Exercise Interventions to Prevent Hamstring Injuries in Athletes: A Systematic Review and Meta-Analysis.

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To cite this article: Rok Vatovec, Žiga Kozinc & Nejc Šarabon (2019): Exercise Interventions to Prevent Hamstring Injuries in Athletes: A Systematic Review and Meta-Analysis., European Journal of Sport Science, DOI: 10.1080/17461391.2019.1689300

To link to this article: https://doi.org/10.1080/17461391.2019.1689300

Accepted author version posted online: 02 Nov 2019.
Title: Exercise Interventions to Prevent Hamstring Injuries in Athletes: A Systematic Review and Meta-Analysis.

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Short title: Hamstring injury prevention: meta-analysis.

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Count: abstract (230 words), body text (3692 words), number of references (43), number of figures (2), number of tables (2)

Key words: prevention, strength, soccer, athletes, muscle injury.
ABSTRACT

The aim of this meta-analysis was to assess the effectiveness of exercise-based interventions for prevention of hamstring injuries in sport. PubMed, Cochrane Central Register of Controlled Trials, Web of Science, ResearchGate, CINAHL, PEDro, ScienceDirect and Google Scholar databases were searched for randomized controlled trials and prospective cohort studies exploring the effects of exercise interventions on hamstring injury incidence. Subgroup analyses were performed to determine effects of several independent variables related to the interventions. Altogether, 17 studies were included. Exercise interventions decreased hamstring injury risk (RR = 0.49; 95%CI = 0.40-0.59; p < 0.001). There were similar effects found for interventions performed ≤2 times per week (RR = 0.35; 95%CI = 0.15 – 0.82;) and the interventions performed >2 times per week (RR = 0.44; 95%CI = 0.31 – 0.61). Similarly, there were similar effects found for the interventions with progressive increase in load (RR = 0.53; 95%CI = 0.37 – 0.74) and the interventions with constant loads (RR = 0.46; 95%CI = 0.36 – 0.58). Other subgroup analyses (intervention supervision, sport type, inclusion of Nordic hamstring exercise and type of the trial) also showed no indications on specific characteristics of the interventions, that increase the preventive effects. Our findings showed that hamstring injury incidence can be decreased with exercise-based interventions, and that weekly frequency and load progression are not among the most important variables to consider in prevention programs design.

Key words: prevention, strength, soccer, athletes, muscle injury.
INTRODUCTION

Hamstring strain injuries are among the most common sport injuries. Previous studies reported high hamstring injury incidence in track and field (Alonso et al., 2009), soccer (Jan Ekstrand, Hägglund, & Waldén, 2011), American football (Brophy et al., 2008), rugby (Brooks, Fuller, Kemp, & Reddin, 2005), and Australian football (Orchard & Seward, 2002). The number of hamstring injuries in soccer has increased in the last decade (Ekstrand, Waldén, & Hägglund, 2016) and now they represent 12% of all injuries and require more than four weeks of recovery in 15.8% players (Ekstrand, Hägglund, & Walden, 2011). Along with a high injury incidence, a high rate of hamstring injury recurrence has been recognized (van der Horst et al., 2016). High injury and re-injury rates call for optimization of rehabilitation protocols and prevention programmes.

The hamstrings are two-joint muscles that span from the ischial tuberosity to the proximal part of the tibia, acting as agonists of hip extension and knee flexion. Most hamstring injuries occur during high-speed running (Brooks, Fuller, Kemp, & Reddin, 2006). Previous studies have managed to record an individual hamstring strain injury, while the subject was sprinting on a treadmill. After taking into account the latencies in the neuromuscular system, the authors concluded that the injury occurred in the late swing phase of the running cycle (Heiderscheit et al., 2005; Schache, Wrigley, Baker, & Pandy, 2009). In this phase, the hamstrings first contract eccentrically to decelerate the previously accelerated limb, and then transit into concentric contraction to produce hip extension. In this part of the running cycle, hamstrings reach their peak length, produce the largest force and perform majority of the negative work (Chumanov, Heiderscheit, & Thelen, 2011; Schache, Dorn, Blanch, Brown, & Pandy, 2012). Hamstring muscles also produce high forces in the early stance phase to counteract the hip torques and gravitational forces, while their length does not change substantially (Chumanov et al., 2011; Mann & Sprague, 1980).

