Prevention of hamstring injuries in male soccer

Exercise programs and return to play

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Exercise programs and return to play

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(met een samenvatting in het Nederlands)

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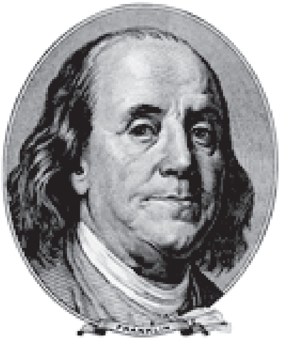

"An ounce of prevention is worth a pound of cure"

- Benjamin Franklin (1706 – 1790)

The name of the 'hamstrings' muscle appears to originate from the early butchery trade in the second half of the 16th century.[1] Slaughtered pigs were hung from their strong tendons on the back of the upper leg, hence the reference to 'ham' (meaning 'crooked' and thus referring to the knee, the crooked part of the leg) and 'string' (referring to the string-like appearance of the tendons).[2]

General introduction

Injury prevention is a vital part of any sport. Soccer is the most popular sport worldwide, with more than 275 million participants of both sexes and among all age groups.[3] Unfortunately, the beneficial health effects of playing soccer regularly are tempered by a high injury rate.[4-9] Injury incidence rates of 20.4–36.9 injuries per 1000 match hours and 2.4–3.9 injuries per 1000 training hours have been reported in male amateur soccer, which is the largest subgroup of soccer players.[4,10] Hamstring injuries are the most common soccer-related muscle injury, accounting for 37% of all soccer muscle injuries. They require extensive treatment and long rehabilitation periods.[4,6,11,12] The amount of tissue damage of the hamstring muscle determines when the affected player can start playing soccer again.[13] Hamstring injuries are commonly graded from 0 to 3, based on MRI-findings (see Table 1.1).[14] Ekstrand et al. found that soccer players with grade 0 hamstring injuries could resume full training after 8 (± 3) days; the lay-off time was 17 (± 10) days for grade 1 injuries, 22 (± 11) days for grade 2 injuries, and 73 (± 60) days for grade 3 injuries.[13]

Table 1.1 Radiological grading of hamstring injury[13]

Grade 0	Negative MRI without any visible pathology
Grade I	Oedema but no architectural distortion
Grade II	Architectural disruption indicating partial tear
Grade III	Total muscle or tendon rupture

Hamstring injuries are notorious for their high rate of recurrence (12–33%).[11,12,15,16] Unfortunately, despite extensive research into the rehabilitation of hamstring injuries, injury occurrence and recurrence rates have not improved in the last 30 years.[17-19] The high recurrence rate is suggested to be due to inadequate rehabilitation and/or a too early return-to-play after a hamstring injury.[20,21]

Understanding the functional anatomy, aetiology and mechanisms of injuries is essential to understanding the causes of any particular type of injury in a given sport.[22] It also makes it possible to design preventive strategies.[22]

Terminology and functional anatomy of the hamstrings

The collective term 'hamstrings' refers to three posterior thigh muscles; the semitendinosus muscle, the semimembranosus muscle and the biceps femoris muscle, the latter consisting of a long head and a short head.[23] The hamstring muscles originate at the ischial tuberosity, from where the semimembranosus, semitendinosus, and long head of the biceps femoris pass posterior from the hip and knee joints (see Figure 1.1). The short head of the biceps femoris is monoarticular, crossing only the knee joint. The main function of the hamstrings is knee flexion and hip extension, but they also assist in internal (semimembranosus and semitendinosus) and external (biceps femoris) rotation of the knee.

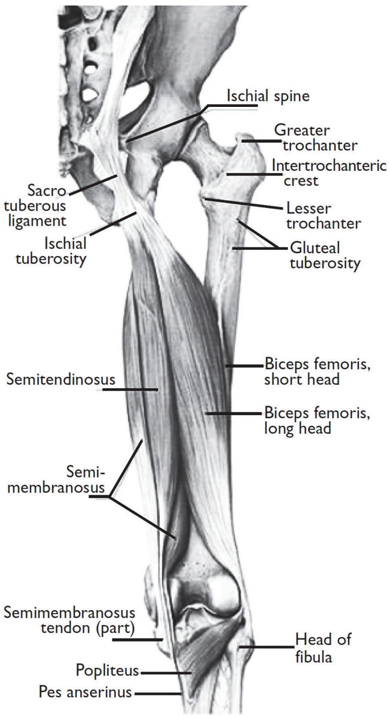

Figure 1.1 Anatomy of the hamstrings.

Aetiology and injury mechanisms of hamstring injuries

Hamstring injuries can be subdivided into two types: the stretch-type hamstring injury and the sprint-type hamstring injury. Stretch-type hamstring injuries are caused by a slow or sudden uncontrolled stretch and occur most frequently in dancing, gymnastics, and (water)skiing.[12] This type of injury typically occurs in the proximal free tendon of the semimembranosus muscle.[24] Although the clinical presentation of the stretch-type injury is usually mild at first, this type of hamstring injury generally implies a longer rehabilitation time.[24]

Sprint-type hamstring injuries occur in explosive running and cutting sports, such as soccer, athletics, rugby, field hockey, and the various varieties of football (e.g. soccer, Australian Rules Football, American Football etc.). In more than 80% of cases, the injury is located in the long head of the biceps femoris.[25,26] Biomechanical analyses have shown that sprint-type hamstring injuries typically occur in the latter part of the swing phase during sprinting.[27-29] Before the foot hits the ground, the hamstring is (sub)maximally stretched over the knee joint, but at the same time it has to counter isokinetic forces from the preswinging leg.[27,28] The higher the sprinting velocity, the greater these isokinetic forces are.[27,28] The vulnerability of the hamstrings to injury during this phase of sprinting is associated with insufficient eccentric hamstring strength.[20,30,31]

The studies described in this thesis focus on sprint-type hamstring injuries, unless stated otherwise.

Risk factors for hamstring injuries

The causes for hamstring injuries are multifactorial,[32] and a number of potential risk factors have been identified.[21,33,34] Some of the risk factors are non-modifiable, such as age, sex and ethnic origin.[35] Modifiable risk factors can be divided into intrinsic and extrinsic factors. Intrinsic risk factors are player related, such as muscle weakness, instability, poor fatigue, poor flexibility, poor core stability, and psychological factors.[21,33,34] Extrinsic factors are environment related, such as playing surface, level of play, field position, and insufficient warm-up.[21,33,34]

Review of the literature on risk factors for hamstring injuries revealed a previous hamstring injury to be the single main risk factor for future hamstring injury,[21,33,34] increasing the risk two- to six-fold compared with no prior hamstring injury.[11,36,37] Interestingly, some studies also identified a history of other injuries, such as anterior cruciate ligament reconstruction, calf muscle strain, and knee injuries to be associated with an increased risk of hamstring injury.[38,39] Body mass index, weight, height, body composition, hip internal rotation range of motion (ROM), hip external rotation ROM, MRI data, limb dominance, playing surface, and playing position are not associated with an increased risk of hamstring injury.[33,34,40] There is conflicting evidence that older age, increased quadriceps peak torque, reduced hip extension ROM, Aboriginal or black origin, and hamstring flexibility and strength imbalances increase the risk of hamstring injury.[33,34] The role of muscle strength and flexibility imbalances is particularly interesting because these are modifiable risk factors and potential points of engagement for hamstring injury prevention.

From research to real-life prevention

Considering the high (re-)injury rates as well as the impact on the injured athlete, research on hamstring injury prevention is warranted. Finch et al. developed the 'TRIPP-framework' for translating research findings into real-life sports injury prevention (see Figure 1.2) .[41] In the first step of the TRIPP-framework, the extent of the injury is assessed in terms of injury incidence and severity. Then, in the second step, risk factors and injury mechanisms that contribute to the sports injury are established. In the third step, preventive measures to reduce the future risk and/or severity of sports injuries are developed, based on the risk factors and injury mechanisms identified in the second step. In the fourth step,

Model stage	TRIPP
1	Injury surveillance
2	Establish aetiology and mechanisms of injury
3	Develop preventive measures
4	"Ideal conditions"/scientific evaluation
5	Describe intervention context to inform implementation strategies
6	Evaluate effectiveness of preventive measures in implementation context

Figure 1.2 The Translating Research into Injury Prevention Practice (TRIPP) framework.[41]

the preventive measures are introduced and their effectiveness evaluated. This can be achieved by time trend analyses or, as stated by Bahr and Krosshaug, preferably by means of a randomised controlled trial.[22] In TRIPP-stage 5, the outcomes of efficacy research are translated into actions to be actually implemented in the real-world context, in order to develop and understand the implementation context. In the final step, the intervention is implemented and evaluated in a real-world context. In other words: is the scientifically proven intervention also effective in real-life? This involves considering the complex relationships between TRIPP-steps 1 and 5 too.[41]

Several studies have reported epidemiological data on hamstring injuries in professional and soccer players,[6,12,42,43] from which it can be concluded that hamstring injury rates in soccer have not improved over the last three decades.[17-19] Therefore, further research on preventive strategies for hamstring injuries is required.

Hamstring injury prevention

Many interventions for preventing of hamstring injuries have been developed and evaluated, such as proprioceptive balance training,[44-46] massage,[47] education,[48] functional training and sport-specific drills,[49,50] and stretching and strengthening exercises.[51-54] Understanding the causes and injury mechanisms of any particular type of injury is fundamental for developing preventive measures.[22] As previously stated (see '*aetiology and injury mechanisms of hamstring injuries*'), biomechanical analyses have shown that the risk of hamstring injury during high-speed running is associated with inadequate eccentric hamstring strength.[20,30,31] As a result, a number of exercise programmes focusing on eccentric hamstring strength have been developed and studied over the past 15 years.[52-57]

Nordic Hamstring Exercise

The Nordic hamstring exercise or Nordic curl, a partner-exercise aimed at improving eccentric hamstring strength, has proven promising for reducing the rate of hamstring injury.[54] The Nordic hamstring exercise can easily be incorporated into regular soccer training sessions,[54] and previous studies of male professional soccer showed that its use reduced the incidence of hamstring injury, and especially recurrent injuries, by 65% to 70%.[52,54] Although the results of these studies of professional soccer are promising, differences between professional and amateur soccer players in terms of medical supervision, level of play, training exposure, training intensity, and compliance with preventive measures mean that data for professional players cannot necessarily be extrapolated to amateur players. Thus the Nordic hamstring exercise needs to be tailored, tested and evaluated in non-professional soccer players. Our Hamstring Injury Prevention Strategies (HIPS) project, a large randomized controlled trial, investigated the preventive effect of the Nordic hamstring exercise on hamstring injuries in male amateur soccer players.

Return to play after hamstring injury

Unfortunately, eliminating all hamstring injuries from soccer through preventive strategies still seems a utopia. Once the initial hamstring injury has occurred, the risk of future hamstring injury increases two- to sixfold.[11,36,37] In fact, 59% of all recurrent hamstring injuries occur within the first month after RTP.[58,59] This suggests that the high rate of recurrent hamstring injuries is due to inadequate rehabilitation and/or a too early return to full training and match play.[20,21]

In the last decade, a growing interest in research has risen on return to play after hamstring injury, including attributed criteria for RTP after hamstring injury. Despite this, the concept of return to play is seldom defined, and a wide variety of criteria are used to support the return to play decision after hamstring injury. The lack of a clear definition of return to play in the literature is a problem for clinicians as well as researchers, as it makes comparing studies on this topic very difficult. Additionally, there is no consensus among researchers or clinicians about which medical criteria should guide the return to play decision after hamstring injury.

The aims and outline of this thesis

The studies described in this thesis focus on the prevention of hamstring injuries and return to play after hamstring injuries in soccer players.

Several exercise programs, such as the well-known 'FIFA11',[62] have been developed to prevent soccer injuries. However, the literature on the effectiveness of these programs has not been systematically reviewed. Therefore, we conducted a systematic review on the effectiveness of general exercise-based injury prevention programmes for soccer players (**Chapter 2**).

An eccentric hamstring strength-training programme based on the Nordic hamstring exercise showed promising results in reducing hamstring injuries in professional soccer players. However, as there are too many potential differences between professional and amateur soccer players (such as medical supervision, level of play, training exposure, training intensity, and compliance with preventive measures), results obtained for professional players cannot necessarily be extrapolated to amateur soccer players. Therefore, our HIPS (Hamstring Injury Prevention Strategies) study focused on the effectiveness of the Nordic hamstring exercise in amateur soccer players. **Chapter 3** describes the design of this randomized controlled trial.

It was hypothesized that implementation of a tailored Nordic hamstring exercise protocol during regular training would reduce the incidence and severity of hamstring injuries. The results of this intervention study, which involved more than 500 players from 32 amateur soccer teams in the Netherlands, are presented in **Chapter 4**.

In the literature, there is ongoing debate about whether hamstring flexibility is associated with the risk of hamstring injury.[21,33,34] To provide new information for this debate, a population of amateur soccer players performed hamstring flexibility tests (e.g. the Sit-and-Reach Test). **Chapter 5** describes normative values for the sit-and-reach test in amateur soccer players. The association between hamstring flexibility and hamstring injury risk was analysed in **Chapter 6**, with adjustment for potential confounders such as age and injury history.

Unfortunately, hamstring injuries may still occur. After the initial injury, the soccer player's risk of sustaining a recurrent hamstring injury increases significantly. Since most recurrent hamstring injuries have been suggested to occur because of inadequate rehabilitation and/or a too early return to play, evaluation of a player's readiness for return to play is essential to prevent recurrent hamstring injuries.[20,21,58] Many different definitions and criteria are used in research as well as daily practice to assess readiness to return to play. In order to provide an overview of the concept of return to play after hamstring injuries, the study described in **Chapter 7** provides a systematic review of definitions and criteria used for return to play after hamstring injury used in the literature.

The results of this systematic review were used as a starting point for a Delphi consensus procedure. A worldwide panel of experts, selected by the FIFA Medical Centers of Excellence network, participated in the Delphi consensus procedure in order to generate one clear definition of return to play after hamstring injury as well as its attributed criteria. The results of this study are presented in **Chapter 8**.

Lastly, in **Chapter 9**, the general discussion addresses the most important findings of the studies, the study limitations, and recommendations for clinicians, researchers, and policymakers regarding future strategies for preventing hamstring injuries in soccer.

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Chapter 2

How effective are exercise-based injury prevention programmes for soccer players? A systematic review

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Abstract

Background The incidence of soccer (football) injuries is among the highest in sports. Despite this high rate, insufficient evidence is available on the efficacy of preventive training programmes on injury incidence.

Objective To systematically study the evidence on preventive exercise-based training programmes to reduce the incidence of injuries in soccer.

Data sources The databases EMBASE/MEDLINE, Pubmed, CINAHL, Cochrane Central Register of controlled trials, PEDro and SPORTDiscus™ were searched for relevant articles, from inception until 20 December 2011. The methodological quality of the included studies was assessed using the PEDro scale.

Study selection The inclusion criteria for this review were (1) randomized controlled trials or controlled clinical trials; (2) primary outcome of the study is the number of soccer injuries and/or injury incidence; (3) intervention focusing on a preventive training programme, including a set of exercises aimed at improving strength, coordination, flexibility or agility; and (4) study sample of soccer players (no restrictions as to level of play, age or sex). The exclusion criteria were: (1) the article was not available as full text; (2) the article was not published in English, German or Dutch; and (3) the trial and/or training programme relates only to specific injuries and/or specific joints. To compare the effects of the different interventions, we calculated the incidence risk ratio (IRR) for each study.

Results Six studies involving a total of 6099 participants met the inclusion criteria. The results of the included studies were contradictory. Two of the six studies (one of high and one of moderate quality) reported a statistical significant reduction in terms of their primary outcome, i.e. injuries overall. Four of the six studies described an overall preventive effect (IRR < 1), although the effect of one study was not statistically significant. The three studies that described a significant preventive effect were of high, moderate and low quality.

Conclusions Conflicting evidence has been found for the effectiveness of exercise-based programmes to prevent soccer injuries. Some reasons for the contradictory findings could be different study samples (in terms of sex and soccer type) in the included studies, differences between the intervention programmes implemented (in terms of content, training frequency and duration), and compliance with the programme. High-quality studies investigating the best type and intensity of exercises in a generic training programme are needed to reduce the incidence of injuries in soccer effectively.

Introduction

With approximately 265 million participants, soccer (football) is the most popular sport in the world across both sexes and all age groups.[1] In addition to the social aspect of the sport, soccer also has beneficial health-related effects.[2] It challenges physical fitness by requiring a variety of skills at different intensities. Running, sprinting, jumping and kicking are important performance components, requiring maximal strength and anaerobic power of the neuromuscular system.[3,4] Consequently, this popular sport also has high injury rates.[5]

Soccer injuries come in a wide variety, but most injuries affect the lower extremities, including the upper leg, knee and ankle.[6,7] In view of the frequency of injury, the resulting costs and not least the personal suffering of the injured players, many studies have focused on injury prevention measures in soccer.[8-10] Several options for preventing soccer injuries have been developed, ranging from protective equipment (e.g. shin guards),[11-13] to warm-up and cool-down routines.[11,14-16]

Intervention programmes focusing on intrinsic risk factors for specific injuries have achieved significant reductions of soccer injuries. For instance, previous studies showed that eccentric strength training reduced the risk of hamstring injury in heterogeneous populations of soccer players.[17-19] It has also been shown that neuromuscular training appears to be effective to reduce the risk of anterior cruciate ligament (ACL) injury in both male and female soccer players.[20,21] A set of exercises focusing on balance, strength, flexibility and stability has been found to reduce the risk of ACL injuries in female youth soccer players.[22,23]

Despite the relatively high incidence of injuries in soccer, insufficient evidence is available on the efficacy of generic (non-specific) preventive training programmes in reducing injury incidence. These multifaceted programmes contain different exercises focusing on multiple joints and/or muscle groups and target prevention of the most common soccer injuries. The purpose of this review is to systematically examine the evidence on the effect of preventive exercise-based training programmes to reduce the incidence of soccer injuries in general.

Methods

Search methods

The databases EMBASE/MEDLINE, Pubmed, CINAHL (Cumulative Index to Nursing and Allied Health Literature), Cochrane Central Register of Controlled trials, PEDro (the Physiotherapy Evidence Database) and SPORTDiscus were searched for relevant articles, from inception till 20 December 2011. The search strategy for MEDLINE was set by one author (NvdH), after which this strategy was modified for use in the other databases. The following combination of key words was used: ((prevention AND training) AND (soccer OR soccer) AND injury). The searches in CINAHL and SPORTDiscus were restricted to peer-reviewed articles. The full search strategy is available on the journal website. Subsequently, the databases were searched independently by two authors (NvdH, AvB). The results of these searches were combined and duplicates were removed. Reference lists of included studies and relevant systematic reviews were also screened for relevant studies.

Eligibility criteria

The relevant citations were first screened on the basis of title and abstract. Articles were independently selected by two authors (NvdH, AvB) if the study met the following criteria.

Inclusion:
- Randomized controlled trial (RCT) or controlled clinical trial (CCT).
- Primary outcome of the study is the number of soccer injuries and/or injury incidence.
- Intervention focusing on a preventive training programme, including a set of exercises aimed at improving strength, coordination, flexibility or agility.
- Study sample of soccer players (no restrictions as to level of play, age or sex).

