–5. doi:10.1016/j.ptsp.2009.12.002.
56. Small K, McNaughton L, Greig M, et al. Effect of timing of eccentric hamstring strengthening exercises during soccer training: implications for muscle fatigability. J Strength Cond Res. 2009;23(4):1077–83. doi:10.1519/JSC.0b013e318194df5c.
57. Marshall PW, Robbins DA, Wrightson AW, et al. Acute neuromuscular and fatigue responses to the rest-pause method. J Sci Med Sport. 2012;15(2):153–8. doi:10.1016/j.jsams.2011.08.003.