The background of hamstring injuries is most often multi-factorial. Previous injury, increasing age, ethnicity, strength asymmetries, decreased flexibility and fatigue are factors commonly studied in relation to hamstring injury risk (Freckleton & Pizzari, 2013). Strength asymmetries shown to be associated with increased injury risk include contralateral strength asymmetries (Orchard, Marsden,
Lord, & Garlick, 1997), concentric knee flexion to concentric knee extension lower than 0.45 and eccentric knee flexion to concentric knee extensor lower than 0.80 (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008). Interestingly, a recent systematic review with meta-analysis failed to prove the effectiveness of isokinetic strength asymmetry testing for assessing the risk for sustaining hamstring injuries (Green, Bourne, & Pizzari, 2018). In soccer, individuals with straight-leg hip flexion ROM <90° are at increased risk for incurring a hamstring injury (Witvrouw, Danneels, Asselman, D’Have, & Cambier, 2003). The strongest risk factor associated with hamstring injuries is a previous hamstring injury. Hagglund, Waldén, & Ekstrand (2006) reported that a previous hamstring injury increases the likelihood for sustaining a new one by 3.5-fold, which indicates a high value of primary prevention.

Primary prevention focuses on modifying risk factors associated with injuries, which most commonly include flexibility deficits, particularly hamstring flexibility, and strength deficits, notably eccentric hamstring strength and quadriceps to hamstring strength ratio (Heiderscheit, Sherry, Silder, Chumanov, & Thelen, 2010). Al Attar, Soomro, Sinclair, Pappas, & Sanders (2017) conducted a systematic review with meta-analysis to evaluate the preventive effects of Nordic Hamstring Exercise (NHE) on hamstring injury incidence in soccer players. They concluded that interventions including NHE significantly reduced the incidence of hamstring injuries by 50%. Another way to load the hamstring in eccentric conditions is performing eccentric actions on a flywheel device. Such exercise was shown to decrease the incidence of hamstring injuries in Swedish soccer players (Askling, Karlsson, & Thorstensson, 2003). Other effective interventions to prevent hamstring injuries include home balance training programme for women soccer players (Söderman, Werner, Pietilä, Engström, & Alfredson, 2000) and implementation of the FIFA11+ soccer warm-up in regular training (Silvers-Granelli et al., 2015; Soligard et al., 2008).

The only recent meta-analysis in the field of hamstring injury prevention has analysed only interventions that included NHE (Al Attar et al., 2017). Furthermore, there seems to be a lack of studies comparing interventions based on independent variables (i.e. specific characteristics of the exercise programmes, such as weekly frequency, progression of the exercise volume or intensity, type of exercise, supervision of the exercise). Therefore, the aim of this study was to conduct a meta-
analysis on the effectiveness of exercise-based interventions for prevention of hamstring injuries and
to compare the interventions based on their independent variables. The authors hypothesised that
exercise interventions significantly decrease hamstring injury risk, regardless of the intervention sub-
type. Additionally, we anticipated dominating effects of (1) interventions involving exercise
progression in exercise intensity, volume and/or content and (2) interventions performed at higher
weekly training frequency (≥ 2 x/week).

METHODS

We followed the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA)
guidelines during all stages of data collection, synthesis and reporting (Moher, Liberati, Tetzlaff,
Altman, & PRISMA Group, 2009).

Study Selection

Studies were included if they met criteria defined based on the PICOS search tool (Methley,
Campbell, Chew-Graham, McNally, & Cheraghi-Sohi, 2014):

- Population (P): Adult or adolescent elite, collegiate or amateur athletes
- Intervention (I): Exercise based interventions (strength, power, stability, balance or flexibility
  training and any combination of those);
- Comparisons (C): Control group, receiving no intervention or placebo intervention;
- Outcome (O): Incidence of hamstring injury in experimental and control groups per 1000h of
  exposure (training/match).
- Study designs (S): Randomized Controlled Trials, Prospective cohort studies with control
  groups.
- Other inclusion criteria: Article published in English language.

Search strategy

Several databases (PubMed, Cochrane Central Register of Controlled Trials, Web of Science,
ResearchGate, CINAHL, PEDro, ScienceDirect and Google Scholar) were searched in May 2019
using a single search term, combined with Boolean Phrases - *hamstring AND (injury OR strain OR avulsion OR rupture) AND (prevention OR rehabilitation OR treatment OR exercise)*. Due to the unmanageable number of hits (>65,000), only first 1000 articles, using relevance filtration, were screened for Google Scholar database. Reference lists of relevant published systematic reviews and included studies were additionally reviewed. Database search was performed independently by two authors (RV and ZK).

**Study selection**

Two reviewers (RV and ZK) independently screened the titles and the abstracts. Potentially relevant articles were screened in full text, followed by additional screening for their eligibility by the third reviewer (NS).