Exclusion:
- The article was not available as full text.
- The article was not published in English, German or Dutch.
- The trial and/or training programme relates only to specific injuries and/or specific joints.

Full text of relevant articles was obtained and checked for inclusion and exclusion criteria independently by two authors (NvdH, AvB). Disagreements between the two authors regarding a study's eligibility were resolved by discussion until consensus was reached or, where necessary, a third author (IvdP) made the final decision.

Data collection

The following data were extracted by two authors (NvdH, AvB): first author; year of publication; follow-up period; number of participants; sex and age of participants; definition primary outcome; description of the intervention; and effect of the intervention.

Initially, the effect of the intervention was assessed by analysing the results in terms of the primary outcome of a study. If different methods are used to describe the primary outcomes in the included studies, the incidence risk ratios (IRRs) were calculated to compare the effects of the intervention between the studies. The IRR is the ratio of the injury rate (injured players divided by all players) in the intervention group divided by the corresponding rate in the control group. In addition, statistically significant results in terms of secondary outcomes were recorded.

Assessment of risk of bias in included studies

Two authors (NvdH, AvB) independently assessed the methodological quality of the included studies using the PEDro scale.[24] The PEDro scale is an 11-item checklist, based on expert consensus, which can be used to rapidly determine the internal validity and statistical quality of RCTs or CCTs.[25] The first item is not used to calculate the total PEDro score, so the maximum score was 10 points. Criteria were only scored as 'yes' or 'no'. Disagreements on the PEDro score were resolved by discussion between the two assessors. If consensus was not achieved, a third author (IvdP) was consulted. A study was considered of moderate quality if the PEDro score was at least 4, and of high quality if the score was 6 or higher.[26,27]

Results

Study selection

Electronic and manual searching yielded 925 relevant articles, with 265 duplicates. Of the remaining 660 articles, 639 were excluded after screening the title and abstract. Twenty-one articles were retrieved from the literature search and subsequently evaluated. After reading the full text we excluded a further 15 articles, without disagreements between the two authors regarding a study's eligibility. No additional reports were found by screening the reference lists and reviews. Articles were predominantly excluded because the intervention protocol used was not in agreement with our definition or the article did not describe an outcome in terms of injuries and/or injury incidence (Figure 2.1).

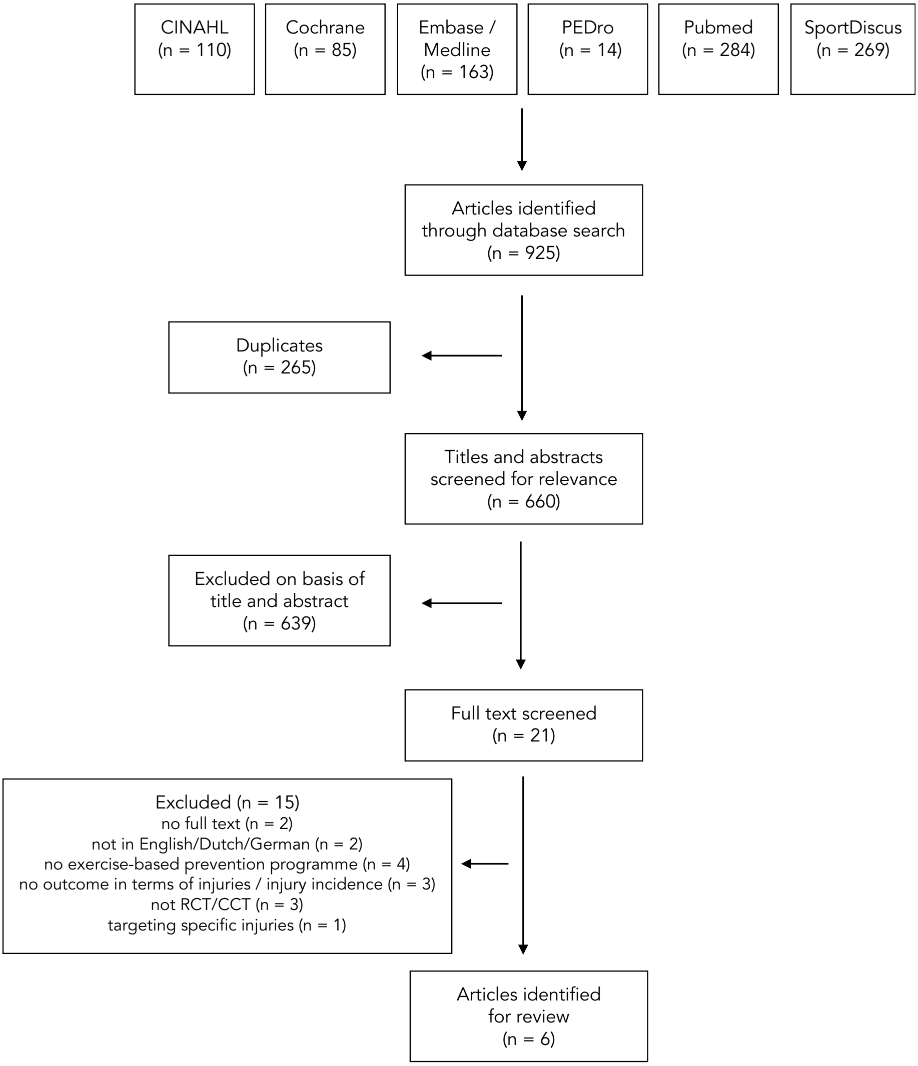

Figure 2.1 Flow diagram literature search and selection.
CCT = controlled clinical trial, RCT = randomized controlled trial.

Study characteristics

Six studies with a total of 6099 participants were included in this review.[28-33] Four studies were RCTs[28,31-33] and two CCTs.[29,30] The number of participants per study ranged from 194 to 2540 players. The samples consisted of youth and adult soccer players, both male and female. Except for the study by Emery et al.,[28] all studies involved outdoor soccer players. All included studies had a follow-up period of one season (ranging from 20 weeks to 8 months), except for the study by Junge et al.[30] (their follow-up period was one year during two seasons). Table 2.1 shows the main characteristics of the included studies.

Methodological quality

The PEDro scores ranged from 2 to 8 points, with a median of 5 points. The results of the quality assessment after consensus are presented in Table 2.2. Three of the six included studies[28,31,33] were of high methodological quality, two others of moderate quality,[29,32] and one of low quality.[30] Some limitations in the low- or moderate-quality studies were lack of randomization,[29,30] low statistical power or inadequate sample size calculation,[29,30,32] no intention-to-treat analysis,[29,30,32] no exposure registration,[29] and high drop-out rate.[30,32]

Interventions and effects

The definition used for injury was similar in nearly all studies , viz. an injury that results in a player being unable to take full part in future soccer training or match play ('time loss' injury).[34] Two studies also used this definition, but with the additional element of 'or any physical complaint caused by soccer that lasted for more than two weeks'[30] and 'soccer injuries resulting in medical attention and/or removal from a session and/or time loss'.[28]

All six studies prescribed soccer-specific exercises aimed at improving strength, coordination, flexibility or agility. One study[32] required participants to do home-based wobble-board exercises, and one study[28] combined soccer-specific exercises with home-based wobble-board training. The participants in the control group of the latter study engaged in a home-based programme including only the stretching components. One study[30] used a multi-modal intervention programme consisting of warm-up, cool-down, taping of unstable ankles, and rehabilitation combined with an exercise-based programme. The exercises focused on balance, flexibility, strength, coordination,

Table 2.1 Study characteristics of the included studies

First author, year	Follow-up period	Participants	Primary outcome	Intervention *	Effect of intervention	Incidence risk ratio (IRR)
Emery et al., 2010[28]	One season of 20 weeks	Male and female indoor soccer players, n = 744 (intervention group: 380, control group 364), aged 13–18 years.	Injuries overall, defined as all soccer injuries resulting in medical attention and/or removal from a session and/or time loss.	Warm-up (15 min) including 5 min stretching and 10 min soccer-specific neuromuscular training programme and a 15 min home based balance training programme.	Significant reduction of the primary outcome ($p = 0.045$): injury rate in intervention group = 2.08 (95% CI 1.54–2.74) injuries/1000 hours, control group = 3.35 (95% CI 2.65–4.17).	0.66 (statistically significant)
Heidt et al., 2000[29]	One year of competitive soccer participation	Female high-school soccer players, n = 300 (intervention group: 42, control group: 258), aged 14–18 years.	Injuries overall, defined as all injuries which caused the player to miss a game or a practice.	Frappier Acceleration Training Programme: sport-specific programme of cardiovascular conditioning, plyometric work, sport cord drills, strength training, and flexibility exercises. Twenty sessions over 7 weeks during pre-season.	Significant reduction of the primary outcome ($p < 0.05$).	0.42 (statistically significant)
Junge et al., 2002[30]	One year (during two seasons)	Male soccer players, n = 194 (intervention group: 101, control group: 93), aged 14–19 years, age = 16.5 ± 1.2.	Injuries overall, defined as any physical complaint caused by soccer that lasted for more than two weeks or resulted in absence from a subsequent match or training session.	General interventions such as improved warm-up, regular cool-down, taping of unstable ankles, adequate rehabilitation and promotion of the spirit of fair play as well as 'F-MARC Bricks': balance, flexibility, strength, coordination, reaction time, and endurance. Once a week supervised by a physiotherapist.	No significant reduction of the primary outcome. Statistically significant differences were found for number of injured players, mild injuries, overuse injuries, noncontact injuries, injuries incurred during training, and injuries of the groin.	0.64 (statistically significant)

Table 2.1 continues on next page

Table 2.1 *Continued*

First author, year	Follow-up period	Participants	Primary outcome	Intervention *	Effect of intervention	Incidence risk ratio (IRR)
Söderman et al., 2000[32]	One season of 7 months	Female soccer players, n = 221 (intervention group: 121, control group: 100), mean age (n = 140) = 20.5 ± 5 years.	Acute lower extremity injuries resulting in absence from at least one scheduled practice session or game.	Balance board training at home (10–15 min). Initially each day for 30 days and then three times a week during the rest of the season.	No reduction of the primary outcome. Significantly higher injury rate of severe injuries in intervention group.	1.16 (not statistically significant)
Soligard et al., 2008[31]	One season of 8 months	Female soccer players, n = 2540 (intervention group: 1320, control group: 1220), youth, aged 13–17years, mean age (n = 1892) = 15.4 ± 0.7 years.	All lower extremity injuries causing the player to be unable to fully take part in the next match or training session.	The11+ intervention programme (20 min): running exercises, strength, balance, jumping, speed running. Every training session during the season (2–5 times a week).	No significant reduction of the primary outcome. The risk of severe injuries, overuse injuries and injuries overall was significantly reduced in the intervention group.	0.67 (not statistically significant)
Steffen et al., 2008[33]	One season of 8 months	Female soccer players, n = 2092 (intervention group: 1091, control group: 1001), aged 13–17 years, mean age (n = 2020) = 15.4 ±.0.8 years.	Injuries overall, defined as all injuries causing the player to be unable to fully take part in the next match or training session.	Warm-up (20 min) including 5 min of jogging and 15 min of The11intervention programme: core stability, balance, dynamic stabilization and eccentric hamstring strength. Initially every training session for 15 consecutive sessions and thereafter once a week during the rest of the season.	No reduction of the primary outcome.	1.20 (not statistically significant)

* The control groups were generally asked to train (and warm-up) as usual.
Age is presented as mean age ± SD (if applicable). CI = confidence interval, F-MARC = FIFA Medical and Research Centre, IRR = incidence risk ratio.

Table 2.2 Assessment of the methodological quality of the included studies with PEDro criteria[24]

	Random allocation	Concealed allocation	Baseline compara-bility	Blinded subjects	Blinded therapists	Blinded assessors	Adequate follow-up	Intention-to-treat analysis	Between-group compari-sons	Point estimates and variability	Total
Emery et al., 2010[28]	1	1	1	0	0	1	0	1	1	1	7
Heidt et al., 2000[29]	1	0	0	0	0	1	1	0	1	0	4
Junge et al., 2002[30]	0	0	1	0	0	0	0	0	1	0	2
Söderman et al., 2000[32]	1	0	1	0	0	0	0	0	1	1	4
Soligard et al., 2008[31]	1	1	0	0	0	1	0	1	1	1	6
Steffen et al., 2008[33]	1	1	0	0	0	1	1	1	1	1	7

0 = no, 1 = yes.

reaction time, and endurance. The other three studies implemented a preventive training programme during the warm-up of training sessions.[29,31,33] One programme, the Frappier Acceleration Training Programme, consists of exercises to improve speed and agility.[29] Another one, called The11, focuses on core stability, balance, dynamic stabilization, and eccentric hamstring strength,[33] while the last one, The11+, combines key exercises from The11 and additional exercises to provide variation and progression with running exercises.[31] The teams in the control groups of these studies were asked to continue their warm-up and training as usual during the season. More detailed information about the interventions studied is provided in Table 2.1.

Only two of the six studies reported a significant reduction in terms of their primary outcome, i.e. injuries overall. One of these studies was a high-quality study,[28] the other was of moderate quality.[29] Emery et al.[28] showed that the injury rate in the intervention group was significantly lower (2.08, 95% CI 1.54–2.74 injuries/1000 hours) than in the control group (3.3, 95% CI 2.65–4.17 injuries/1000 hours). Heidt et al.[29] reported a significantly lower injury incidence in the intervention group than in the control group (14.3% vs. 33.7%). The statistically significant results in terms of secondary outcomes are presented in Table 2.1.

To compare the effects of the different interventions we calculated the IRR for each of the included studies (see Table 2.1). Four of the six studies[28-31] reported an overall preventive effect (IRR < 1), although the effect in one study was not statistically significant.[31] The three studies which described a significant preventive effect were of high,[28] moderate[29] and low quality.[30] The mean reduction in injury rate in these studies was 44%.[28-30] The mean overall reduction (for the six included studies) was 19%.[28-33]

Discussion

This review systematically describes the evidence from RCTs and CCTs on the effect of generic exercise-based programmes to prevent soccer injuries. The conclusions of the six included studies were contradictory. Only two studies reported a significant reduction in terms of the primary outcome.[28,29] The result of our analysis is inconclusive, however, as different outcome measures and injury definitions were used. As regards the effect of the interventions in terms of one identical outcome, namely IRR, four of the six studies[28-31] described a preventive effect, although the effect in one (high-quality) study was not significant.[31] The three studies which described a significant preventive effect were of high,[28] moderate quality[29] and low quality.[30] The other high-quality study reported no differences between the two groups at all.[33]

The possible effect of an intervention depends on several factors, which were not identical for all included studies. The first aspect is the study sample in the included studies. Only two studies included male soccer players,[28,30] and one of these showed a significant reduction in terms of the primary outcome, i.e. injuries overall.[28] The other four studies included only female players and two of them showed a significant preventive effect of the intervention.[29,31] Each sex may have its own risk factors and its own risks of sustaining an injury, or more specifically an ACL injury.[35] It is well-known that female players have a 2–3 times higher ACL injury risk than male players.[36,37] Nevertheless, a recently published review reported that females benefit less from ACL prevention programmes than males (risk reduction of 52% vs. 85% resp.).[38]

Another important factor that deserves further attention is the content of the intervention programmes analysed in this review. Despite the fact that we defined the content in the inclusion criteria, the contents did differ, which limits their comparability. In the study by Junge et al.[30] the exercise programme was part of other general preventive interventions such as taping, rehabilitation, and promotion of fair play. This makes it difficult to identify the specific effect of the set of preventive exercises alone. Two other studies primarily focused on balance training,[28,32] while the remaining three studies described the effects of a training programme focusing on several aspects like core stability, balance, strength, and flexibility.[29,31,33] A general comment regarding the content of the program is about the rationale for specific parts of the intervention programmes in the included studies. One can imagine that e.g. neuromuscular training can not reduce head injuries. The hypothesis is that performing certain exercises on a regular basis would reduce the incidence of the most common (lower extremity) injuries. However, Soligard et al. showed no significant reduction for their primary outcome (all lower extremity injuries), while a significant risk reduction is found for overall injuries in the intervention group.[31] The majority of the included studies targeted prevention of all injury.[28-30,33]

Besides the content of the programme, training frequency and duration also varied greatly between the included studies. The frequency of the intervention programmes ranged from one to five sessions a week, during an intervention period that ranged from 7 weeks to 8 months. The three studies reporting a significant preventive effect of the intervention programme differ greatly.[28-30] The participants of one study had 20 sessions over a 7-week period.[29] In the second study a physiotherapist weekly visited one training session per team and supervised the performance of the intervention programme. It is not reported that the teams also perform the programme without supervision of the physiotherapist.[30] The third study did not report the training frequency, but the participants performed the intervention during a 20-week season.[28] Although the participants of the study by Söderman et al.[32] performed the intervention three times a week, the effect of preventive exercises in general may be positively influenced by a higher frequency (more than once a week). Since the differences in intensity of the programme compared to the effect of the intervention in the included studies it would be interesting to study any underlying dose-response relationship in more detail.

Compliance may also be a key factor in the potential effect of an intervention programme. Soligard et al.[39] confirmed in a previous study that the risk of overall and acute injuries was reduced by more than one third among players with high compliance compared to players with intermediate compliance. Four of the six included studies recorded the participants' compliance with the intervention. The study by Emery et al.,[28] the high-quality study which showed a preventive effect of the intervention, did not clearly report compliance. The authors stated that response in terms of self-reported compliance with the home-based programme was very poor (< 15%). Completion of warm-up was indicated for every practice and game at all teams for which weekly exposure data were complete. It is unclear, however, whether all components of the prescribed warm-up were completed for each session.[28] In the two Norwegian studies, compliance with the The11 programme was 52%[33] vs 77% for The11+.[31] Finally, Söderman et al.[32] excluded 30% of the participants who had completed the study but had performed the prescribed balance board training during fewer than 35 training sessions.

It is hard to conclude from the present review which components are relevant in injury prevention programmes. To be able to develop effective training programmes, it is highly important to establish the aetiology and mechanisms of injuries before introducing and implementing a preventive measure.[40,41] The training programmes implemented in the studies included in this review involve different exercises focusing on the prevention of the most frequently reported soccer injuries. Since these injuries have their own aetiologies and risk factors, it is hard to design a 'one size fits all' intervention programme. Even when focusing on one common type of injury in soccer (knee injuries), it still seems difficult to decide which exercises should be implemented in a preventive programme. The literature reports contradictory effects of different exercises. Some studies reported positive, preventive effects on knee injuries,[22,23,42] while others reported only a trend towards reduction,[43,44] or no reduction at all.[45,46] Sadoghi et al.[38] recently reported on the effectiveness of ACL injury prevention training programmes. In their review, they suggested that such programmes have a substantial beneficial effect. However, they were not able to recommend a specific type of prevention programme on the basis of the currently published evidence.[38] This confirms the difficulties of designing an exercise-based intervention programme.

Before introducing and implementing a preventive training programme, it also seems relevant to improve the ability to identify players at risk for sustaining an injury.[5] This would make it possible to design such programmes specific enough to achieve the maximum effect. Finally, external factors like behaviour/fair play[41,47] and sports culture[40] play a role in sustaining injuries. A better understanding of these factors may lead to improvements in the prevention of soccer injuries.