**Quality assessment**

Study quality was assessed by two authors (RV and NS) using the PEDro Scale (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003), which assesses study quality based on a ten-level scale. Potential disagreements between scores were resolved by consulting the third author (ZK) and additional revision. Studies scoring from 9 - 10 scores were considered as ‘excellent’, 6 - 8 as ‘good’, 4 - 5 as ‘fair’ and less than 4 as ‘poor’ quality. Since PEDro scale was primarily designed to assess randomized controlled trials, the risk of bias assessment results for prospective cohort studies should be interpreted cautiously. The maximum PEDro score for a prospective cohort study is 8.

According to PEDro Scale, study quality was assessed for the following domains: 1. subjects were randomly allocated to groups, 2. allocation was concealed, 3. the groups were similar at baseline regarding the most important prognostic indicators, 4. there was blinding of all subjects, 5. there was blinding of all therapists who administered the therapy, 6. there was blinding of all assessors who measured at least one key outcome, 7. measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups, 8. all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by “intention to treat”, 9. the results of between-group
statistical comparisons are reported for at least one key outcome, 10. the study provides both point measures and measures of variability for at least one key outcome.

**Data extraction**

Study design, intervention (type, duration, intensity, supervision), population (sex, number, average age and average BMI, sport type), injury definition and outcome data from eligible studies were extracted and entered into Microsoft Excel 2016 (Microsoft, Redmond, USA). If only risk measures were reported without sample size or number of injuries per 1000h of exposure, the authors of a respective article were contacted in order to obtain the missing information. In two cases, a study included two intervention groups, which were treated as a separate study when pooling results to obtain total effect size.

**Data synthesis and analysis**

Review Manager (Version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) was used for quantitative analysis using random effects model (weighted for study sample size) and inverse variance method for pooling the main effect. Numbers of injuries per 1000h of exposure in intervention and control group, as well as sample sizes were entered for analysis. Effect sizes were expressed as risk ratios (RR) and were calculated with respective 95% confidence intervals (95%CI). Additionally, subgroup analyses were performed, based on (a) weekly intervention frequency (≤2 times a week vs. >2 times a week) (b) inclusion of NHE exercise in the program (as the only exercise or within a multi-exercise program) (c) inclusion of progression in intervention, which we defined as an increase of volume, load or both at any time throughout the intervention period, (d) supervision of the exercise, (e) type of sport and (f) type of trial (RCT vs prospective cohort studies). Statistical heterogeneity among studies was assessed by calculating $I^2$ statistics. The statistical significance threshold was set at $p \leq 0.05$ for all analyses.

**RESULTS**
After removal of the duplicates, 3951 titles were identified as potentially relevant for our meta-analysis. After screening the titles, 73 studies were included for abstract examination. Twenty-seven studies were left for full-text evaluation, upon which 16 studies were left. In addition, 1 study was found through screening the reference lists of present systematic reviews. Therefore, our meta-analysis included 17 studies altogether (10 randomized controlled trials, 7 prospective cohort studies). Figure 1 summarizes the process of database search and study selection. Characteristics of individual studies, including the PEDro score, are available in Tables 1 and 2.

The scores of quality assessments ranged from 4 to 6 (median = 5) for randomized controlled trials, and from 2 to 5 (median = 2) for prospective cohort studies. The differences between study types occurred mostly because of the non-randomized nature of the prospective cohort studies. In both study types, blinding of the subjects, therapists and assessors was the most common issue. Funnel plot of the studies can be also found as a Supplementary file 1.

Exercise interventions decreased the incidence of hamstring injuries by 51 % (RR = 0.49; 95%CI = 0.40-0.59; p < 0.001; I² = 54 %) compared to control groups, which maintained their regular training regimen. There were similar pooled effects found for randomized controlled trials (RR = 0.47; 95%CI = 0.31-0.79; I² = 54%) and prospective cohort studies (RR = 0.49; 95%CI = 0.39-0.62; I² = 59%) (p = 0.84 for subgroup differences). Similarly, comparable reductions of injury risk (65% and 56 %) were found for interventions performed ≤2 times per week (RR = 0.35; 95%CI = 0.15 – 0.82; p < 0.02; I² = 74 %) and the interventions performed >2 times per week (RR = 0.44; 95%CI = 0.31 – 0.61; p < 0.001; I² = 60 %), respectively (p = 0.62 for subgroup differences). Moreover, similar effects were found for interventions with progressive increase in exercise intensity or volume (RR = 0.53; 95%CI = 0.37 – 0.74; p < 0.001; I² = 48 %) and the interventions with constant loads (RR = 0.46; 95%CI = 0.36 – 0.58; p < 0.001; I² = 49 %).
Interventions including the NHE exercise reduce the injury risk by 54% (RR = 0.46; 95%CI = 0.35-0.60; p < 0.001; I² = 51%), similar to the interventions not including NHE, which reduced the hamstring injury risk by 48% (RR = 0.52; 95%CI = 0.38-0.72; p < 0.001; I² = 60%) also revealed comparable effects. Moreover, similar effects were found for supervised (RR = 0.48; 95%CI = 0.39-0.58; I² = 53%) and non-supervised interventions (RR = 0.60; 95%CI = 0.27-1.35; I² = 56%). Note that only 3 studies fall into non-supervised category. The last subgroup analysis was conducted to compare interventions carried-out on soccer players (RR = 0.49; 95%CI = 0.42-0.57; I² = 63%) and other sports (RR = 0.39; 95%CI = 0.31-0.49; I² = 40%). The effects were similar in both subgroups, with 51% and 61% reductions in hamstring injury risk, respectively. Note that majority of the studies (n = 14) were carried out on soccer players.

An additional analysis was performed only for the interventions including FIFA 11+ warm-up intervention, which turned out to reduce hamstring injury risk by 55% (RR = 0.45; 95%CI = 0.34 – 0.61; p < 0.001; I² = 0%).

**Discussion**

The aim of this study was to review the studies exploring the effects of exercise interventions on hamstring injury incidence, and to perform meta-analysis with sub-group analysis to explore the effects of different independent variables (intervention and population characteristics) on the magnitude of preventive effects. Our results showed that exercise interventions reduce the incidence of hamstring injuries by about 50%. This is in accordance with the previous review by Al Attar et al. (2017), who reported that interventions including NHE successfully decrease the risk for sustaining a hamstring injury.

Interventions with a higher weekly frequency (>2) do not seem to be more effective than those with lower frequency (≤2). A recent meta-analysis (Ralston, Kilgore, Wyatt, Buchan, & Baker, 2018) reported negligible differences in strength gains between exercise programs with different weekly frequencies.
frequency. Considering that exercise interventions included in this review are largely resistance-
exercise based, this is not surprising. Unfortunately, there was a high heterogeneity between studies
regarding reporting the volume of the exercise, with some authors reporting set and repetitions, some
reported duration and some did not report it at all. Due to these discrepancies, additional subgroup
could not be performed to elucidate the effects of weekly exercise volume. To conclude, two exercise
sessions per week appear to be a sufficient stimulus to provide protective effects for hamstring
muscles, which is consistent with the insights on the field of resistance training adaptations.

Similarly, comparison of exercise programs with and without load (volume or intensity) progression
showed comparable effects. This implies that constant stimulus is sufficient for reducing injury risk. It
is also important to note that for the NHE, the load may increase through the exercise program without
adding extra load, as weaker athletes are not able to perform the NHE through full range of motion at
first (Ditroilo, De Vito, & Delahunt, 2013). Thus, such individuals will experience load progression
mirrored in higher range of active motion while performing NHE. Moreover, the duration of some
interventions was perhaps too short for progression to be justified. Supervision of the training also did
not seem to play the role in reducing hamstring injury risk. However, only 3 studies in this review
used unsupervised intervention, therefore limiting the strength of this analysis. There were also similar
effects between programs performed on soccer players and other population, but this analysis was also
limited by ratio in number of the studies between subgroups (13 and 4, respectively).

Furthermore, comparison of interventions including NHE and other interventions showed to have
similar effects. Several authors have associated hamstring eccentric weakness with increased risk for
injury (Opar, Williams, & Shield, 2012). A 10-week intervention including NHE and load progression
improved hamstring eccentric strength at 60°/s for 11% (Mjolsnes, Arnason, osthagen, Raastad, &
Bahr, 2004), while Brockett, Morgan, & Proske (2001) showed that performing NHE shifts the
optimal angle for torque development towards longer muscle lengths. A systematic review has
reported that eccentric exercise improves flexibility of the muscle-tendon complex (O’Sullivan,
McAuliffe, & Deburca, 2012). Performing eccentric exercises for 6 weeks can improve hamstring
reported that preseason eccentric training on a flywheel reduces the risk for sustaining a hamstring injury in soccer players. Considering all these data, performing NHE exercise seems to be a very promising way for hamstring injury prevention. However, this exercise is not without limitations. In NHE, the movement is limited to the knee, while the hip is static, which is not the case for most movements in sport. Furthermore the exercise is demanding and fatiguing (Marshall, Lovell, Knox, Brennan, & Siegler, 2015), and the hamstrings do not always reach longer lengths, while it was suggested that hamstring injury occurs at long muscle lengths, either during swing phase of running (Askling, Tengvar, Saartok, & Thorstensson, 2007a) or other lengthened positions (Askling, Tengvar, Saartok, & Thorstensson, 2007b). Considering that our analysis showed similar effects of programs including NHE and those that do not include it, we can conclude that other exercises, if chosen properly, can reduce the rates of hamstring injuries at least as good as the NHE.