A limitation of our review is that the generalizability of the results remains unclear. The included studies predominantly focused on young, female outdoor soccer players. The participants' age was below 19 years in five studies.[28-31,33] However, the largest group of active participants in soccer worldwide concerns is that of adult male players, who also have high injury rates.[1,5] It is also unclear if the results of our review can be generalized to other levels of play and/or across sexes. Only two studies included male participants: 44.6% of the sample in the study by Emery et al.[28] (n = 332) and the entire study sample used by Junge et al.[30] (n = 194). Generalizing the results of our review to the largest soccer population (adult male players) must be done with considerable caution. Finally, it is unclear whether the results reported by Emery et al.,[28] who included only indoor soccer players, can be generalized to outdoor soccer players. Although indoor and outdoor soccer have several similarities, it is not evident that the injuries are comparable. Some studies reported that indoor soccer has a higher injury incidence/risk than outdoor soccer,[5,48] while others described no differences between indoor and outdoor soccer in injury incidence or risk factors.[49]

Drawing conclusions about the effectiveness of an intervention programme also requires taking the choice of primary outcome in a study into account. We used the results in terms of the primary outcome in the included studies to describe the effect of an intervention, because there may be insufficient statistical power for conclusions based on the secondary outcomes. However, some studies[30,31] only reported a preventive effect in terms of secondary outcomes. Finally, the mean IRR of the six included studies (19% reduction) should be interpreted with care. By calculating this score the methodological quality of the included studies is not taken into account. Besides this, the calculation is not based on a meta-analysis. Ideally, relative weights should be given to each included study before calculating the overall IRR.

Conclusion

The calculated IRRs for the studies included in our review indicate that there is conflicting evidence for the effectiveness of exercise-based programmes to prevent soccer injuries. There is thus a need for more high-quality studies investigating the best type and intensity of exercises in a generic training programme (for a specific population in terms of sex, level of play, and age), in order to reduce the incidence of injuries in soccer effectively.

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Chapter 3

The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: study protocol for a randomized controlled trial

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Abstract

Background Hamstring injuries are the most common muscle injury in male amateur soccer players and have a high rate of recurrence, often despite extensive treatment and long rehabilitation periods. Eccentric strength and flexibility are recognized as important modifiable risk factors, which has led to the development of eccentric hamstring exercises, such as the Nordic hamstring exercise. As the effectiveness of the Nordic hamstring exercise in reducing hamstring injuries has never been investigated in amateur soccer players, the aim of this study is to investigate the effect of this exercise on the incidence and severity of hamstring injuries in male amateur soccer players. An additional aim is to determine whether flexibility is associated with hamstring injuries.

Study design Cluster-randomized controlled trial with soccer teams as the unit of cluster.

Methods Dutch male amateur soccer players, aged 18 to 40 years, were allocated to an intervention or control group. Both study groups continued regular soccer training during 2013, but the intervention group additionally performed the Nordic hamstring exercise (25 sessions over 13 weeks). Primary outcomes are the incidence of initial and recurrent hamstring injury and injury severity. Secondary outcomes are hamstring-and-lower-back flexibility. Compliance to the intervention protocol was also monitored.

Discussion Eccentric hamstring strength exercises are hypothesized to reduce the incidence of hamstring injury among male amateur soccer players by 70%. The prevention of such injuries will be beneficial to soccer players, clubs, football associations, health insurance companies, and society.

Trial registration NTR3664.

Background

Soccer is the most popular sport worldwide, with 275 million participants of either sex and of all ages.[1] In general, sports participation generates a physically active lifestyle. However, the beneficial health effects of sport are tempered by the risk of injury.[2] Unfortunately, soccer has a high injury rate, with male amateur soccer players being particularly prone to injury.[3-7] Of all players, 60–100% sustain at least one injury per soccer season.[8,9] In terms of incidence rates in amateur players, soccer leads to 21.9 injuries per 1000 match hours and to 3.4 injuries per 1000 training hours.[3-7]

Hamstring injuries, defined as any physical complaint affecting the posterior side of the upper leg irrespective of the need for medical attention or time loss from soccer activities,[10] are the most common soccer-related muscle injury.[11,12] They account for 13–17% of all soccer injuries and require extensive treatment and long rehabilitation periods, leading to absence from training and matches for up to 90 days.[8,7,12,13] Hamstring injuries also have a high recurrent rate, varying from 12% to 33%.[12,15]

Of a number of potential risk factors for hamstring injuries, such as age, previous hamstring injury, muscle architecture, fatigue, flexibility, core stability and strength, flexibility and strength are considered important modifiable risk factors.[16-18] Biomechanical analyses have shown that hamstring ruptures typically occur in the latter part of the swing phase during sprinting.[19,20] Before the foot hits the ground, the hamstring is (sub)maximally stretched over the knee joint, but at the same time it has to counter isokinetic forces from the preswinging leg. The higher the sprinting velocity, the greater these forces are.[19,20] The vulnerability of the hamstring to injury during this phase of sprinting is associated with inadequate eccentric strength of the hamstring.[21-23] Exercises to increase eccentric muscle strength, such as the Nordic hamstring exercise or hamstring curl have shown to reduce the rate of hamstring injury by 65–70%, and particularly recurrent injuries, in professional soccer players.[24,26]

Male amateur soccer players form the largest subgroup of soccer players worldwide, with the incidence of injury increasing with higher levels of play.[3,4] Strategies to prevent hamstring injuries, such as the Nordic hamstring exercise, may reduce the incidence of hamstring injury, medical costs, and personal suffering of the injured player.[27-29]

The aims of this study are to investigate the preventive effect of the Nordic hamstring exercise on the incidence and severity of hamstring injuries in male amateur soccer players and to establish whether flexibility is associated with an increased risk of hamstring injury.

Methods/design

Design and randomization

This prospective, cluster-randomized, parallel group trial was designed in accordance with the consolidate standards of reporting trials (CONSORT) guidelines (Figure 3.1).[30] Soccer teams were used as the unit of cluster to avoid the risk of bias if individuals were randomized to the intervention programme.[31] After computer-generated random assignment of team numbers, an equal number of teams were randomized to the control or intervention group by an online research randomizer (www.randomizer.org).

Study setting

This trial is being carried out in collaboration with the Royal Netherlands Football Association (KNVB). Soccer teams from four separate districts playing in Dutch first class ("Eerste Klasse") amateur field soccer competition were invited to participate. These teams generally play one or two matches a week, with two or three training sessions per week. After the four districts had been selected, instruction meetings, to inform the purpose and methods of the study, were held for the coaches and medical staff of participating teams, organized by the research team in each district.

Eligibility criteria

Dutch male amateur soccer players, aged 18–40 years, were eligible for inclusion. Players who joined a participating team after the start of the trial were not included. All players were asked to give their informed consent before the start of this study. Players unwilling to do so were excluded from the trial.

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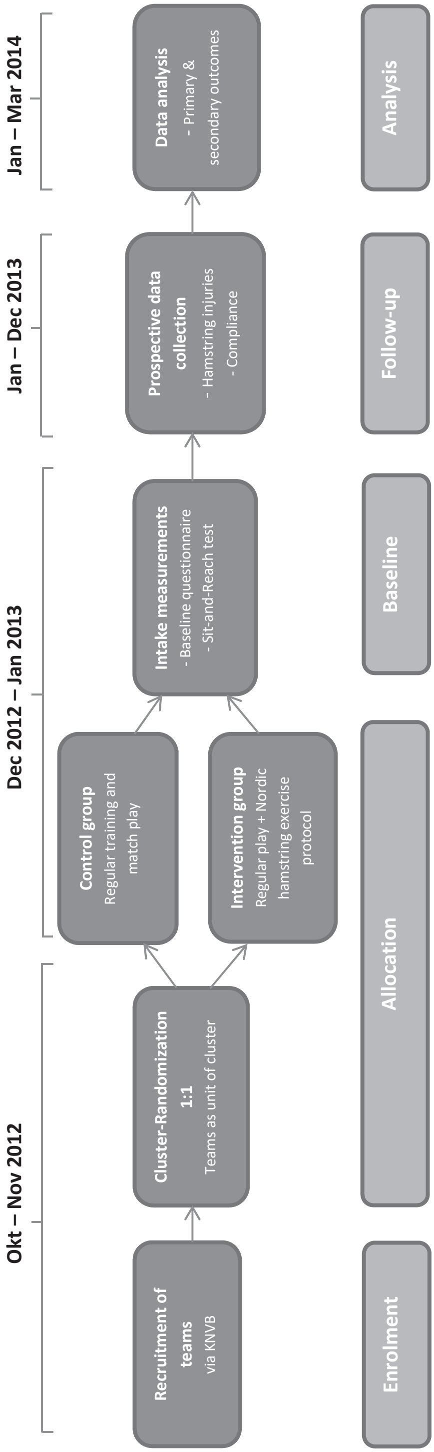

Figure 3.1 Consolidate Standards of Reporting Trials (CONSORT) Flow diagram of trial design.

Intervention

The 'Nordic hamstring exercise', in literature also referred to as the Nordic Curl, improves the eccentric strength of the hamstring muscles. The exercise is performed in pairs (see Figure 3.2).[24]

Players start in a kneeling position, with the torso from the knees upward held rigid and straight. The training partner ensures that the player's feet are in contact with the ground throughout the exercise by applying pressure to the player's heels/lower legs. The player then lowers his upper body to the ground, as slowly as possible to maximize loading in the eccentric phase. Hands and arms are used to break his forward fall and to push him back up after the chest has touched the ground, to minimize loading in the concentric phase.[32] The exercise was supervised by the team coach or medical staff and took place immediately after the completion of normal training as recommended by Small et al, before cooling-down.[33]

After the winter break in the 2012–2013 season (last 2 weeks in December), all teams started their normal training schedule about 3–5 weeks before the competition restarted (the season typically runs from July to May), which is typical for elite amateur soccer competition in Western Europe. The intervention (see Table 3.1) started at the beginning of this training schedule, with a constructive phase (wk 1–5) and a maintenance phase (wk 6–13).[24,25]

Players in the intervention group were instructed to perform 25 sessions of the Nordic hamstring exercise during the first 13 weeks after the winter break. Players were told

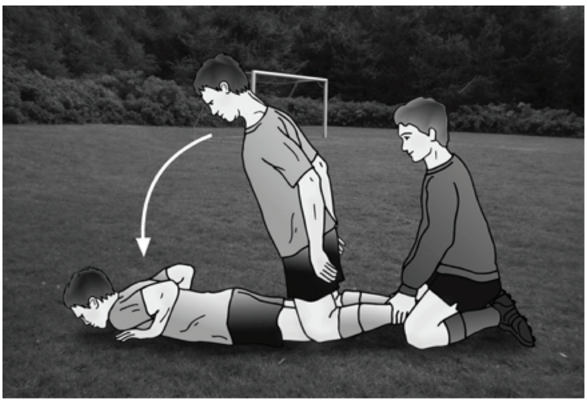

Figure 3.2 The Nordic hamstring exercise (adapted from Petersen et al.[24]).

Table 3.1 Nordic hamstring exercise protocol

Week	Frequency	Number of sets	Repetitions per set
1	1 p/week	2 p/training	5
2	2 p/week	2 p/training	6
3	2 p/week	3 p/training	6
4	2 p/week	3 p/training	6, 7, 8
5	2 p/week	3 p/training	8, 9, 10
6–13	2 p/week	3 p/training	10, 9, 8

about the possibility of Delayed Onset of Muscle Soreness (DOMS), a known side-effect of eccentric exercises.[32] Players who were injured at the beginning of the intervention could start the protocol week 1 after full recovery. Players who sustained an injury during the intervention period, which limited the execution of the Nordic hamstring exercise, were instructed to contact the research team.

Data collection

Baseline characteristics

Prior to the start of the intervention, all players completed a questionnaire to record baseline characteristics: date of birth, weight, height, nationality, years of experience as a soccer player, leg dominance, field position, preventive measures taken (such as inlays, taping, bandages, thermal pants, muscle strengthening exercises or stretching), and other injuries incurred before the start of the study (in particular, hamstring injuries and anterior cruciate ligament injuries).

Hamstring injuries

The medical staff of participating teams (e.g. physical therapists and/or sports masseurs) are responsible for registering all hamstring injuries for a full calendar year (2013). A hamstring injury is defined as any physical complaint affecting the posterior side of the upper leg irrespective of the need for medical attention or time loss from soccer activities.[10] A recurrent hamstring injury is defined as an injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.[10] Recurrent injuries are subdivided into 'early recurrences' within

2 months after a player's return to full participation, 'late recurrences' between 2 and 12 months after a player's return to full participation and 'delayed recurrences' more than 12 months after a player's return to full participation.[10] All hamstring injuries are registered on a special form, and a so-called recovery form is completed when the player is fully recovered. Data are being collected on the epidemiology (location, type, and duration of the injury) and aetiology (including intrinsic and extrinsic factors, such as injury history and field condition) of the hamstring injury and information on residual complaints and tertiary prevention.

Hamstring-and-lower-back-flexibility

Hamstring-and-lower-back-flexibility (HLBF) was measured in all players at the start of the study, using the Sit-and-Reach Test (SRT) (see Figure 3.3).[34-37]

The medical staff was instructed how to perform the SRT procedure at the soccer club. Participants were not allowed to warm up before doing the SRT. A player is asked to sit on the floor, with the legs together, the knees extended, the ankles in 90° dorsiflexion and the soles of the bare feet placed against the foot panel of the test box. Then, the player is asked to place his hands on top of each other with the hand palms facing

Figure 3.3 The Sit-and-Reach Test.

downward, and to slowly reach forward as far as possible, moving a reach indicator along the measuring scale on the box, and to hold the maximum stretch for 2 seconds. The test supervisor ensures that the player's knees, arms and fingers remain extended throughout the test. Both knees should be locked during the test. Measurements are repeated twice, with a 15-second interval, during which the player is allowed to sit up straight, but not to stand up or stretch. SRT scores were recorded to the nearest 0.5 cm. HLBF was not measured in players who were unable to perform the SRT as instructed (e.g. because of limited knee extension after injury).

Exposure and compliance

The number of times a player performed the Nordic hamstring exercise protocol (intervention group), the number and duration (in minutes) of training sessions (both group and individual training) followed, and the number and duration (in minutes) of matches played will be recorded weekly for 1 year by the team coach, using a computer-based registration form. Match exposure is defined as play between teams from different clubs.[10] Training exposure is defined as team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' soccer skills or physical condition.[10] Coaches will also record reasons why players do not attend training or matches (e.g. sickness, injury, hamstring injury, individual training, training elsewhere or other) per individual player.

The research team will remain in contact weekly (by telephone, email, or visits) with team coaches and players having a view to encouraging compliance with data registration. In addition, newsletters, evaluation meetings, and a website designed for this specific study will be used to stimulate participation and compliance.

The intervention teams will be monitored with regard to implementation and performance of the Nordic hamstring exercise and other self-initiated preventive strategies for hamstring injuries (e.g. core stability, plyometric exercises etc.) and the control teams will be monitored with regard to self-initiated preventive measures for hamstring injuries, specifically the Nordic hamstring exercise.

Outcomes

Primary outcomes are the incidence of initial and recurrent hamstring injury, the severity of the injury, and the number of intervention sessions completed. Secondary outcomes are hamstring-and-low-back flexibility (HLBF) and compliance. Data will be collected from all participants. The incidence of injuries is reported as the number of injuries per 1000 player-hours for both matches and training.[10] Injury severity is defined as the number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection.[10]

Sample size

On the basis of the literature, we expected that the intervention would lead to a 70% reduction in the rate of hamstring injury compared with control.[24] During a soccer season, about 1 in 11 players has a hamstring injury with a 30% chance of recurrent hamstring injury.[24] With 2-sided testing, a significance level of 0.05, and power of 0.8, each study group should include 175 players. With a clustered design, an inflation factor (icc = 0.05) of 1.9 was applied to the sample size, and with an estimated drop-out rate of 7%[8,24] we calculated that 712 players would need to be recruited (n = 356 for intervention group and n = 356 for control group). Since first-class amateur teams consist of about 19 players, a total of 38 teams was considered sufficient.

Statistical methods

SPSS version 21.0 will be used to analyse the quantitative data. Descriptive statistics (means and standard deviations) will be used to describe baseline characteristics and exposure data. The incidence of initial and recurrent hamstring injuries will be analyzed on an intention-to-treat basis.

T-tests and Mann-Whitney U-test will be used for continuous variables and Chi-square tests for categorical variables. Poisson general log-linear analysis and cox hazard regression with survival curves will be used to compare the intervention and control groups.

Compliance with the intervention will be calculated on the basis of information provided by the team coaches. As the protocol consists of 25 sessions, compliance will be calculated per team as: *nh* (amount of Nordic hamstring exercise sessions) / 25 * 100 = % compliance. Additional analysis will be performed to check whether certain variables are related to missing data or drop-out.

Ethical approval and informed consent

This trial was approved by the medical ethics committee of the University Medical Centre Utrecht (File number 12-575/C). Where applicable, important modifications will be communicated with the same ethics committee that proved approval. The trial was registered in the Dutch trial register (NTR3664) as the HIPS (Hamstring Injury Prevention Strategies) study. All participants received brief and comprehensible oral and written information, in accordance with the Helsinki declaration.[38] Informed, written consent is obtained from all participants by one of the researchers (NH) before baseline tests. Personal information about enrolled participants will be used confidentially before, during and after the trial.

Discussion

Hamstring injuries in amateur soccer can lead to medical costs, work absenteeism, reduced performance, and personal suffering.[27] The Nordic hamstring exercise has been shown to substantially reduce the incidence of hamstring among professional soccer players.[24-26] However, because there are differences in medical staff, level of play, training frequency, training intensity, and compliance to preventive measures between professional and amateur soccer players, the data for professional players cannot necessarily be extrapolated to amateur players. Even so, it would be worthwhile to reduce the incidence of such injuries among amateur players. Not only for the players themselves, but also for society, health insurance companies, football associations, and football clubs. Eccentric strength training may be an effective way to prevent these injuries, to benefit of all concerned (more matches played, reduced absenteeism and medical costs). This study has the advantage of a large study population (2 x 20 teams), and the use of terminology and methodology consistent with the consensus statement on injury definitions in soccer will generate data that can be compared with those of other studies.[10] Data modification and data loss are limited by the use of specially designed, computer-based registration forms by team coaches and medical staff.

Trial status

Participants were recruited in October-November 2012 and were randomized to the intervention and control groups in December 2012. The intervention started in January 2013. Data collection is in progress and will be completed in January 2014. Data analyses is expected to be completed in May 2014.

List of abbreviations

CONSORT: Consolidate Standards of Reporting Trials; DOMS: Delayed Onset of Muscle Soreness; HIPS: Hamstring Injury Prevention Strategies; KNVB: Royal Netherlands Football Association; HLBF: Hamstring-and-Low-Back-Flexibility; SRT: Sit-and-Reach Test.

Acknowledgements

The authors thank the Royal Dutch Football Association (KNVB) and players, coaches, medical staff members and other representatives of participating clubs for their contributions during the trial.