Balance ability has been consistently shown to be associated with injury risk (for review, see Hrysomallis (2007)). In this paper, two randomized controlled trials that studied the preventive effect of balance training on hamstring injury incidence were included. Emery, Rose, McAllister, & Meeuwisse (2007) concluded that adding 5 minutes of balance training to a regular warm-up in addition to a balance based home programme decreased the incidence of hamstring injuries. Similarly, Söderman et al. (2000) reported that a home balance training programme reduces the risk for sustaining a hamstring injury in female soccer players. The intervention group performed the home balance programme, comprising 5 exercises, every day for the first month, and 3 times a week for the rest half year. The combined effect of these two studies was very high (RR = 0.22; 95%CI = 0.05-1.05.) It has been suggested that balance training improves inter-muscular coordination (leading to enhanced active joint stability) and helps to reduce knee valgus during landing movements (Hrysomallis, 2007).

Authors have previously associated decreased hamstring flexibility with increased risk for sustaining a hamstring injury. For instance, previously injured soccer players were found to have 6° smaller range of motion for straight-leg hip flexion ROM (Witvrouw, Danneels, Asselman, D’Have, & Cambier, 2003). Increasing hamstring flexibility is implicated in particular in relation to maximal-stretch-
mechanism injuries (Askling et al., 2007b). Two studies in this review included substantial amount of stretching in their exercise programs. Arnason, Andersen, Holme, Engebretsen, & Bahr (2007) showed that passive stretching after training and proprioceptive neuromuscular facilitation stretching during warm-up reduced the incidence of hamstring injuries in soccer players. Verrall, Slavotinek, & Barnes (2005) decreased the number of hamstring injuries by implementing several preventive measures, including hamstring passive stretching. Further research is needed to evaluate the isolated effect of stretching on hamstring injury incidence.

Implementation of the FIFA11 and FIFA11+ warm-up reduces the incidence of hamstring injuries in soccer players. Two studies on the preventive effect of the FIFA11+ warm-up were included in our meta-analysis. Both of them concluded that introduction of the FIFA11+ reduced the incidence of hamstring injuries, with similar effect size compared to overall pooled effect of all studies.

Limitations

Several limitations of this systematic review and meta-analysis should be acknowledged. First, only papers in English language were included for the review, leaving the possibility that studies in other languages have been missed out. Second, we did not consider re-injuries in this review. Therefore, the effectiveness of the interventions is only relevant in context of primary prevention of hamstring injuries. Third, the effects of several independent variables, such as level of play and injury definition within the individual studies remain unexplored, due to substantial heterogeneity in definition and reporting between authors. Fourth, a lot of exercise programs are multi-modal, containing balance, resistance and/or flexibility exercise. It is difficult to determine the most important exercise mode for hamstring injury prevention, although all three seem to be effective as an isolated intervention. Careful combination and modulation of all exercise modes is probably the best approach for coaches for now, with consideration of individuals’ characteristics, such as strength and flexibility deficits. Finally, one of the specific concerns arise from splitting the interventions between NHE and non-NHE for one of the subgroup comparisons. We classified interventions that included NHE as part of a multi-exercise program (such as FIFA 11+) into the NHE subgroup. It is therefore not entirely clear, whether NHE on
its own or as a part of a broader program is more effective. Included studies had a relatively high risk of bias, which can be explained to some point with the fact that it is almost impossible to ensure blinding in exercise intervention studies, which can reduce the PEDro score up to 3 points. Thus, the lack of studies assessed as high-quality should not be attributed to poor experience or skill of the researchers on the field, but rather to the nature of the exercise-based intervention protocols.

Conclusion

The aim of this paper was to systematically review and meta-analytically assess the effects of exercise interventions on the incidence of hamstring injuries in sport. Our results confirmed the findings from previous reviews, which showed that interventions are successful in reducing hamstring injury risk. Furthermore, this meta-analysis showed that weekly frequency and load progression are not among the most important variables in these interventions. All eccentric exercise, balance training and muscle stretching are effective strategies to reduce hamstring injury rates. Additionally, a specific warm-up routine (FIFA 11+), which includes a combination of resistance and balance exercises, was found to be a good example of time-efficient and effective comprehensive intervention in this respect.

Acknowledgements

The study was supported by the Slovenian Research Agency through the program "Kinesiology of monostructural, polystructural and conventional sports (P5-0147 (B)) and the project TELASI-PREVENT (Body asymmetries as a risk factor in musculoskeletal injury development: studying etiological mechanisms and designing corrective interventions for primary and tertiary preventive care). The authors alone are responsible for the content and writing of this article.

**Declarations of interest:** The authors report no conflict of interest
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Methley, A. M., Campbell, S., Chew-Graham, C., McNally, R., & Cheraghi-Sohi, S. (2014). PICO,
https://doi.org/10.1186/s12913-014-0579-0

https://doi.org/10.1046/j.1600-0838.2003.367.x


LIST OF FIGURES

Figure 1. Flowchart of database search and study selection.

Database items after removal of the duplicates (n = 3951)

Papers included after title screening (n = 73)

Full-text retrieved after abstract screening (n = 27)

Included upon full text screening (n = 16)

Excluded upon abstract examination (n = 46);
- not addressing hamstring injury prevention (n = 46)

Excluded upon full text examination (n = 11);
- cross-over studies (n = 5)
- study protocols (n = 4)
- duplicates of the same study (n = 2)

Identified through additional search (n = 1)

Included in the meta-analysis (n = 17)
Figure 2. Forrest plot of meta-analysis showing all studies and subgroup analysis based on study type. Single paper including multiple experimental cohorts is listed twice, with different letter label (a,b) following year of publication.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Risk Ratio Random, 95% CI</th>
<th>Risk Ratio Random, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.1.1 Randomized controlled trials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Askling et al. 2003</td>
<td>0.30 [0.10, 0.88]</td>
<td></td>
</tr>
<tr>
<td>Emery et al. 2007</td>
<td>0.29 [0.03, 2.75]</td>
<td></td>
</tr>
<tr>
<td>Engebretsen et al. 2008</td>
<td>1.09 [0.57, 2.06]</td>
<td></td>
</tr>
<tr>
<td>Petersen et al. 2011</td>
<td>0.30 [0.17, 0.53]</td>
<td></td>
</tr>
<tr>
<td>Sebrell et al. 2014</td>
<td>0.08 [0.00, 1.31]</td>
<td></td>
</tr>
<tr>
<td>Silvers-Granelli et al. 2015</td>
<td>0.37 [0.21, 0.63]</td>
<td></td>
</tr>
<tr>
<td>Soligard et al. 2008</td>
<td>0.50 [0.16, 1.51]</td>
<td></td>
</tr>
<tr>
<td>Soderman et al. 2000</td>
<td>0.18 [0.02, 1.42]</td>
<td></td>
</tr>
<tr>
<td>van de Hoef et al. 2019</td>
<td>0.89 [0.56, 1.44]</td>
<td></td>
</tr>
<tr>
<td>van der Horst et al. 2015</td>
<td>0.43 [0.22, 0.86]</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td>0.47 [0.31, 0.70]</td>
<td></td>
</tr>
<tr>
<td><strong>Total events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heterogeneity: Tau² = 0.19; Chi² = 19.48, df = 9 (P = 0.02); I² = 54%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test for overall effect: Z = 3.73 (P = 0.0002)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **1.1.2 Prospective cohort studies** | | |
| Arnason et al. 2008a | 0.63 [0.48, 0.84] | | |
| Arnason et al. 2008b | 0.85 [0.57, 1.25] | | |
| Brocks et al. 2008a | 0.54 [0.40, 0.73] | | |
| Brocks et al. 2006b | 0.35 [0.26, 0.51] | | |
| Grooms et al. 2013 | 0.18 [0.02, 1.43] | | |
| Kraemer et al. 2009 | 0.40 [0.29, 0.56] | | |
| Nouni-Garcia et al. 2017 | 0.51 [0.35, 0.75] | | |
| Seagave et al. 2014 | 0.08 [0.00, 1.43] | | |
| Verrall et al. 2005 | 0.30 [0.14, 0.61] | | |
| **Subtotal (95% CI)** | 0.49 [0.39, 0.62] | | |
| **Total events** | | | |
| Heterogeneity: Tau² = 0.06; Chi² = 19.62, df = 8 (P = 0.01); I² = 59% | | |
| Test for overall effect: Z = 5.96 (P < 0.00001) | | |

| | | |
| **Total (95% CI)** | 0.49 [0.40, 0.59] | | |
| **Total events** | | | |
| Heterogeneity: Tau² = 0.06; Chi² = 39.08, df = 18 (P = 0.003); I² = 54% | | |
| Test for overall effect: Z = 7.05 (P < 0.00001) | | |
| Test for subgroup differences: Chi² = 0.04, df = 1 (P = 0.84); I² = 0% | | |
### Table 1: Characteristics of randomized controlled trials