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Chapter 4

The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial

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Am J Sports Med 2015;43(6):1316-1323

Abstract

Background Hamstring injuries are the most common muscle injuries in soccer and have a high rate of recurrence. Eccentric hamstrings strength is recognized as an important modifiable risk factor. This led to the development of prevention exercises such as the Nordic Hamstring Exercise (NHE). The effectiveness of the NHE on hamstring injury prevention has never been investigated in amateur soccer.

Hypothesis/purpose This study investigated the preventive effect of the NHE on the incidence and severity of hamstring injuries in male amateur soccer players.

Study design Cluster-randomized controlled trial with soccer teams as the unit of cluster.

Methods Male amateur soccer players (mean age 24.5 years, SD 3.8 years) from 40 teams were randomly allocated to an intervention (n = 20 teams, 292 players) or control group (n = 20 teams, 287 players). The intervention group was instructed to perform 25 sessions of the NHE in a 13-week period. Both the intervention and control group performed regular soccer training and were followed for hamstring injury incidence and severity during the calendar year 2013. At baseline, personal characteristics (e.g. age, injury history, field position) were gathered from all participants via questionnaire. Primary outcome was injury incidence. Secondary outcomes were injury severity and compliance to the intervention protocol.

Results In total 38 hamstring injuries were recorded, affecting 36 of 579 players (6.2%). The overall injury incidence rate was 0.7 (95% CI, 0.6–0.8) per 1000 player hours; 0.33 (95% CI, 0.25–0.46) in training and 1.2 (95% CI, 0.82–1.94) in matches. Injury incidence rates were significantly different between intervention (0.25; 95% CI, 0.19–0.35) and control group (0.8; 95% CI, 0.61–1.15) $\chi^2(1, n = 579)$ 7.865, p = 0.005. Risk for hamstring injuries was reduced in the intervention group compared to the control group (Odds Ratio, 0.282; 95% CI, 0.11–0.721) and was statistically significant (p = 0.005). No statistically significant differences were identified between intervention and control group regarding injury severity. Compliance to the intervention protocol was 91%.

Conclusion Incorporating the NHE protocol in regular amateur training significantly reduces hamstring injury incidence, but does not reduce hamstring injury severity. Compliance to the intervention was excellent.

Introduction

Soccer is the most popular sport in the world with more than 275 million participants.[1] Unfortunately, research on sports injuries show high injury incidence rates for soccer, with male amateur soccer players being particularly prone to injury.[2-7] Injury incidence rates of 20.4 to 36.9 injuries per 1000 match hours and 2.4 to 3.9 injuries per 1000 training hours have been reported in male amateur soccer.[2,8,9]

Hamstring injuries are the most common soccer-related muscle injury.[10-12] They account for 37% of all soccer muscle injuries, requiring extensive treatment and long rehabilitation periods.[10-13] Recurrence rates for hamstring injuries remain high (12–33%) despite preventive measures.[12-15] Multiple potential risk factors for hamstring injuries, such as age, player position, previous hamstring injury, muscle architecture, fatigue, flexibility, core stability and strength have been reported.[16-21]

The Nordic Hamstring Exercise (NHE) or Nordic curl has shown to be an effective tool to increase eccentric hamstring strength, developing higher maximal eccentric hamstring strength torques when compared to regular hamstring curls.[22] Previous studies on male professional soccer players have shown that adopting the NHE in regular training reduced hamstring injury incidence rates by 65–70%, with a particularly preventive effect in reducing recurrent injuries.[23,24]

Male amateur soccer players form the largest subgroup of soccer players worldwide.[3,6] Strategies to prevent hamstring injuries, such as the NHE, may reduce the incidence of hamstring injury, medical costs, and personal suffering of the injured player.[23,25,26] Although previous studies in professional soccer have shown promising results, differences between professional and amateur soccer players in medical staff, level of play, training exposure, training intensity and compliance to preventive measures have to be considered. Therefore, the findings for professional players cannot be extrapolated to amateur soccer players.

The aim of this study was to investigate the preventive effect of the Nordic hamstring exercise on the incidence and severity of hamstring injuries in male amateur soccer players.

Materials and methods

Study setting

The present study was a cluster-randomised controlled trial, carried out in collaboration with the Royal Netherlands Football Association (KNVB). Soccer teams from four geographically separated districts playing in high-level amateur field soccer competition ("KNVB Eerste Klasse") were invited to participate. These teams generally play one and sometimes two matches a week, with two or three training sessions per week. Dutch high-level amateur soccer team generally have a physical therapist present at all matches and training. Occasionally, a sports massage therapist is present at matches and training, with a physical therapist available for additional consulting in case of any injury. The trial was approved by the medical ethics committee of the University Medical Center Utrecht (file No. 12-575/C) and registered in the Dutch trial register as the HIPS (Hamstring Injury Prevention Strategies) study. More detailed information is available in the study protocol.[27]

Eligibility criteria

Dutch male amateur soccer players aged 18–40 years were eligible for inclusion. Players who joined a participating team after the start of the trial were not included. All players were informed using an information letter and asked to give their informed consent before the start of this study. Players unwilling to do so were excluded from the trial.

Randomisation procedures

Soccer teams were used as the unit of cluster to avoid the risk of bias if individuals were randomised to the intervention programme. After computer-generated random assignment of team numbers, an equal number of teams were randomised to the control or intervention group by an online research randomizer (http://www.randomizer.org).

Intervention

Nordic hamstring exercise

The 'Nordic hamstring exercise' (NHE), in literature also referred to as the Nordic Curl, is designed to improve eccentric strength of the hamstring muscles.[22] The exercise is performed in pairs (Figure 4.1).[23]

Players start in a kneeling position, with the torso from the knees upward held rigid and straight. The training partner ensures that the player's feet are in contact with the ground throughout the exercise by applying pressure to the player's heels/lower legs. The player then lowers his upper body to the ground, as slowly as possible to maximize loading in the eccentric phase. Hands and arms are used to break his forward fall and to push him back up after the chest has touched the ground, to minimize loading in the concentric phase.[22]

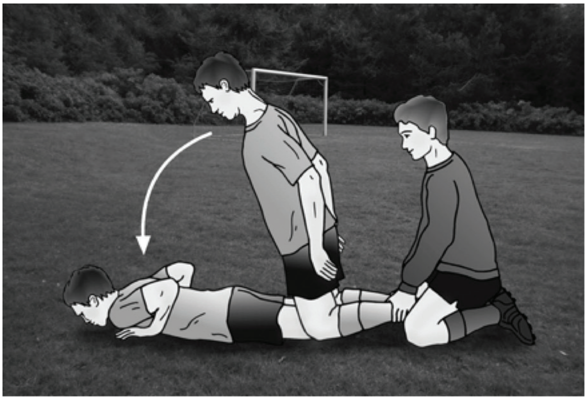

Figure 4.1 The nordic hamstring exercise (adapted from Petersen et al.[33]).

Exercise procedures

For the purpose of the present study, the exercise was supervised by the team coach or medical staff (e.g. physical therapist and/or sport masseur). Exercises took place immediately after the completion of normal training as recommended by Small et al, before cooling-down.[28] After the winter break in the 2012–2013 season (last 2 weeks in December), all teams started their normal training program about 3–5 weeks before the competition re-started (the season runs from July to May), which is typical for amateur soccer competition in Western Europe. The intervention (see Table 4.1) started with a

Table 4.1 Nordic hamstring exercise protocol

Week	Frequency	Number of sets	Repetitions per set
1	1 p/week	2 p/training	5
2	2 p/week	2 p/training	6
3	2 p/week	3 p/training	6
4	2 p/week	3 p/training	6, 7, 8
5	2 p/week	3 p/training	8, 9, 10
6–13	2 p/week	3 p/training	10, 9, 8

build up phase (wk 1–5) during preparation for competition and a maintenance phase (wk 6–13) during competition.[23,24]

Instructions

Players in the intervention group were instructed to perform 25 sessions of the Nordic hamstring exercise during the first 13 weeks after the winter break. Players were informed about the possibility of Delayed Onset of Muscle Soreness (DOMS), a known side-effect of eccentric exercises.[22] Players who were injured at the start of the intervention could start the protocol week 1 after full recovery. Specific instructions were provided for players who sustained an injury during the intervention period, which limited performing the Nordic hamstring exercise. Players sustaining an injury within the first 5 weeks of the intervention period were instructed to restart the program after full recovery. The program had to be restarted from one week back in the program from where the player was when he sustained his injury. Players sustaining an injury between week 6 and week 13 of the intervention period were instructed to restart the program from week 4.

Data collection

Baseline characteristics

Prior to the start of the intervention, all players completed a questionnaire to record baseline characteristics: date of birth, weight, height, nationality, years of experience as a soccer player, leg dominance, field position, preventive measures taken (such as taping, bandages, thermal pants, muscle strengthening exercises or stretching), and other injuries incurred before the start of the study (in particular, hamstring injuries and anterior cruciate ligament injuries).

Hamstring injuries

The medical staff of participating teams were responsible for registering all hamstring injuries for a full calendar year (2013). A hamstring injury was defined as any physical complaint affecting the posterior side of the upper leg irrespective of the need for medical attention or time loss from soccer activities.[29] All hamstring injuries were registered on a special form, and a so-called recovery form was completed when the player was fully recovered. Data were being collected on the epidemiology (location, type, and duration of the injury) and etiology (including intrinsic and extrinsic factors, such as injury history and field condition) of the hamstring injury and information on residual complaints and tertiary prevention.

Exposure and compliance

The number of times a player performed the NHE protocol (intervention group), the number and duration (in minutes) of training sessions (both group and individual training) followed and the number and duration (in minutes) of matches played were recorded weekly for 1 year by the team coach, using a computer-based registration form. Coaches also recorded reasons why players did not attend training or matches (e.g., sickness, hamstring injury, other injuries, individual training, training elsewhere or other) per individual player.

The research team had regular contact (by telephone, email, or visits) with team coaches and players with a view to encourage compliance and data registration. In addition, newsletters, evaluation meetings, and a website designed for this specific study were also used to stimulate participation and compliance. The intervention teams were monitored with regard to implementation and performance of the Nordic hamstring exercise and other self-initiated preventive strategies for hamstring injuries (e.g. core stability, plyometric exercises etc.). The control teams were monitored with regard to self-initiated preventive measures for hamstring injuries, specifically the NHE.

Outcomes

The primary outcome of this study was hamstring injury incidence. Injury incidence was reported in absolute numbers as well as an injury incidence rate for number of injuries per 1000 player hours in both matches and training.[29] Secondary outcomes were injury severity and compliance to the intervention protocol. Injury severity was defined as the number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection.[29] Injury severity was also classified in subcategories as slight (0 days); minimal (1–3 days); mild (4–7 days); moderate (8–28 days); severe (> 28 days) and career ending.[29]

Statistical methods

SPSS version 21.0 was used to analyse the quantitative data, using a 0.05 level of significance for all statistical tests. Descriptive statistics (means and standard deviations) were used to describe baseline characteristics and exposure data. Hamstring injury incidence was analyzed based on an intention-to-treat basis. Injury incidence was only calculated from players whose full training and match exposure during all 52 weeks of the study was registered.

No effect of the intervention was expected until full completion of the NHE protocol. Therefore, the period before (week 1–13) and after (week 14–52) full completion of the NHE protocol were seperately analysed. To assess the effect of the intervention on injury incidence and injury severity, Chi-square tests were used for categorical variables and t-tests for continuous variables, respectively. Odds Ratios (OR) and Relative Risks (RR) were calculated to quantify associations between intervention and injury risk.

Compliance with the intervention was calculated on the basis of information provided by the team coaches. As the protocol consisted of 25 sessions, compliance was calculated per team as: *n* (amount of Nordic hamstring exercise sessions) / 25 x 100 = % compliance.

Results

A total of 110 soccer teams from four soccer districts were asked to participate in this study. The 40 included teams were randomized by club to the intervention and control group. Four teams (two intervention-teams and two control-teams) withdrew participation before the start of the study because the medical staff was not able to perform baseline measurements as instructed. Another two teams from the control group were lost to follow-up due to trainer and/or medical staff replacements during the study period and two teams from the intervention group were lost to follow-up because of unwillingness to continue the intervention and injury registration due to players' complaints about DOMS. Players from 32 teams completed the study: 16 teams in the intervention group (n = 292 players) and 16 teams in the control group (n = 287 players). Figure 4.2 shows selection and allocation of players.

Baseline characteristics of all players included in the study are summarized by allocated group in Table 4.2. No statistical significant differences in baseline characteristics were found between intervention and control group.

Exposure

During the study period, players in the study had an average exposure of 92.9 (95% CI, 77.2–108.6) hours. The mean training and match exposure was 58.4 (95% CI, 41–75.8) hours and 34.5 (95% CI, 20.5–48.5) hours, respectively. There were no significant differences between match or training exposure between intervention and control group (Table 4.3).

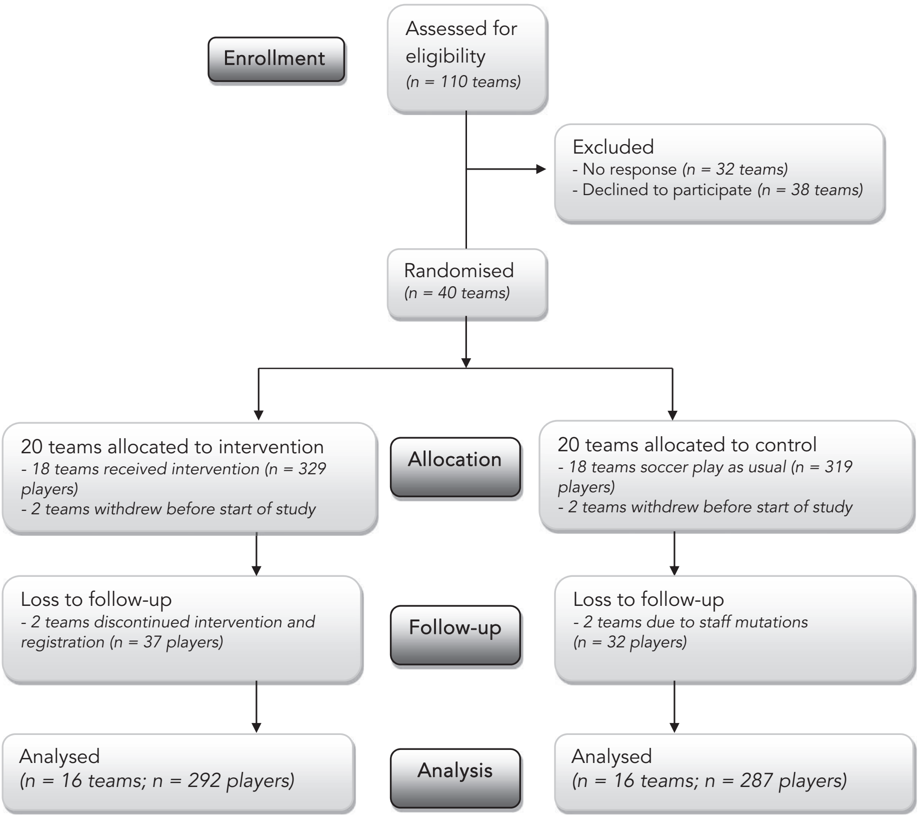

Figure 4.2 Flow chart of study population.

Table 4.2 Baseline characteristics of soccer players in intervention and control group[a]

	Intervention group (n = 292) Mean (SD) / %	Control group (n = 287) Mean (SD) / %
Age (years)	24.5 (± 3.6)	24.6 (± 4.1)
Height (cm)	183.4 (± 6.4)	183.5 (± 6.4)
Weight (kg)	77.6 (± 7.8)	78.4 (± 8.2)
BMI (kg/m^2)	23.1 (± 1.7)	23.3 (± 1.8)
Dutch nationality	91% (n = 263)	94% (n = 243)
Soccer experience (years)	17.8 (± 4.0)	18.3 (± 4.6)
Leg dominance		
Right leg	70% (n = 203)	68% (n = 174)
Left leg	21% (n = 60)	20% (n = 52)
Two-legged	7% (n = 19)	12% (n = 31)
Field position		
Forwarder	28% (n = 80)	27% (n = 69)
Midfielder	35% (n = 101)	36% (n = 92)
Defender	35% (n = 102)	36% (n = 92)
Goalkeeper	11% (n = 31)	10% (n = 25)
Preventive measures taken		
Taping/bandages	1% (n = 3)	0% (n = 0)
Thermal pants	15% (n = 43)	24% (n = 50)
Strengthening exercises	15% (n = 42)	13% (n = 34)
Stretching	26% (n = 76)	32% (n = 81)
Hamstring injury in previous year	24% (n = 69)	20% (n = 47)
Other soccer injuries in previous year	60% (n = 174)	57% (n = 144)
History of ACL surgery	5% (n = 13)	5% (n = 11)

[a] Values are presented in mean ± SD or percentage (No.).

Hamstring injury characteristics

During the registration period, 36 initial hamstring injuries were recorded in 579 players (6.2%) (see Table 4.3). The overall injury rate for both groups was 0.7 (95% CI, 0.6–0.8) per 1000 player hours; 0.33 (95% CI, 0.25–0.46) in training and 1.2 (95% CI, 0.82–1.94) in matches. Most injuries occurred during matches when compared to training (23 vs 11 respectively; other injuries occurred during warming-up (n = 1) or were not reported (n = 1)). No statistical significant differences were found regarding field position (defenders 36%; midfielders 32%; attackers 32%). No hamstring injuries were recorded for goalkeepers. Members of team medical staff reported players' accelerations as the

Table 4.3 Comparison of the intervention and control group[a]

	Intervention group	Control group
Exposure in hours (SD) per player		
Total exposure	90.5 (15.4)	96.6 (16.0)
Match exposure	34.0 (13.8)	35.1 (14.3)
Training exposure	56.5 (17.0)	61.5 (17.7)
Total number of hamstring injuries (HSI)[b]	11	25
HSI before end of intervention period (wk 1–13)	5	7
HSI after end of intervention period (wk 13–52)[b]	6	18
Mean days of soccer absenteeism due to HSI (SD)	31 (15)	28 (19)
Total number of injuries by HSI severity[c]		
Slight (0 days)	0	1
Minimal (1–3 days)	0	1
Mild (4–7 days)	0	2
Moderate (8–28 days)	4	5
Severe (> 28 days)	2	9

[a] Values are presented in mean ± SD or No.
[b] Significantly different between the intervention and control groups ($p < 0.05$).
[c] After end of intervention period (wk 13–52).

most frequent etiology (53%), more than the player decelerating (15%), shooting (6%), slipping (3%), cutting (9%) and overstretching the knee (3%) and other (21%).

Effects of the intervention on injury incidence

Eleven hamstring injuries (31%) were recorded in the intervention group and 25 (69%) in the control group. Five of the 11 hamstring injuries (45%) in the intervention group and 7 of 25 hamstring injuries (28%) in the control group occurred within the 13-week intervention period. At the end of the 13-week intervention period, there was no statistical significant difference ($p = 0.427$) in hamstring injury incidence between intervention and control group (OR 0.628; 95% CI, 0.197–1.999).

After the intervention period, 18 hamstring injuries (72%) were recorded in the control group and 6 (55%) in the intervention group, showing a significant difference in hamstring injuries between both groups, $\chi^2(1, n = 579) = 7.865$, $p = 0.005$. Risk for injuries was reduced in the intervention group after performing the NHE protocol (RR 3.384; 95% CI, 1.362–8.409) (OR 0.282; 95% CI, 0.110–0.721) and was statistically significant ($p = 0.005$).

Effects of the intervention on injury severity

After the intervention period, players in the intervention and control group were absent from soccer play for an average of 31 (SD 15) days and 28 (SD 19) days respectively. The difference in injury severity between intervention and control group was not statistically significant $t(22) = 0.374$, $p = 0.342$.

Compliance

Two teams did not fully report compliance to the intervention protocol due to loss to follow up. The compliance of intervention teams to the protocol was 91%. Reasons for not achieving full compliance to the intervention protocol were players complaining about DOMS and not having two training activities due to mid-week matches or other activities. DOMS were mainly reported in the first weeks (build up phase) of the NHE protocol. None of the teams in the control group performed a Nordic hamstring exercise protocol comparable to the intervention program.

Discussion

This cluster-randomized controlled trial evaluated the preventive effect of the Nordic hamstring exercise on the incidence and severity of hamstring injuries in male amateur soccer players. The results show that performing the Nordic hamstring exercise protocol in regular amateur soccer training results in a reduced risk of hamstring injury in male amateur soccer players. The Nordic hamstring exercise protocol did not reduce hamstring injury severity.

The effectiveness of eccentric strengthening for hamstring injury prevention can be explained from previous biomechanical analyses. Hamstring ruptures typically occur in the latter part of the swing phase during sprinting.[30-32] In this phase, where the hamstrings are (sub)maximally stretched due to hip flexion and knee extension, the hamstring muscles have to decelerate knee extension i.e. performing an eccentric contraction in a lengthened position.[31-32] The higher the sprinting velocity, the greater these forces are.[31-32] The risk of hamstring injury during high-speed running is associated with inadequate eccentric strength of the hamstrings.[33-35]

Effective injury prevention via eccentric strengthening of the hamstring muscles has been demonstrated before, mainly in professional soccer.[23,24,36] Askling showed significant hamstring injury incidence reduction in a subgroup of professional soccer players performing additional hamstring strength training with eccentric overload compared to a control group performing training as usual.[36] Arnason (2008) and Petersen (2011) also investigated the preventive effect of eccentric strengthening on hamstring injury incidence in a much larger study population of professional soccer players.[23,24] Although a preventive effect was found, these studies were mainly conducted on professional players. Additionally, the biggest effect was found for recurrent hamstring injuries as defined by Fuller (2006).[29] The present study did record recurrent hamstring injuries following the same definition.[29] However, since there were only two recurrent injuries recorded, both from the same player, recurrent injuries were not included in the analyses and effects were thus not specified for recurrent injuries as previously been done.

This study focused specifically on male amateur adult soccer players and was characterized by the large study population (40 amateur teams). Other strengths of this study are the tailored intervention design specific for amateur soccer and the high compliance to the intervention protocol (91%) compared to similar exercise-based intervention studies.[37-39]

Some methodological issues should be considered. This study could have been limited by information bias, as participants were not blinded within the study. Unfortunately, it is usually impossible to achieve and maintain blinding in exercise-based field studies. Athletes are taking part in the intervention and know what measures were performed and we did not produce a sham intervention for blinding purposes.[40] Second, in view of the expected large number of hamstring injuries in this study, it was not feasible to verify injury diagnosis by an independent medical doctor including appropriate additional diagnostic imaging (e.g. MRI, ultrasound). The adopted definition of hamstring injury was similar to previous research and in accordance with the consensus statement on injury definitions in studies of soccer.[23,24,29,36] Although guidelines from the consensus statement have been generally adopted in studies of football injuries, no subclassifications on hamstring injury type or hamstring injury location can be provided without thorough medical assessment (preferably including MRI). Therefore, a specifically designed hamstring injury registration form was used to verify the hamstring injury and exclude other potential conditions for posterior upper leg pain (such as referred pain or adductor-related injuries). When judging the distribution of hamstring injury severity in our study population, significantly more moderate and severe injuries are reported than slight, minimal or mild injuries. Underreporting of slight, minimal or mild injuries could have led to lower overall hamstring injury incidence rates, although hamstring injury incidence rates in this study were similar to incidence rates described in a similar population by Van Beijsterveldt et al., reporting hamstring injury incidence rates of 1.5 per 1000 player hours.[10] Additionally, medical staff of participating teams were specifically instructed on the adopted hamstring injury definition and regular contact was established to encourage compliance to hamstring injury registration.

Previous studies, as well as Fuller's consensus statement, have stated that injury incidence rates should be reported as the number of injuries per 1000 hours of soccer play.[29] Although the present study intended to monitor exposure of every included player, this study had some data loss regarding exposure due to coach and player replacements. Exposure was therefore only calculated from data of players whose exposure had been reported for a full year. It should be considered that for studies on hamstring injuries it is not the amount of hours of soccer play (exposure) that might be crucial, but rather match or training intensity. Biomechanical analyses have shown that the hamstring muscle is particularly prone for injury during high intensity movements in soccer such as accelerating, high speed running and cutting.[31-35] Subsequently, as previously stated by Petersen, this would require registration of individual activity and intensity by GPS (Global Positioning System), biomechanical analyses, video and so forth.[23] From these registration methods, only high-risk activities should be registered as exposure. Unfortunately, this approach was not feasible in the current trial. Because all participating clubs played at the same performance level, had approximately similar training and match exposure and were randomized by an independent randomizer we assumed similar intensity regarding both training and matches.

Injury prevention is an essential part of sports participation in order to reduce sports injuries, direct and indirect medical costs and personal suffering of the injured player.[41] The NHE has proven to be an effective preventive measure for hamstring injuries in soccer.[23-24] Unfortunately, positive outcomes from intervention studies do not necessarily lead to subsequent prevention of injuries.[42] Interventions can only prevent injuries when they are adopted and used by the intended end users.[43] The present field study was conducted in collaboration with the Royal Netherlands Football Association (KNVB), team coaches, team medical staff and team players. This collaboration as well as the specific parameters and build-up of the intervention protocol should provide a basis for implementation of the Nordic hamstring exercise in soccer training for Dutch amateur teams. Policy makers and Football Associations should continue to make a joint effort to ensure and investigate implementation of injury preventive strategies, such as the NHE, in order to make injury prevention truly work.

As stated by Klügl, there is a lack of research on implementation and effectiveness of injury preventive strategies in a real-world context.[44] This knowledge is essential as positive study outcomes do not directly translate into injury prevention. Future research should therefore focus on pitfalls and opportunities on implementation of eccentric strengthening as an injury preventive strategy in soccer. Additionally, studies with longer follow-up should be performed to analyze the long-term effects of NHE and effectiveness on recurrent injuries in an amateur population.

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Chapter 5

Hamstring-and-lower-back flexibility in male amateur soccer players

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Abstract

Objective This study investigated the hamstring-and-lower-back flexibility (HLBF) of male adult amateur soccer players, using the sit-and-reach test (SRT), with a view to obtaining population-based reference values and to determining whether SRT scores are associated with player characteristics.

Design Cross-sectional cohort study.

Setting Teams from high-level Dutch amateur soccer competitions were recruited for participation.

Participants Dutch male high-level amateur field soccer players (n = 449), aged 18–40 years. Players with a hamstring injury at the moment of SRT-measurement or any other injury that prevented them from following the SRT protocol were excluded.

Main outcome measures SRT scores were measured and then population-based reference values were calculated: > 2SD below mean (defining 'very low' HLBF), 1SD–2SD below mean ('low' HLBF), 1SD below mean to 1SD above mean ('normal' HLBF), 1SD–2SD above mean ('high' HLBF), and > 2SD above mean ('very high' HLBF). Whether SRT scores were correlated with player characteristics was determined using a Pearson correlation coefficient or Spearman's rho.

Results SRT scores ranged from 0 to 43.5 cm (mean 22.0 cm, SD 9.2). The cut-off points for population-based reference values were < 3.5 cm for 'very low', 3.5–13 cm for 'low', 13.0–31.0 cm for 'normal', 31.0–40.5 cm for 'high', and >40.5 cm for 'very high'. SRT scores were significantly associated with players' height (ρ = -0.132, p = 0.005), BMI (r = 0.114, p = 0.016), and history of anterior cruciate ligament surgery (p < 0.001).

Conclusions The present study is the first to describe the HLBF of amateur soccer players. The SRT reference values with cut-off points may facilitate evidence-based decision-making regarding HLBF and the SRT might be a useful tool to assess injury risk, performance or for diagnostic purposes.

Introduction

The sit-and-reach test (SRT) is one of the most commonly used instruments to measure hamstring-and-lower-back flexibility (HLBF) and is often used to diagnose or assess the risk of injury and to evaluate performance.[1,2] The classical SRT was first described by Wells and Dillon in 1952.[3] Since then, the SRT has been incorporated in many HLBF and fitness test protocols, such as the Eurofit Test of Physical Fitness.[1,4-9] The SRT has a high intrarater reliability and test-retest reliability.[2-4,8,10] For practical use by clinicians (e.g. sports physicians, physical therapists, sports masseurs etc.), the SRT is quick and simple to perform and requires little skill and training, both for administering the test and interpreting the scores.[5,11] Furthermore, the SRT is particularly useful in largescale evaluation of HLBF in the field setting, such as team monitoring of HLBF over time.[11,12]

HLBF is an important modifiable risk factor for injuries and is easy to measure in clinical practice by instruments such as the SRT. As such, HLBF deserves attention in sports injury-related research.[13-15] HLBF is an integral part of the current cause-effect model for hamstring injury, although research contains controversial findings regarding the contribution of hamstring flexibility on increased injury risk.[16] Mendiguchia's new conceptual model for hamstring injury suggests that hamstring flexibility could particularly turn into a risk factor when combined with other risk factors, such as strength, and increase the likelihood of injury.[16] Regarding the relationship between strength and flexibility, fundamental research has shown that the ratio of the change in resistance to the change in length of the muscle, termed stiffness, is associated with an increased risk of injury.[17-19] As a less stiff muscle can extend to a greater length, it can better absorb applied forces.[17,20] Sports requiring optimal use of the stretch-shortening cycles of the hamstring muscles generally involve rapid acceleration and deceleration, such as is seen in rugby, American football, and soccer, all of which are high-risk sports for hamstring injuries.[21-22] Therefore, evaluating hamstring muscle flexibility, by instruments such as the SRT, is a regular assessment in sports medical evaluation because reduced HLBF has been proposed as a predisposing factor for increased risk of hamstring injury.[23]

A reduced HLBF can be a risk factor not only for sports injuries,[24-28] such as acute hamstring injuries,[27] muscle damage following eccentric exercises,[26] patellar tendinopathy,[28] anterior knee pain,[28] low back pain,[25] but also for reduced performance.[24] Competitive soccer players have a reduced HLBF compared with recreational athletes,[29,30] possibly as a result of the long-term impact of soccer training on the muscle-tendon system. It potentially makes soccer players more susceptible to hamstring injuries.[29,31,32] Indeed, the highest rate of hamstring injury is seen in soccer,[33] accounting for 47% of all muscle strains in the sport and the most lost playing time when compared with all other injuries.[22] Hamstring injuries are characterized by a high recurrence and substantial lost playing time.[22,34] Therefore, identifying soccer players with a reduced HLBF, measured with the SRT, might facilitate identification of those players at risk of injury.[35]

Accurate diagnostics and valid prediction rules for HLBF can improve the effectiveness of treatment, prevention, and training. However, the interpretation of outcomes for many clinical tests, such as the SRT, is still highly subjective.[36] The lack of population-based reference data with appropriate cut-off points makes it difficult to use the results of clinical tests for evidence-based decision-making or research.[37,38] To our knowledge, no studies have measured HLBF in soccer players. The aim of this study was to measure HLBF in male adult amateur soccer players, with a view to establishing population-based reference values and to determining whether HLBF in this population is associated with specific player characteristics.

Methods

This cross-sectional study was part of the Hamstring Injury Prevention Strategies (HIPS) study, a study of interventions to prevent hamstring injuries in male adult soccer players in the Netherlands (trial number NTR3664).[39] Baseline data, including SRT scores, of 616 soccer players were available for the current study.

Subjects

Soccer teams from Dutch high-level amateur field soccer competitions ('1e Klasse') were invited to participate. Teams were included if the coaches and medical staff agreed on participation and players were willing to sign informed consent. Male players aged between 18 and 40 years were eligible for inclusion.

Teams were regarded as drop-out if the medical staff did not return the player questionnaires or SRT scores of the team or did not follow the SRT testing protocol. Individual players were excluded if they suffered from a hamstring injury at the moment of inclusion or any other injury that prevented them from following the SRT protocol.

Individual players were regarded as drop-out if they were not available for flexibility testing.

Procedures

Instruction meetings for the medical staff of participating teams were organized in each district 2–6 weeks before the study started in January 2013. During these meetings, the aims of the study and the SRT for flexibility measurements were explained. Team medical staff were provided with a SRT box, written instructions, and intake questionnaires and were responsible for collecting and returning the questionnaires and SRT scores. Data were collected during the first soccer team activity after the winter break in January 2013.

Instruments

Intake questionnaires

Information about player characteristic (date of birth, self-reported height and weight, nationality, years of soccer experience, dominant leg (i.e. kicking leg), field position, current injury status, and soccer injury history) was obtained with a questionnaire. This questionnaire defined soccer injuries, in accordance with Fuller's consensus statement, as any physical complaint sustained by a player that results from a soccer match or soccer training, irrespective of the need for medical attention or time loss from soccer activities.[40]

Sit-and-Reach Test

Flexibility was measured using the classical SRT protocol as described by Ayala et al.[5] Meta-analysis has shown that the classical SRT protocol has a better criterion-related validity than modified versions of the SRT protocol.[12] For this test, a standard SRT box (30.5 cm high) with a sliding reach indicator on top of a measuring scale (0–50 cm) was used. The 35-cm mark was aligned with the foot panel of the box. The test has a high intra-rater reliability (Intra-class Correlation Coefficient (ICC) = 0.92–0.98) and test-retest reliability (ICC = 0.92–0.95) for the SRT.[1,2,6,10]

The SRT was performed before normal training and the player was not allowed to do any warming-up or stretching exercises before the test. The player was tested while sitting on the floor, with the legs together, the knees extended, and the soles of the bare feet placed against the foot panel of the test box (see Figure 5.1/Video 1). He was

Figure 5.1 Test position of the Sit-and-Reach Test (SRT).

instructed to place his hands on top of each other with the hand palms facing downward and to reach forward slowly, pushing the reach indicator as far as possible along the measuring scale. Throughout the test, a member of the medical staff made sure that the knees of the player remained extended; the knees could be fixed during the test. The maximum position had to be reached gradually and maintained for 2 seconds. Two measurements were taken, with a 30-second interval, for each player.[5] In between the two measurements, the player had to sit up straight so that the hip extensor muscles were returned to a neutral position; the player was not allowed to stand up or stretch. Test scores were recorded to the nearest 0.5 cm. If a player could not reach the zero mark on the box, the test score was reported as zero.

Statistical analysis

All statistical procedures were performed using SPSS 22.0 (IBM Corp. 2011, Armonk, NY, USA). Player characteristics were reported as means and standard deviations (SD) for continuous variables (age, height, weight, BMI, soccer experience), and as number of players and percentages for ordinal or categorical variables (nationality, leg dominance, field position and injury history).

SRT scores are reported as means in cm, standard deviations (SD), range and quartiles (5). Population-based reference values of HLBF were calculated as: > 2SD below mean (defining 'very low' HLBF), 1SD–2SD below mean ('low' HLBF), 1SD below mean to 1SD above mean ('normal' HLBF), 1SD-2SD above mean ('high' HLBF), and > 2SD above mean ('very high' HLBF).

Pearson correlation coefficient (PCC) or Spearman's rho was calculated to determine whether player characteristics were correlated with SRT scores. Continuous variables were checked for normal distribution by using the Kolmogorov-Smirnov test. Subsequently, differences in player characteristics among subgroups of HLBF were analyzed with Chi-Square tests and ANOVAs. Statistical significance was accepted at the $p = 0.05$ level.

Ethical considerations

This study was approved by the medical ethics committee of the University Medical Center Utrecht, Netherlands (File number 12-575/C). All players were asked to provide written informed consent prior to the start of this study. Players unwilling to do so were excluded from the trial.

Results

Baseline data of 449 soccer players from 29 teams were available for analysis. A flow chart of the study population is presented in Figure 5.2.

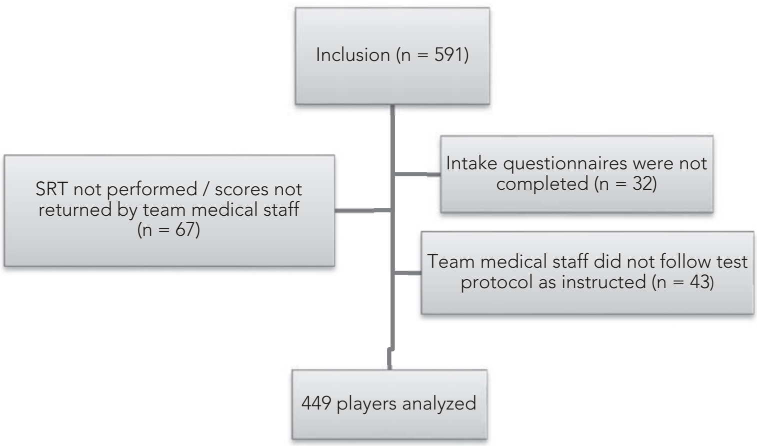

Figure 5.2 Flow chart of the study population.

Player characteristics

Player characteristics are summarized in Table 5.1. Their mean age was 24.5 years (SD 3.8) and they had played soccer for a mean of 18.1 years (SD 4.2). The right leg was dominant in 68.1% of the players. Field positions were proportionally represented, although some players reported multiple field positions (e.g. midfielder and forward). Almost one in four players (23.3%) had had one or more hamstring injuries in the previous year.

Table 5.1 Player characteristics (n = 449)

	Mean (SD) / %
Age (years)	24.5 (± 3.8)
Height (cm)	183.5 (± 6.4)
Weight (kg)	78.2 (± 8.2)
BMI (kg/m^2)	23.2 (± 1.8)
Dutch nationality (%)	95.3% (n = 428)
Soccer experience (years)	18.1 (± 4.2)
Leg dominance	
Right leg	68.1% (n = 305)
Left leg	22.8% (n = 102)
Two-legged	9.2% (n = 41)
Field position	
Forward	26.9% (n = 121)
Midfielder	35.6% (n = 160)
Defender	35.9% (n = 161)
Goalkeeper	10.9% (n = 49)
Hamstring injury in previous year	23.3% (n = 99)
Other soccer injuries in previous year	60.4% (n = 269)
History of anterior cruciate ligament surgery	4.7% (n = 20)

SRT scores

SRT scores are presented in Table 5.2. The mean overall SRT score of all players was 22.0 cm (SD 9.2; range 0–43.5 cm). Fifteen players (3.3%) scored 0 cm on both tests. The lower and upper limits of the normal range of SRT scores for this population (mean ± 1SD) were 13.0 and 31.0 cm, respectively. The lower and upper critical limit values for HLBF (mean ± 2SD) were 3.5 and 40.5 cm, respectively. The population-based reference values for the SRT in male adult amateur soccer players are presented in Table 5.3.