<table>
<thead>
<tr>
<th>Study with PEDro Score</th>
<th>Population characteristics and sample size (experimental; control)</th>
<th>No. of injuries</th>
<th>Injury definition</th>
<th>Data collection method and timeframe</th>
<th>Intervention</th>
<th>Supervision</th>
<th>Progressive intervention</th>
<th>Weekly frequency</th>
<th>Exercise volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petersen et al., 2011 (PEDro = 6)</td>
<td>Professional and amateur male soccer players; mean age 23.25 years (n = 461; 481)</td>
<td>15</td>
<td>Acute</td>
<td>Physical therapists and medical staff; standardized injury registration form (1 year)</td>
<td>Yes: (physical) coach</td>
<td>Yes</td>
<td>Progressively increased up to 3 ×; Maintenance: 1 ×</td>
<td>10 weeks of NHE exercises</td>
<td>3 sets</td>
</tr>
<tr>
<td>van der Horst et al., 2015 (PEDro = 5)</td>
<td>High-level amateur male</td>
<td>31</td>
<td>Any</td>
<td>Physiotherapists and medical staff; special form</td>
<td>Yes: team coach</td>
<td>Yes</td>
<td>2×</td>
<td>13 weeks of NHE exercises</td>
<td>3 sets</td>
</tr>
<tr>
<td>Study</td>
<td>Author</td>
<td>Setting</td>
<td>Participants</td>
<td>Intervention</td>
<td>Follow-up</td>
<td>Outcomes</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Askling et al., 2003</td>
<td>Professional male soccer players; mean age: 24.5 years (n = 292; 287)</td>
<td>eccentric exercise using flywheel</td>
<td>No; No</td>
<td>10 weeks</td>
<td>Only before study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emery et al., 2007</td>
<td>Adolescent high school basketball players (male and female); mean age: 25 years (n = 15)</td>
<td>eccentric exercises</td>
<td>Yes</td>
<td>18 weeks</td>
<td>(war-up):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Intervention Details:**
- Askling et al., 2003: 10 weeks of eccentric exercise using flywheel.
- Emery et al., 2007: 18 weeks of balance exercises.

**Follow-up:**
- Askling et al., 2003: 10 weeks.
- Emery et al., 2007: 18 weeks.

**Outcomes:**
- Askling et al., 2003: Only before study.
- Emery et al., 2007: (war-up):
<table>
<thead>
<tr>
<th>Study</th>
<th>Gender</th>
<th>Age (years, n)</th>
<th>Injury causing session or match; further classification</th>
<th>Exercise description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Söderman et al., 2000 (PEDro = 4)</td>
<td>Female</td>
<td>6 (n = 494; 426)</td>
<td>All traumatic injuries resulting in absence of at least one training session or match; further classification</td>
<td>Half year of single-leg exercises</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1st month: 5 exercises; 7 × 3×15s for each leg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rest of the season: 3 ×</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soligard et al., 2008 (PEDro = 5)</td>
<td>Young</td>
<td>15.4 (n = 1055; 837)</td>
<td>Injury causing player to be unable to fully participate in next match or training session</td>
<td>Each training session and match: 20 min</td>
</tr>
<tr>
<td>Study</td>
<td>Gender</td>
<td>Age Range</td>
<td>Sports Injury</td>
<td>Treatment Length</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-----------</td>
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<td>------------------</td>
</tr>
<tr>
<td>Silvers-Granelli et al., 2015 (PEDro = 6)</td>
<td>Male</td>
<td>18 – 25 years (n = 675; 850)</td>
<td>Physical complaint</td>
<td>5 months</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>Team athletes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>home</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Engbretsen et al., 2008 (PEDro = 5)</td>
<td>Male</td>
<td>18 – 36 years (n = 60; 59)</td>
<td>Physical complaint</td>
<td>10 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>of NHE exercises</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sebelien et al., 2014 (PEDro = 5)</td>
<td>Semi-professional</td>
<td>18 – 36 years (n = 60; 59)</td>
<td>POSTERIOR THIGH PAIN</td>
<td>14 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>WITH DIRECT CONTACT</td>
<td>(1 year)</td>
</tr>
</tbody>
</table>
Van de Hoef et al., 2019 (PEDro = 4)

<table>
<thead>
<tr>
<th>Amateurs</th>
<th>E</th>
<th>Not reported</th>
<th>Player completed a short report every week; medical staff</th>
<th>One season (39 weeks) of bounding exercise program</th>
<th>Yes</th>
<th>Yes</th>
<th>2 × (addition to regular training)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male soccer players; mean age: 23 years (n = 229; 287)</td>
<td>E = 31</td>
<td>C = 26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 – 5 minutes</td>
</tr>
</tbody>
</table>