Table 5.2 Sit-and-Reach Test scores (n = 449)

	Mean (SD)	Range	Quartiles (25–50–75)
SRT 1 (cm)	21.2 (± 9.2)	0.0–43.0	15.0–21.5–27.5
SRT 2 (cm)	22.8 (± 9.4)	0.0–45.0	17.0–23.5–30.0
$SRT_{average}$ (cm)	22.0 (± 9.2)	0.0–43.5	16.0–22.5–28.5

Table 5.3 Population-based reference values for the Sit-and-Reach Test

SRT score	HLBF
> 40.5	Very high
31.5–40.5	High
13.0–31.0	Normal
3.5–12.5	Low
< 3.5	Very low

Player characteristics associated with SRT scores

Player height was negatively correlated with SRT scores (ρ = -0.132, p = 0.005) whereas BMI was positively correlated with SRT scores (r = 0.114, p = 0.016). Players with a history of anterior cruciate ligament (ACL) surgery had a higher SRT score (mean 7.6 cm) than players without such a history ($p < 0.001$). Age, weight, soccer experience, leg dominance, field position, and previous hamstring injury were not associated with HLBF. There was a difference in BMI between the 'Very low HLBF' and 'High HLBF' group (Δ -1.36, p = 0.045) and for 'history of ACL surgery' (χ^2 (4, n = 422) = 25.424, p = 0.000).

5

Discussion

This study investigated the HLBF of male adult amateur soccer players, with a view to establishing population-based reference values for the SRT and to determining whether player characteristics are associated with SRT scores.

Population-based reference values

The mean SRT score was 22.0 cm and normal values ranged from 13.0 to 31.0 cm in male adult amateur soccer players. These soccer players had a substantially lower flexibility than other athletes.[4,5,41] Using the same protocol, Ayala et al. found SRT scores of 35.9 (± 10.1) cm and 38.1 (± 9.7) cm among 243 recreationally active young adults (mean age 21 years).[5] Soccer training reduces muscle flexibility in both the short and long term,[42] and since our participants had played soccer for an average of 18 years, this could explain why they had lower SRT scores than the recreationally active young adults described by Ayala et al.[5] Moreover, the study population of Ayala et al. contained both men and women, and it is recognized that women generally have higher SRT scores than men.[8] The SRT scores of Spanish male professional futsal players were reported as 44.1 (± 7.8) cm and 42.4 (± 7.5) cm.[1,2] The difference in SRT scores between these studies and our study might be due to more extensive stretching protocols during the training sessions of professional players, which could increase their overall muscle flexibility.[31] Furthermore, unlike in our study, in the other studies participants followed a 5-minute warming-up and stretching protocol before testing. This could have affected hamstring flexibility, because it has been shown that 120–150 seconds of stretching results in changes in the viscoelastic properties of muscles that last 20 minutes.[43,44] Therefore most SRT-protocols, including the original protocol by Wells and Dillon, do not recommend a warming-up prior to testing and this study adhered to these guidelines.[3]

Associations with player characteristics

To our knowledge, no previous study has reported associations between HLBF and player characteristics. We found HLBF (SRT score) to be significantly associated with the height of adult soccer players. Our results show that taller players have lower hamstring flexibility than shorter players. However the methodology of the SRT might have contributed to this correlation due to differences in the proportional length of the arms and legs, as tall adolescents with longer legs relative to their arms have a poorer performance on the SRT.[45] Clinicians could therefore consider using a modified version of the classical SRT protocol to establish a relative zero point for each person, thereby solving this methodological problem of tall players.[45]

We also found HLBF to be significantly correlated with a history of ACL surgery, with SRT scores being substantially higher in players who had undergone surgery. In contrast, Ekstrand and Gillquist reported no difference in lower extremity muscle tightness between players with and without soccer injuries in the previous year.[29] In their study, Ekstrand and Gillquist analyzed all knee injuries, but did not report additional analyses for players with history of ACL surgery. In players with recent ACL surgery, this increased flexibility might be a result of rehabilitation, during which extensive (hamstring) stretching exercises are combined with a period without soccer. Unfortunately, we do not know whether a hamstring tendon autograft was used for ligament reconstruction, because this could potentially help explain the change in hamstring length or flexibility in this subgroup.[46] However, since ACL surgery should, theoretically, not directly influence HLBF, this finding suggests that ACL surgery influences SRT test scores in some other way. In conclusion, the normal range of SRT scores presented here should not be applied to players with a history of ACL injury.

Methodological considerations

The main strength of this study is the large, representative population of 449 soccer players all playing at the same amateur level, with similar training and competition loads. All player characteristics, such as age, field positions, and injury history, were well represented among the players. Moreover, all players performed the SRT following a standardized, easily executed protocol with the same measuring device, for which the members of medical staff of the teams had received identical instructions. The test protocol used in this study is simple and requires little skill or training, both with regard to test administration and data interpretation.[1] This enabled a team of players to be tested in a short time, which increases the practical usability of this test for both research purposes and in the field. This supports the representativeness and relevance of the reported population-based SRT reference values.

A potential study limitation is the lack of a criterion standard. Several different tests to measure hamstring flexibility or HLBF are available, such as the knee extension angle, sacral angle, straight leg raise, toe touch test, and different versions of the SRT.[4,6] However, no criterion standard has yet been established and these tests do not possess sufficient concurrent validity to assume that they each measure solely hamstring flexibility or HLBF.[1,6] In the current study, we chose to measure flexibility with the classical SRT, which measures a combination of hamstring and lower back flexibility (HLBF).[3]

It has been argued that the SRT score may be influenced by other anthropometric and physical factors,[4,6,11] such as limb and trunk length, gastrocnemius length, and flexibility of the shoulders, spine, and ankles. We did not correct for these factors, as the test was performed in a way that is clinically and easily applicable on the soccer field. The SRT reference values we determined represent statistically determined limits for HLBF in soccer players. Given that the standard sit-and-reach box has a range of 0 to 50 cm, a normal range of 13.0–31.0 cm leaves more room for distinguishing between players with a high than a low HLBF. In total, 3.3% of players scored 0 cm on the SRT in this study, and these individuals may be at risk of hamstring injuries because of a limited HLBF.

Future research

Future research will have to determine whether the SRT reference values can indeed identify players at increased risk of hamstring injuries due to reduced flexibility. If this is the case, then the reference values can be further refined to identify players with very poor and very high flexibility, but also the intermediate categories of flexibility with differing injury risk.

Practical applications

As a reduced HLBF is often suggested to be a modifiable, intrinsic risk factor for soccer injuries and diminished performance, identification of players with reduced HLBF is essential.[34,47-49] The SRT is a preferable test for clinicians to measure HLBF as it is reliable, quick and simple to perform, and easy for group measurements in the field setting.[11,12] Normal values of the SRT for male players – the largest subgroup in soccer – provide a basis for targeted injury prevention or performance-enhancing strategies.

The present study provides population-based reference HLBF values (measured with the SRT) for male amateur soccer players: very low' (< 3.5 cm), 'low' (3.5–12.5 cm), 'normal' (13.0–31.0 cm), 'high' (31.5–40.5 cm), and 'very high' (> 41.5). With a mean SRT score of 22.0 cm, male adult amateur soccer players have a lower HLBF than other groups of sportsmen. Coaches and practitioners should be aware of population-specific differences when using the SRT for diagnostic purposes or to assess injury risk and/or performance, and remember that the HLBF references values are not appropriate for players with a history of ACL injuries.

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Chapter 6

No relationship between hamstring flexibility and hamstring injuries in male amateur soccer players: a prospective study

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Abstract

Background In soccer, although hamstring flexibility is thought to play a major role in preventing hamstring injuries, the relationship between hamstring flexibility and hamstring injuries remains unclear.

Purpose To investigate the relationship between hamstring flexibility and hamstring injuries in male amateur soccer players.

Study design Case-control study; level of evidence, 3.

Methods This study included 450 male first-class amateur soccer players (mean age, 24.5 years). Hamstring flexibility was measured by performing the sit-and-reach test (SRT). The relationship between hamstring flexibility and the occurrence of hamstring injuries in the following year, while adjusting for the possible confounding effects of age and previous hamstring injuries, was determined with a multivariate logistic regression analysis.

Results Of the 450 soccer players, 21.8% reported a hamstring injury in the previous year. The mean (± SD) baseline score for the SRT was 21.2 ± 9.2 cm. During the 1-year follow-up period, 23 participants (5.1%) suffered a hamstring injury. In the multivariate analysis, while adjusting for age and previous injuries, no significant relationship was found between hamstring flexibility and hamstring injuries ($p = 0.493$).

Conclusion In this group of soccer players, hamstring flexibility (measured with the SRT) was not related to hamstring injury. Age and previous hamstring injuries as possible confounders did not appear to influence this relationship. Other etiological factors need to be examined to further elucidate the mechanism of hamstring injury.

Clinical relevance It is not possible to predict an increased risk of hamstring injuries in soccer by measuring hamstring flexibility.

Introduction

Soccer is the most frequently played sport worldwide, with about 265 million registered and unregistered players. Playing soccer is supposed to be beneficial for health because regular exercise during sport generally reduces the risk of many diseases.[1,2] However, this statement is challenged by the relatively high risk of injury among soccer players. In 2013, about 850,000 injuries are reported among the 1.4 million registered soccer players in the Netherlands.[3] Hamstring injuries in male amateur soccer are responsible for 15.9% of the injuries.[4] In players suffering from a hamstring injury, long-term absence from sport, or even an early end of a sport career, is reported.[5] In addition, the risk of recurrences is 16.2%, which is above the average rate compared to other types of sport injuries.[4,6] In soccer players, hamstring flexibility is often measured to determine the risk of incurring a hamstring injury and to decide whether exercises are needed to increase hamstring flexibility.[7] However, the relationship between hamstring flexibility and hamstring injuries remains unclear.

A hamstring injury is defined as a muscle or tendon injury of the semitendinosus muscle, semimembranosus muscle or biceps femoris muscle, which prevents a player from taking full part in soccer training or matches.[9] Various nonmodifiable risk factors for hamstring injuries in soccer players have been identified, including increased age, and at least 1 previous hamstring injury.[9,10] Limited hamstring flexibility is a potential modifiable risk factor related to a hamstring injury.[11]

Clark[12] reported that flexibility of the hamstring muscles plays a major role in sprint-type hamstring injuries, which are the most frequently occurring hamstring injuries in soccer. In the late swing phase of a sprint, with the knee at or near full extension, the hamstring muscles are stretched and endure a maximum peak force between 85% and 95% of the gait cycle. Consequently, when the hamstring muscles are at a (sub)maximum length during the sprint, a considerable force will be endured.[13] A player with limited hamstring flexibility is therefore assumed to be at a higher risk for an injury during a sprint than a player who has more flexible hamstring muscles. However, the evidence for a relationship between hamstring flexibility and hamstring injuries is conflicting.[11,14,15]

Two important risk factors for hamstring injuries are age and previous hamstring injuries. Increasing age can cause a loss of muscle mass, a reduction in skeletal muscle fiber size, a number of muscle fibers, and denervation of muscle fibers, which can result in decreased hamstring flexibility and an increased risk factor for hamstring injuries.[16] According to Gabbe et al.,[17] a previous hamstring injury can result in increased hamstring flexibility but also an increased risk for hamstring injuries. Therefore, because both risk factors are related to the risk of hamstring injuries and hamstring flexibility, age and previous hamstring injuries are possible confounders in the relationship between hamstring flexibility and hamstring injuries. Because of these confounders, the relationship between hamstring flexibility and hamstring injuries may have been overestimated in previous studies.[11]

Therefore, to verify our hypothesis, we investigated the relationship between hamstring flexibility and hamstring injuries, after adjusting for confounders, in male amateur soccer players.

Methods

Design

This prospective study was part of the Hamstring Injury Prevention Strategies (HIPS) study and was carried out in close collaboration with the Royal Netherlands Football Association (KNVB). The Medical Ethics Committee of the University Medical Centre Utrecht approved the study (No. 12-575/C). The design of the HIPS study has already been published.[18]

The aim of the HIPS study is 2-fold. First, a randomized controlled trial was performed to study the effect of the Nordic hamstring exercise (an eccentric exercise added to regular soccer training) on the occurrence and prevention of hamstring injuries in amateur soccer players.[19] Second, the present study examined whether limited flexibility of the hamstring muscles is associated with an increased risk of hamstring injuries.

Participants

During October and November 2012, all male first-class amateur soccer teams in the Netherlands (districts West 1, West 2, South 1 and East) were invited to participate in the HIPS study. These teams play at high-level amateur soccer competitions with 1 or sometimes 2 matches per week and 2 to 3 training sessions per week. Players of these teams who were aged 18 to 40 years and who agreed to participate were eligible for inclusion in the HIPS study. All participants received an information letter providing details on the aim of this study, the hamstring flexibility test, and data collection. After receiving the letter, all participants were asked to provide informed consent. Exclusion criteria for this study were: 1) being absent during the measurement of hamstring flexibility in January 2013, 2) being unable to perform the hamstring flexibility test correctly for any reason, or 3) suffering from a current hamstring injury.

Measurements

Player characteristics

Player characteristics were collected using a questionnaire that was filled in by all participants at baseline of the HIPS study in January 2013. The questionnaire included questions on age, years of soccer experience, field position, and hamstring injuries in the year before to the study.

Hamstring flexibility

To measure hamstring flexibility, all participants performed the sit-and reach test (SRT) supervised by a member of the medical staff of the soccer team (Figure 6.1). The SRT

Figure 6.1 The sit-and-reach test.

is a reliable and valid test to estimate hamstring flexibility.[20-22] In this study, participants performed the SRT according to the protocol described by Ayala et al.[23] No warm-up was allowed before testing. During the test, the participant was sitting on the floor with the knees extended and the legs together. The soles of the bare feet were placed against the foot panel of the SRT box. The hands were placed on top of each other with the palms facing downwards and then pushing the reach indicator on the box as far as possible along the measuring scale. The examiner placed his hands on the knees of the participant to keep the knees extended. The maximum score had to be maintained for at least 2 seconds. The score on the SRT was defined as the amount of centimeters that the participant was able to reach on the box and was registered by a member of the medical staff of the soccer team. When it was impossible for a participant to reach the zero mark on the box, the score on the test was 0 cm.

Diagnosis of a hamstring injury

The medical staff members of the soccer teams were instructed to diagnose hamstring injuries according to the consensus statement of Fuller et al.:[24] 'Any physical complaint affecting the posterior side of the upper leg, irrespective of the need for medical attention or time loss from soccer activities'.

Procedure

Before the start of this study, the researchers instructed the medical staff of all participating teams on how to perform the SRT and how to diagnose a hamstring injury according to the above-mentioned definition. These instructions were provided 2 to 6 weeks before the start of the study in January 2013 during meetings in all 4 of the participating districts. In that month, which is midseason, immediately after the winter break in the Dutch amateur soccer season, the medical staff performed measurements of hamstring flexibility in all participating players. In the Netherlands, high-level amateur soccer teams generally have a physical therapist present at all matches and training sessions. Occasionally, a sport massage therapist is present at matches and training, with a physical therapist available for additional consulting in case of any injury. During the 1-year period, the medical staff registered each hamstring injury of the participating players of their team using a special injury registration form and an injury recovery form. The registration form included questions on the mechanism of the injury in terms of 'during a sprint' or 'landing after a jump', location of the injury, and the date of the injury.

The recovery form included a question on how long the player was absent from training and matches. If a player was transferred to another team during the year, thereby making registration by the medical staff impossible, the researchers periodically contacted the individual players by telephone about possible hamstring injuries.

Statistical analysis

The minimal required sample size for the present study was calculated based on the formula of Peduzzi et al.[25] A sample of at least 300 participants was required. In this calculation, 1 risk factor, 2 possible confounding variables, and a 10.0% risk of a hamstring injury per year were assumed. This hamstring injury risk was based on a previous study with a similar sample.[4]

Descriptive statistics were used for baseline characteristics. For player characteristics, age and years of soccer experience (means ± SDs) were calculated. Players with a previous hamstring injury were presented in percentages. Also, field positions were presented in percentages.

The mean score of the SRT was calculated for all participants. Then, the mean scores for different subgroups, based on age and previous hamstring injuries, were calculated. Players were first divided into 2 equal age categories based on the median age. An independent-samples *t* test was used to investigate significant differences ($p < 0.05$) in hamstring flexibility between the 2 age categories. Second, 2 categories related to the history of hamstring injuries were formed: participants with and participants without a hamstring injury in the year before the study. An independent-samples *t* test was used to investigate significant differences ($p < 0.05$) in hamstring flexibility between these 2 categories.

The distribution of hamstring injuries in the previously mentioned categories of age and previous hamstring injuries was calculated and analyzed by using the chi-square analysis. Of all hamstring injuries, the percentage of injuries related to a sprint (according to the injury form) was calculated. Also, the mean absence from training and matches (according to the recovery form) was calculated.

To study the relationship between hamstring flexibility as an independent variable and the occurrence of hamstring injuries as a dependent variable, a univariate logistic regression analysis was used. The possible confounding variables, age (as a continuous variable) and previous hamstring injuries, were also analyzed in univariate logistic regression to investigate whether these variables might be related to hamstring injuries. To investigate the relationship, after adjusting for the possible confounding effects of age and previous hamstring injuries, a multivariate logistic regression analysis was performed. The enter method was used to create a model that included all variables including the possible confounders. Flexibility was considered a significant predictor when $p < 0.05$ in the multivariate logistic regression analysis. All analyses were performed with the Statistical Package of Social Sciences, version 20.0, for Windows (SPSS Inc).

Results

Inclusion of participants

In total, 621 amateur soccer players participated in the HIPS study. Of all participants, 96 were excluded because they reported a current hamstring injury or did not report their current status. Also, 75 participants did not perform the SRT correctly at baseline and were also excluded. Finally, 450 participants who met the inclusion criteria were included in the present study.

Participant characteristics

The characteristics of the included participants are summarized in Table 6.1. The mean (± SD) age of the participants was 24.5 ± 3.7 years. The mean years of soccer experience of the participants was 18.1 ± 4.1 years. In the year before the study, 98 (21.8%) participants reported a hamstring injury.

Hamstring flexibility

The mean scores for the hamstrings flexibility on the SRT are presented in Table 6.2. The overall mean score for hamstring flexibility was 21.2 ± 9.2 cm. The players were equally divided regarding their age into 2 categories, with 23.9 years as a cutoff point. No significant differences were found in the mean SRT score between the groups on age ($p = 0.105$) and previous injuries ($p = 0.436$) (Table 6.2). Also, years of soccer experience and field position were not significantly related to hamstring flexibility.

Table 6.1 Characteristics of the study participants (n = 450 soccer players)

	n (%) or Mean ± SD
Age, y	24.5 ± 3.7
Years of experience	18.1 ± 4.1
Previous hamstring injury in the year before the study	98 (21.8)
Field position*	
Goalkeeper	49 (10.9)
Defender	164 (36.4)
Midfielder	159 (35.3)
Attacker	118 (26.2)

* A player can hold more than 1 field position.

Table 6.2 Sit-and-reach test scores

Subgroup	n (%)	Score, cm, Mean ± SD
All players	450 (100.0)	21.2 ± 9.2
Age category, y		
18–23.9	225 (50.0)	20.5 ± 8.7
23.9–40.0	225 (50.0)	21.9 ± 9.6
Previous hamstring injury in the year before the study*		
Yes	98 (21.8)	20.6 ±10.2
No	351 (78.2)	21.4 ±8.9

* There was 1 missing value.

6

Hamstring injuries

During the study period, 23 hamstring injuries were reported, which resulted in a hamstring injury rate of 5.1%. There was no significant relationship between the category of age and hamstring injuries ($p = 0.134$) and the category of previous hamstring injuries and hamstring injuries ($p = 0.305$) as analyzed with the chi-square analysis (Table 6.3). Additionally, years of soccer experience and field position were also not significantly related to hamstring injuries. In 17 cases (73.9%), the hamstring injury was related to a sprint of the participant. The mean absence from soccer training and matches caused by the injury was 35.0 ± 25.7 days.

Table 6.3 Distribution of hamstring injuries

Subgroup	n (%)
All players	23 (5.1)
Age category, y	
18–23.9	8 (3.6)
23.9–40.0	15 (6.7)
Previous hamstring injury in the year before the study*	
Yes	7 (7.1)
No	16 (4.6)

* There was 1 missing value.

Logistic regression

In the univariate analysis, hamstring flexibility showed no significant relationship with hamstring injuries ($p = 0.496$) (Table 6.4). Adding the 2 possible confounders (age and a previous hamstring injury) in the multivariate analysis did not influence the level of significance ($p = 0.493$) (Table 6.4). Age and previous hamstring injuries were not significantly related to hamstring injuries in both the univariate analysis ($p = 0.176$ and $p = 0.309$, respectively) and the multivariate analysis ($p = 0.150$ and $p = 0.285$, respectively).

Table 6.4 Regression analysis of factors related to hamstring injuries

	Univariate analysis		Multivariate analysis	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Sit-and-reach test	0.984 (0.941–1.030)	0.496	0.985 (0.942–1.029)	0.493
Age	1.074 (0.968–1.192)	0.176	1.080 (0.973–1.199)	0.150
Previous hamstring injury	1.611 (0.643–4.033)	0.309	1.657 (0.657–4.178)	0.285

Discussion

The most important finding of our study was that a relationship between hamstring flexibility (as estimated by the SRT) and hamstring injuries was not found in male amateur soccer players. Adjustment for confounding by age and previous hamstring injuries did not influence these results. As far as we know, this is the first study to focus on the relationship between hamstring flexibility and hamstring injuries that also adjusted for possible confounding variables (age and previous hamstring injury).

In this study, the mean score on the SRT (21.2 cm) is similar to those in two earlier studies in which mean scores of 23.5 and 22.8 cm, respectively, were reported in recreational active male participants (mean age, 23.6 and 22.9 years, respectively).[26,27] The hamstring injury rate (5.1%) was lower than the hamstring injury rate in the previous year (21.8%). This could possibly be explained by the fact that the hamstring injury rate of the previous year was calculated based on the registration forms of the participants, which are retrospective data. This is contrary to the collected data of the hamstring injuries during the study period, which are prospective data. Underregistration of minimal injuries by the medical staff during the study period could be a possible explanation. However, the hamstring injury rate in the present study was also slightly lower than that in an earlier prospective study in amateur soccer players in the Netherlands in which the same definition of a hamstring injury was used (10.0%),[4] lower than that in a study of professional soccer players in Denmark (12.3%),[28] and much lower than that in a large study of hamstring injuries in professional soccer players in Europe.[29] A possible explanation for this difference in injury rates may be the Nordic hamstring exercise, which is a 13-week training program performed in the period immediately after measurements of hamstring flexibility are taken. This intervention was part of the HIPS study and was shown to be effective in preventing hamstring injuries.[19] This could have reduced the number of hamstring injuries in this prospective study.

Similar to our results, Arnason et al.[14] and Engebretsen et al.[15] did not find a relationship between hamstring flexibility and hamstring injuries. In both these Norwegian studies, the Passive Knee Extension Test (PKET) was used to measure hamstring flexibility. However, opposite results were reported by Witvrouw et al.,[11] who concluded that limited hamstring flexibility increased the risk of hamstring injuries, albeit the difference in hamstring flexibility between injured/uninjured players in that study was small. To measure hamstring flexibility, they used the straight-leg-raise test (SLRT). The differences in the tests used to measure hamstring flexibility might explain the aberrant findings of the study of Witvrouw et al.[11] when compared with our study and the Norwegian studies.[14,15]

Both the SLRT and the PKET are clinical tests that can be performed best by health care professionals.[30] No validation studies can be found that have investigated the validity or reliability of the PKET. Although the SLRT is considered the 'gold standard' for measuring hamstring flexibility, evidence for the validity of this test is also lacking. Therefore, in our study, the SRT was used to measure the hamstring flexibility. The use of the SRT has both negative and positive aspects. Although the reliability of the SRT is high, the score on the test is known to be influenced by lumbar and thoracic flexibility of the participants. Thus, the hamstring flexibility score on the SRT can be slightly underestimated or overestimated.[22,31] However, because the SRT is an easy-to-perform field test, in our opinion, this test is more applicable for the medical staff of an amateur soccer team. The SRT can be performed in a more standardized way than other hamstring flexibility tests, which reduces the risk of compensation and less accuracy.

The rationale for the hypothesis that hamstring flexibility and hamstring injuries are related is found in the kinematic process of the sprint in which hamstrings endure high forces in a stretched position. The hamstring muscles lengthen 50 to 90% of the gait circle during a sprint.[32,33] However, there is no supporting evidence that the hamstrings are maximally stretched during the last swing phase in a sprint. In speeds ranging from 80% to 100% of the maximal sprint, no variation in muscular tendon stretch of the hamstrings seems to occur. This is in contrast to the muscular tendon force of the hamstrings, which increases significantly in speeds ranging from 80% to 100% of a maximal sprint.[32] Therefore, during a sprint, it may not be the reduced hamstring flexibility that is responsible for a hamstring injury but the reduced eccentric hamstring strength of a soccer player.[33,34]

Some methodological limitations of this study need to be addressed. First, the staff of the amateur soccer teams diagnosed players with a hamstring injury. Generally, the staff consists of sports massagers (nonprofessionals in sports medicine) or physical therapists. Although the staff was well instructed by the researchers on how to diagnose hamstring injuries before the study, the diagnosis of a hamstring injury was not confirmed by a physician. A registration form was used to verify the hamstring injury. Other medical conditions that can cause posterior pain of the upper leg, for example, referred pain from the lower back or adductor-related injuries, could therefore be excluded. Second, all types of hamstring injuries were recorded, although it was hypothesized that hamstring flexibility might be related to sprint-type hamstring injuries. It was not possible for the staff of the amateur soccer teams to identify the specific sprint-type injuries. However, on the injury form, the players reported that 70% of the injuries was related to a sprint, indicating that sprint-type injuries were the most common hamstring injuries in the present study.

Conclusion

The present study shows that hamstring flexibility (as estimated with the SRT) is not related to hamstring injuries. The possible confounders of age and previous hamstring injuries do not influence this relationship. Consequently, our results suggest that it is not possible to identify players at risk for hamstring injuries by measuring their hamstring flexibility.

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Chapter 7

Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria

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Abstract

Background More than half of the recurrent hamstring injuries occur within the first month after return-to-play (RTP). Although there are numerous studies on RTP, comparisons are hampered by the numerous definitions of RTP used. Moreover, there is no consensus on the criteria used to determine when a person can start playing again. These criteria need to be critically evaluated, in an attempt to reduce recurrence rates and optimize RTP.

Objective To carry out a systematic review of the literature on (1) definitions of RTP used in hamstring research and (2) criteria for RTP after hamstring injuries.

Study design Systematic review.

Methods Seven databases (PubMed, Embase/MEDLINE, CINAHL, PEDro, Cochrane, SPORTDiscus, Scopus) were searched for articles that provided a definition of, or criteria for, RTP after hamstring injury. There were no limitations on the methodological design or quality of articles. Content analysis was used to record and analyze definitions and criteria for RTP after hamstring injury.

Results Twenty-five papers fulfilled inclusion criteria, of which 13 provided a definition of RTP and 23 described criteria to support the RTP decision. "Reaching the athlete's pre-injury level" and "being able to perform full sport activities" were the primary content categories used to define RTP. "Absence of pain", "similar strength", "similar flexibility", "medical staff clearance", and "functional performance" were core themes to describe criteria to support the RTP decision after hamstring injury.

Conclusion Only half of the included studies provided some definition of RTP after hamstring injury, of which reaching the athlete's pre-injury level and being able to perform full sport activities were the most important. A wide variety of criteria are used to support the RTP decision, none of which have been validated. More research is needed to reach a consensus on the definition of RTP and to provide validated RTP criteria to facilitate hamstring injury management and reduce hamstring injury recurrence.

PROSPERO systematic review registration number CRD42015016510.

Introduction

"When will I be able to play again?" This question about return-to-play in sports (RTP) is of great importance for every athlete after a hamstring injury. The major concern of athletes, trainers, management, and other stakeholders is to start playing as soon as possible, but this might be in conflict with the athlete's actual physical fitness and readiness for match play.[1-3] This is emphasized by the high rate of recurrence of hamstring injuries (12–33%).[4-7] This high rate of recurrence is suggested to occur due to inadequate rehabilitation and/or too early RTP.[8,9] Of these recurrences, 59% occur within the first month after RTP.[10] Recurrent hamstring injuries require more extensive rehabilitation than the initial injury, and a previous injury is the undisputed single risk factor for future injury.[11,12] These hamstring injury rates have not improved over the last 20–30 years in professional soccer and Australian Football.[13-15]

Although there have been numerous studies of RTP after hamstring injuries in recent years, the actual term is seldom explicitly defined, with definitions such as "return to sport", "return to competition", "return to competitive play", "return to pre-injury level" and "return to activity" being used.[16-19] Studies on RTP after other musculoskeletal injuries such as anterior cruciate ligament injury and ankle injury, are also hampered by the lack of a clear definition for RTP.[20-22] This makes a comparison of study outcomes difficult and emphasizes the need for a clear definition of RTP.

In addition to the lack of a clear definition of RTP, there is no consensus in the literature or among sports medical practitioners on when an athlete is ready to resume playing after a hamstring injury. In the absence of clear scientific evidence, RTP decisions are not standardized,[23,24] and this has prompted interest in criteria to support the RTP decision after hamstring injury.[25,26] These criteria need to be critically evaluated to reduce recurrence rates and optimize RTP.

The aim of this study was therefore to carry out a systematic review of the literature on (1) definitions of RTP used in hamstring research and (2) criteria for RTP after hamstring injuries.

Materials and methods

Study design

A systematic search was conducted in PubMed, Embase/MEDLINE, CINAHL, PEDro, Cochrane, SPORTDiscus, and Scopus to collect articles describing a definition or criteria for RTP. This review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines.[27] Registration in the PROSPERO international database of prospectively registered systematic reviews was performed prior to study initiation (registration number CRD42015016510).[28]

Search strategy

The search strategies, containing key words such as "return to play", "return to sport" and "hamstring injury", were developed by the primary author (NH) in collaboration with a specialized librarian (see Appendix 7.1). Searches were undertaken from the date of database inception to November 2014. The same databases were then searched independently by two authors (NH, SH). Cohen's Kappa was calculated for interobserver agreement. All references of the included studies were assessed for inclusion if missed by the initial search.

Eligibility criteria

Retrieved articles were screened by two independent authors (NH, SH). Article selection was not limited by study design. Studies needed to describe a definition of, or criteria for, RTP after acute hamstring injury in adult athletes (aged > 18 years). Articles that used definitions adopted from other studies were excluded, as were studies that reported only on RTP after surgical interventions. Additionally, articles not available as full text were excluded, although corresponding authors were contacted for information. Differences in article selection and inclusion between the two researchers were resolved in a consensus meeting or, if necessary, a third author (BH) was consulted to make the final decision.

Data extraction

If multiple articles were published by the same research group and used the same definition and/or criteria, data were extracted from only one of the articles. The following data were extracted using standardized extraction forms by two authors (NH, SH): first author and year of publication; population and study design; definition of hamstring injury; definition of RTP; described criteria for RTP (Table 7.1).

Data analyses

The methodological quality of the included articles was not assessed because the aim of this systematic review was to collate and synthesize all information on the definition of RTP and its criteria. Descriptive statistics were used to summarize the frequency of different study designs. Definitions of, and criteria for, RTP were analyzed by content analysis.[29,30] Two authors (NH, SH) separately performed each step of the analytical process to ensure adequate categorization of information and appropriate thematic analysis consistent with the literature.[29] After each step, coding procedures were discussed and if no consensus was reached, a third author (BH) made the final decision.

Content analysis

The first step in the content analysis was to create tentative labels for RTP definition and criteria within the articles, using an open coding procedure.[31] Open coding means that notes and headings are written in the text while it is read. The written material is read through again, and as many headings as necessary are written down in the margins to describe all aspects of the definition and criteria for RTP.[32]

The second step was to perform axial coding in order to identify relationships among open codes. Axial coding, termed "axial" because coding occurs around the axis of a category, links categories at the level of properties and dimensions.[31] Two authors [NH, SH] independently assessed whether headings identified during open coding were associated.[30] For instance, one article might describe concentric hamstring strength testing and no findings on magnetic resonance imaging (MRI) as criteria to support the decision for RTP after hamstring injury. A second article might describe eccentric hamstring strength testing as a criterion. A relationship between eccentric and concentric strength testing could be identified from these codes (e.g., "strength testing"), whereas the relationship between no findings on MRI and eccentric hamstring strength testing is more far-fetched.

In the third step, final content categories were identified by selective coding.[31] In this phase, content categories are established and it is determined whether axial coding categories are correlated with these content categories (such as a hypothetical content category "strength testing" as stated in the aforementioned example).[31]

Results

Search results

Of 1303 articles retrieved, 608 were excluded as duplicate publications and a further 584 were excluded after screening of the title and abstract (Figure 7.1). The remaining full-text articles (n = 111) were checked for relevant content, based on eligibility criteria, by two researchers (NH and SH). Five articles were identified from the reference lists of retrieved articles. Our third author (BH) was consulted to decide on two articles for potential inclusion. The article by Fuller et al.[33] was included and one other article was excluded.[34] In total, 25 articles met the inclusion criteria. Cohen's Kappa was 0.79 at this point, indicating substantial agreement.[35]

Types of publications and their contents

Of the 25 articles, 18 were clinical studies (2 randomized controlled trials, 12 cohort studies, 3 case series, and 1 case report), 1 a narrative review, 4 clinical commentaries, 1 a survey report, and 1 a conference abstract (Table 7.1).

Definition of RTP

Thirteen articles (52%) defined RTP (Table 7.1).

Coding

Open coding of the relevant content of the articles resulted in open codes for the "definition of RTP after hamstring injury" (Table 7.1, "definition of RTP"). After axial coding, related codes were grouped into two final content categories (e.g., selective coding): "activity level" and "medical advice" (Figure 7.2).

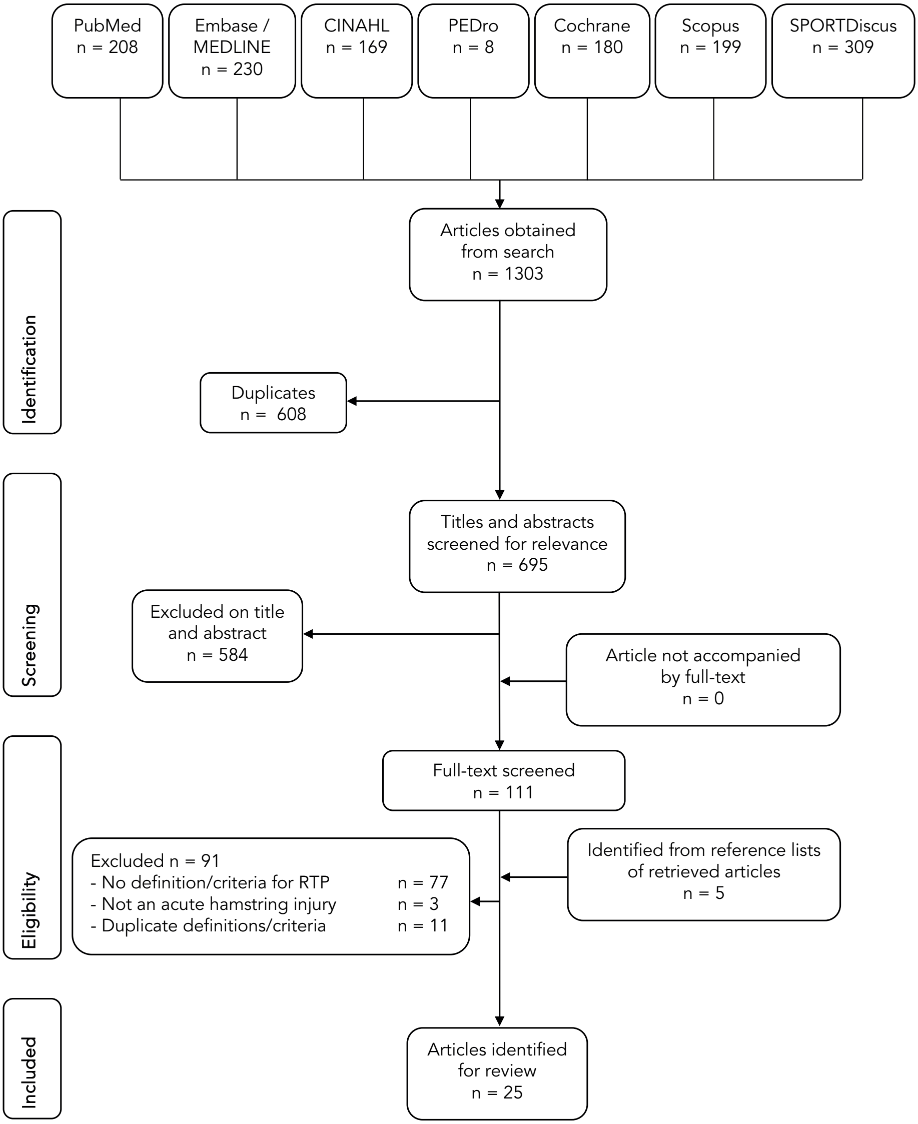

Figure 7.1 **Study selection flow chart.**

Activity level

Most authors used terms such as "reaching pre-injury level"[36,37,41,48] and "full activity"[36,44,49,53] to define RTP after hamstring injury. Other terms include "availability for match selection and/or full training",[41,49,53] "a completed game",[39] and "a 100% recovery score on fitness and skill testing".[33]

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Table 7.1 Definition of RTP and criteria for RTP after hamstring injury within the included studies – including step 1 of content analysis