**NHE** - Nordic hamstring exercise; **E** – experimental group; **C** – control group
Table 2: Characteristics of prospective cohort studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Population characteristics and sample size (experimental; control)</th>
<th>Injuries on the hamstring that prevented a player to take full part in the next planned activity</th>
<th>Data collection method and time frame</th>
<th>Intervention Supervision</th>
<th>Progression Intervention</th>
<th>Weekly frequency</th>
<th>Exercise volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooks et al., 2006a</td>
<td>Professional male rugby players; mean age: 25.5 years (n = N/A)</td>
<td>Any injury to the hamstring reported using standard report form (2 seasons)</td>
<td>Team medical personnel reported</td>
<td>Yes</td>
<td>No</td>
<td>Strength: 1.8 × 7.5</td>
<td>Stretch: 2.6 × 25 s</td>
</tr>
<tr>
<td>PEDro = 5</td>
<td></td>
<td>Two seasons of strengthening and stretching exercises</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brooks et al., 2006b</td>
<td>Professional male rugby players; mean age: 25.5 years (n = N/A)</td>
<td>Any injury to the hamstring reported using standard report form (2 seasons)</td>
<td>Team medical personnel reported</td>
<td>Yes</td>
<td>No</td>
<td>Strength: 1.3 × 7.5</td>
<td>Stretch: 2.6 × 28 s</td>
</tr>
<tr>
<td>PEDro = 5</td>
<td></td>
<td>Two seasons of strengthening and stretching exercises, including NHE</td>
<td></td>
<td></td>
<td></td>
<td>NHC: 1.3 × NHE: 2.8</td>
<td>6.7</td>
</tr>
</tbody>
</table>
Arnason et al., 2008a
PEDro = 2
Profession: Male soccer players; (n = N/A)
E = 72, C = 11, 4
4 (per 10,000h)
Any acute injury from muscle action that prevented the player to participate in next match or training session
Registers by team physiotherapist using specific form (1 year)
One season of PNF stretching during warm-up, static stretching and NHE after training
Preseason: Yes, Yes, (Only NHE)
Season: 3 ×; PNF: 3×30s, Stretching: 3×8-12

Arnason et al., 2008b
PEDro = 2
Profession: Male soccer players; (n = N/A)
E = 44, C = 52
4 (per 10,000h)
Any acute injury from muscle action that prevented the player to participate in next match or training session
Registers by team physiotherapist using specific form (1 year)
One season of PNF stretching during warm-up, static stretching after training
Preseason: Yes, No
Season: 3 ×; PNF: 3x30s, Stretching: 3 × 45s
<table>
<thead>
<tr>
<th>Study</th>
<th>PEDro</th>
<th>College</th>
<th>E</th>
<th>A Limitation</th>
<th>Training Program</th>
<th>Frequency</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grooms et al., 2013</td>
<td>3</td>
<td>Collegiate</td>
<td>1</td>
<td>Male</td>
<td>5 years; 18 – 25 years, mean age: 20.1 years (n = 34;30 )</td>
<td>Reported by athletic trainer (2 seasons)</td>
<td>Yes; Yes</td>
</tr>
<tr>
<td>Kraemer et al., 2009</td>
<td>2</td>
<td>Elite</td>
<td>48</td>
<td>Female</td>
<td>21 years (n = N/A)</td>
<td>Any physical complaint that resulted in medical attention and loss of at least 1 day of activity</td>
<td>Yes</td>
</tr>
<tr>
<td>Verrall et al., 2005</td>
<td>2</td>
<td>Professional</td>
<td>8</td>
<td>Male</td>
<td></td>
<td>2 years of balance and stability exercise</td>
<td>Yes</td>
</tr>
<tr>
<td>Study</td>
<td>Nationality</td>
<td>PEDro</td>
<td>Occupation</td>
<td>Number of Participants</td>
<td>Inclusion Criteria</td>
<td>Exclusion Criteria</td>
<td>One Season of NHE Exercise</td>
</tr>
<tr>
<td>----------------------------------------------</td>
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<td>-------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Seagrave et al., 2014</td>
<td>Professional Male Baseball Players (n = 65; 34)</td>
<td>2</td>
<td>Any injury to the hamstrings that caused removal from line-up for at least 1 day; based on clinical examination</td>
<td>Yes: strength and conditioning coach</td>
<td>No: reported.</td>
<td>Not reported.</td>
<td>Yes: strength and conditioning coach</td>
</tr>
<tr>
<td>Nouni-Garcia et al., 2017</td>
<td>Amateur European Soccer Players (n = 43; 43)</td>
<td>4</td>
<td>Injury causing an absence from next training session or match;</td>
<td>Yes: team physical therapist</td>
<td>No: reported.</td>
<td>2</td>
<td>2 × 15 min</td>
</tr>
</tbody>
</table>
NHE - Nordic hamstring curl exercise; N/A – sample size not reported; E – experimental group; C – control group