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
A Hamid et al.[36]	RCT	Patients; N/R; Age > 18y	Grade-2 hamstring muscle injury	Full activities with progressive increase of training load until reaching pre-injury level	Pain free on direct palpation Pain free on hamstring contraction Pain free on active knee extension test Symmetrical range of movement with unaffected side (difference between affected and unaffected side of < 10°) Concentric hamstring strength (60, 180 and 300°/s) within 10% of uninjured side
Askling et al.[37]	Prospective cohort study	18 sprinters; 8 F – 10 M; 15–28y and 15 dancers; 1 M – 14 F; 16–24y	First time acute sudden pain from the posterior thigh when training, competing or performing	Able to train, compete or perform at their pre-injury level	Sprinters: competing at similar best times as pre-injury level Dancers: being able to train and perform without restriction
Askling et al.[38]	Cohort study	11 healthy students; 5 M – 6 F; age 28 ± 7y and 11 athletes; 8 M – 3F; age 21 ± 7y	Unilateral, MRI-verified acute hamstring strain	No signs of remaining injury on clinical examination of the injured leg	No pain during palpation and strength testing No strength difference between legs Range of motion during passive straight leg raise should be close (< 10% deficit) to that of the uninjured leg. No pain from static contraction in the end position of straight leg raise

Table 7.1 continues on next page

Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Connell et al.[39]	Prospective cohort study	61 M professional Australian Football players; age 24 ± 3.8y	Acute onset of posterior thigh pain or stiffness, disabling the player from training or match play	Return to competition (completed game)	None provided
Coole and Gieck[40]	Clinical commentary	N/A	Not provided	Not provided	Isokinetic testing within 10% of normal – equal flexibility Pain free 2 mile endurance run Pain free controlled sprinting Pain free functional activities peculiar to sport Full return of cerebromuscular capabilities
Cooper and Conway[41]	Case series	25 athletes; N/R; N/R	Complete distal semitendinosus tendon ruptures	Play at the preinjury level or – for those athletes whose sport was not in season – clearance to play.	Return of 80% isotonic knee flexion strength as compared with the normal opposite leg No pain when sprinting Having progressed through a sport-specific functional rehabilitation program Being cleared to play at the preinjury level of professional or amateur competition

Table 7.1 continues on next page

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Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Delveaux et al.[42]	Survey report	N/A	Not provided	Not provided	Complete pain relief Muscle strength performance Subjective feeling reported by player Muscle flexibility Specific soccer test performance Respect of a theoretical period of competition break Running analysis Physical fitness Balance control assessment Medical imaging Dynamic functional testing performance Correction of potential sacroiliac or lumbar joint dysfunction Quadriceps – hamstrings EMG analysis
Dembowski et al.[43]	Case report	1 M collegiate polevaulter; 18y	Not provided	Not provided	Eccentric strength within 10% of the uninvolved extremity Single leg triple hop within 10% bilaterally Pain free Illinois Agility Test within 18.4 seconds

Table 7.1 continues on next page

Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Fuller and Walker[33]	Prospective cohort study	55 M professional football players; N/R	Any injury that prevented a player from taking a full part in training activities typically planned for the day and/or match play not including the day on which the injury was sustained	Achievement of a 100% recovery score on fitness and skill testing	Pain free completion of match pace football element assessment at normal match speed
Hallén and Ekstrand[44]	Cohort study	89 M professional football teams; N/R	A traumatic distraction or overuse thigh muscle injury to the anterior or posterior thigh muscle groups leading to a player being unable to fully participate in training or match play	The decision-making process of returning an injured or ill athlete to practice or competition. This ultimately leads to medical clearance of an athlete for full participation in sports	Not provided

Table 7.1 continues on next page

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Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Heiderscheit et al.[45]	Clinical commentary	N/A	Not provided	Not provided	Four consecutive pain-free repetitions of maximum effort manual strength test in each prone knee flexion position (90° and 15°) Less than a 5% bilateral deficit should exist in the ratio of eccentric hamstring strength (30°/s) to concentric quadriceps strength (240°/s). Knee flexion angle at which peak concentric knee flexion torque occurs should be similar between limbs. Functional ability testing (sportrelated movements specific to the athlete, with intensity and speed near maximum).
Heiser et al.[46]	Retrospective cohort study	Football players; N/R; N/R	A sudden pain in the posterior thigh during a movement requiring rapid contraction of the hamstring muscles	Not provided	Run at "near-full" speed Display of adequate agility Strength at 95% of baseline score Hamstring:quadriceps ratio of 0.55 or greater at a testing speed of 60°/sec.

Table 7.1 continues on next page

Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Kilcoyne et al.[47]	Retrospective case series	48 athletes; 40 M – 8 F; age 18–20y n = 30 age 21–25y n = 17	Sudden posterior thigh pain while running or jumping, physical disability, pain with resisted prone knee flexion, and tenderness to palpation of the muscle-tendon unit of the hamstring	Not provided	Ability to perform at 90% speed during full sprint drills. Athletes' self-perceiving equivalent hamstring function and strength between injured and uninjured legs on strength testing Pain-free during all drills, including rolling sprints.
Malliaropoulos et al.[48]	Cohort study	260 elite track and field athletes; 150 M – 110 F; 18–25y	Acute, first-time posterior thigh muscle injury sustained during training or competition	Training or competing at preinjury level without any symptoms or signs of injury (such as pain, swelling, and/or tenderness)	Normalization of AROM deficit Isokinetic hamstring strength deficit of less than 5% measured at 60°/s and 180°/s compared with the injured side No difference in singlelegged triple hop test

Table 7.1 continues on next page

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Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Mendiguchia and Brughelli[16 b]	Clinical commentary	N/A	Not provided	Not provided	Optimum angle for peak torque < 28° during knee flexion Optimum angle for peak torque < 8° symmetry between legs Similar hip extension strength (< 10% asymmetry) Similar horizontal force between legs (< 20% asymmetry) Edema size and/or length as shown on MRI Lumbar rotation stability (No anterior pelvic tilt during ASLR test)
Moen et al.[49]	Prospective cohort study	80 competitive or recreational athletes; N/R; 29 ± 7y	Acute, MRI-verified, posterior thigh pain	Return to unrestricted sports activity in training and/or match play	Clearance by supervising physiotherapist
Nett et al.[50]	Conference abstract	24 athletes; 19 M – 5 F; age 24y (range 16–46y)	Acute clinical grade 1–2 hamstring injuries	Not provided	Full hamstring strength No tenderness No pain No side-to-side differences during running
Orchard[51]	Clinical commentary	N/A	Not provided	Not provided	Normal strength (> 90% of the unaffected side) Normal range of motion Performance at training dictates readiness for matches

Table 7.1 continues on next page

Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Petersen and Hölmich[52]	Clinical commentary	N/A	An incident occurring during scheduled games/competitions or practice and causing the athlete to miss the next game/competition or practice session	Not provided	Pain-free participation in sports specific activities
Petersen et al.[53]	Case series	942 soccer players; N/R; N/R	Sudden physical complaint of posterior thigh sustained during a soccer match or training, irrespective of medical attention or time loss from soccer activities	Availability for match selection or full participation in team training if the injury occurred during a period without match play	Consultation between medical staff and player
Reurink et al.[26]	Cohort study	53 M athletes; mean age 27y (range 18–46y)	Clinical diagnosis of hamstring injury by registered sports medicine physician	Successful and asymptomatic completion of physiotherapy programme, including functional sport-specific activities	Successful and asymptomatic completion of a functional criteria-based four-staged physiotherapy programme, including a final supervised sport-specific (outdoor) training phase Less than 10% side-to-side-difference at isokinetic strength testing 5 days of team training before participation on partial match play

Table 7.1 continues on next page

Table 7.1 *Continued*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a] [a]	Criteria for RTP after hamstring injury[a]
Sanfilippo et al.[54]	Prospective cohort study	25 recreational athletes; 20 M – 5 F; 24 ± 9y	Acute, sudden onset, hamstring injury	Not provided	No significant pain with straight leg raise Full hamstring strength No tenderness to palpation No apprehension during full effort, sport-specific movements Clearance by physiotherapist
Silder et al.[55]	RCT	24 athletes; 19 M – 5 F; age 24 ± 9y	A sudden-onset posterior thigh pain	Completion of rehabilitation	No palpable tenderness along the posterior thigh Subjective readiness (no apprehension) after completing a series of progressive sprints working up to full speed 5/5 On manual muscle testing
Tol et al.[25] [b]	Cohort study	52 M players; mean age 24y (range 18–38y)	MRI-positive hamstring injury	Not specified	Painless passing and running Painless shooting scenarios Painless competitive 1vs1 drills Painless scoring scenarios
De Vos et al.[56]	Prospective cohort study	64 patients; 61 M – 3 F; median age 28y (range 23–33y)	Clinical and radiological diagnosis of grade 1 or 2 acute hamstring injury	Completion of criteria-based rehabilitation programme	Symptom-free (e.g., pain and stiffness) during: · full range of motion · full-speed sprinting · sport-specific movements (such as jumping and cutting). Clearance by physical therapist Unhindered functional sports-specific testing

[a] Step 1 of content analysis: results of open coding. [b] These studies used different criteria at different stages in the rehabilitation program; only criteria that supported the final RTP-decision were included in this table. AROM = active range of motion; ASLR = active straight leg raise; EMG = electromyography; F = female; M = male; MRI = magnetic resonance imaging; N/A = not applicable N/R = not reported; RCT = randomised controlled trial; RTP = return-to-play; y = years; SD = standard deviation.

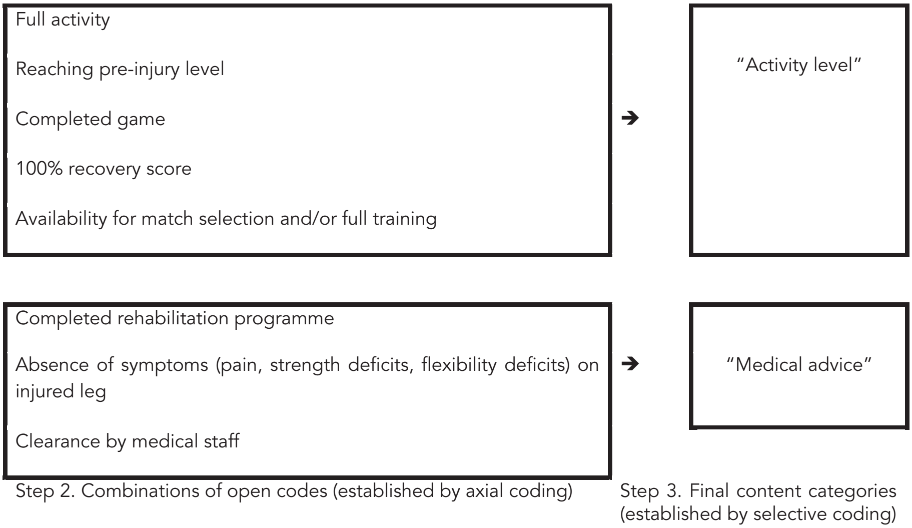

Figure 7.2 Axial and selective coding of definition for return-to-play, steps 2 and 3 of content analysis.

Medical advice

RTP after hamstring injury was also defined on the basis of medical information.[26,38,40,44,48,55,56] "Absence of symptoms on injured leg",[38,48] "clearance by medical staff",[41,44,56] and "completion of a rehabilitation program"[26,55,56] were used as terms to define RTP. Most articles provided additional medical criteria to support the RTP definition[26,38,41,48,55,56] (see next section).

RTP criteria

Of the 25 included articles, 23 articles (92%) provided criteria for RTP after a hamstring injury (Table 7.1).

7

Coding

After open coding and subsequent axial coding of criteria for RTP (Table 7.1, "criteria for RTP after hamstring injury"), related codes were grouped into five final content categories (e.g., selective coding): "absence of pain", "similar strength", "similar flexibility", "medical staff clearance", and "functional performance" (Figure 7.3).

No pain during palpation No pain during controlled sprinting No pain during functional activities peculiar to sport No pain / tenderness No pain during Illinois Agility Test No pain during active knee extension test No pain during strength testing No pain from static contraction in end position of straight leg raise No pain during straight leg raise No pain during 2 mile endurance run	→ “Absence of pain”
Equal HQ-ratio HQ-ratio of 0.55 or greater Equal peak torque knee flexion angle Optimum peak torque angle < 28° during knee flexion Optimum peak torque < 8° symmetry between legs Equal horizontal force Full strength Strength at 95% of baseline Isokinetic strength testing of affected leg within 5–10% of normal unaffected leg Muscle strength performance Return of isotonic knee flexion strength of 80% Eccentric strength of affected leg within 10% of unaffected leg Equal hip extension strength	→ “Similar strength”
Similar range of motion between legs Equal flexibility	→ “Similar flexibility”
Competing at best times Self-perceived hamstring strength Specific soccer test performance Running analysis Physical fitness Balance control assessment Dynamic functional testing performance Running analysis Single leg triple hop within 10% Full speed running Adequate agility Full sprint drills at 90% 5 days of team training	→ “Functional performance”
Rehabilitation program without restrictions Progression through a sport specific rehabilitation programme Clearance by medical staff	→ “Medical staff clearance”
Respect of a theoretical period of competition break Medical imaging Full return of cerebromuscular capabilities HQ EMG analysis Correction of SI or lumbar joint dysfunctions	→ “Other”
Step 2. Combinations of open codes (established by axial coding)	Step 3. Final content categories (established by selective coding)

Figure 7.3 Axial and selective coding of criteria for RTP, steps 2 and 3 of content analysis. EMG = electromyography; HQ = hamstrings-quadriceps; RTP = return-to-play; SI = sacroiliac.

Absence of pain

Absence of pain on palpation and during performance testing was used as a criterion for RTP after hamstring injury in 15 studies.[25,26,33,36,38,40-43,45,47,50,52,54-56] In some studies, pain was tested via direct palpation of the hamstring muscle.[36,37,54,55] Askling et al. and Hamid et al. additionally stated that hamstring contraction should not elicit pain when tested in the end position of the passive straight leg raise.[36,37] Other studies considered a pain-free state during strength and flexibility testing as fitness for RTP, but did not mention how strength and flexibility tests were performed.[37,45,54,56] Pain-free running, such as in a 2-mile endurance run or controlled sprinting, and pain-free functional activities peculiar to a given sport were also used as criteria for RTP.[25,33,40,41,45,47,50,52,54,56]

Similar strength

A similar hamstring strength in the affected and the unaffected legs was used as a criterion in 15 studies.[16,26,36,38,40-43,45-48,50,51,54,55] Most studies considered a deficit of < 10% as being similar.[16,26,36,40,43,45,46,48,54] Hamstring strength was measured in different positions with different tools. Kilcoyne et al. assessed strength as athletes' self-reported hamstring function during strength testing.[47] Other studies reported manual resistance testing at the heel with the knee flexed at 0°, 15°, 45°, and 90° in prone position.[38,45] There were also variations in test procedures with the tibia in neutral, external rotated, and internal rotated position.[55] Dembowski et al. measured eccentric hamstring strength with a hand-held dynamometer using the break method.[43] Mendiguchia tested isokinetic hip extension at 60° per second,[16] where other included studies tested at 60°/s, 180°/s, 240°/s, and 300°/s.[25,36,40] Cooper also assessed isotonic knee flexion strength, but differed from other studies as the criterion for RTP required the injured leg to reach 80% strength, instead of > 90% strength, relative to the normal opposite leg.[41] Multiple studies endorsed isokinetic strength testing under both concentric and eccentric conditions, stating that there should be less than a 5–10% deficit in the ratio of eccentric hamstring strength (30°/s, 60°/s, or 180°/s) to concentric quadriceps strength (240°/s) between the injured and uninjured legs.[36,45,46,48,54] Heiser et al. stated the hamstring:quadriceps ratio should be ≥ 0.55 at a testing speed of 60°/s.[46] In addition, it was suggested that the knee flexion angle at which peak concentric knee flexion torque occurs should be similar between limbs.[16,45]

Similar flexibility

Normal hamstring flexibility or range of motion was used as a criterion in seven studies.[36,38,40,42,45,48,51] Only the study by Askling et al. specified normal hamstring flexibility as a < 10% deficit between the injured and the uninjured legs.[38]

Flexibility or range of motion was tested via passive straight leg raise[38] or by active knee extension in supine position with the hip flexed at 90°.[48] Other studies did not specify measurement methods or cut-off values for flexibility measurements.

Functional performance

Thirteen studies reported performance during field testing as a criterion for RTP after hamstring injury.[25,26,37,42,43,45-48,50,51,53,56] One study used best sprint times comparable to those before injury.[37] Nett et al. stated that no asymmetry should occur during running,[50] whereas Reurink et al. stated no asymmetry should be present during the sport-specific (outdoor) training phase,[26] although neither study defined asymmetry. Training and performance without any restriction was also reported as a criterion.[25,37,56] According to Heiderscheit et al., functional ability testing should incorporate sport-related movements performed at near-maximum intensity and speed.[45] Tol et al. specified this further by using pain-free running, passing, shooting, scoring, and competitive one-to-one drills as criteria for RTP for soccer players.[25] Single leg triple hops and a pain-free Illinois Agility Test within 18.4 s were also reported as functional performance criteria for RTP after hamstring injury.[43,48] Reurink et al. additionally stated that, after full recovery, 5 days of team training are required before clearance for (partial) match play.[26]

Medical staff clearance

Five studies reported that the athlete should be certified as medically fit before returning to play,[41,49,53,54,56] but few studies described how this was done. In the study by Petersen et al., this decision was made in consultation between medical staff and the player.[53] Cooper et al. mentioned additional criteria (e.g., return of > 80% isotonic knee flexion strength as compared with the normal opposite leg, no pain when sprinting, and having progressed through a sport-specific rehabilitation program) that need to be met before medical staff give their approval for RTP.[41] Three studies reported that the athlete should have progressed through a sport-specific rehabilitation program without restrictions before RTP, but none of the studies described the content of such a program.[26,41,56]

Other

Other criteria for RTP after hamstring injury used were full return of cerebromuscular capabilities (not further specified by Coole et al.), extent of edema, and lumbar rotation stability.[16,40] Anterior pelvic tilt was not allowed during the active straight leg raise test in the study by Mendiguchia and Brughelli.[16] Additionally, in the study by Delvaux et al., sports physicians reported adherence to a theoretical period of competition break, medical imaging, correction of sacroiliac or lumbar dysfunction, and quadriceps-hamstrings electromyography analysis as criteria for RTP.[42]

Discussion

Statement of principal findings

In this article, we systematically reviewed the literature on definitions and criteria for RTP after hamstring injuries. Only 52% of the included articles defined RTP, whereas 92% provided criteria to support the RTP decision. Although different definitions have been used, we found that terms referring to "activity level" (e.g., reaching pre-injury level, full activity) or "medical advice" (e.g., clearance by medical staff, absence of symptoms, and completion of a rehabilitation program) were often used to define RTP after hamstring injury.

A variety of criteria have been used to support the RTP decision, subdivided into five content categories: "absence of pain" (e.g., on palpation and during performance), "similar strength" (e.g., < 10% deficit between the affected and unaffected leg), "similar flexibility", "medical staff clearance", and "functional performance".

Strengths of the study

Various medical and sport databases were used to collect detailed information on the definition of RTP after acute hamstring injury,[57] and the inclusion of studies using a different methodology provides a broad understanding of RTP. PRISMA guidelines were followed as much as possible to ensure transparent reporting of this systematic review.[27]

Article selection and data retrieval were done by two researchers independently, to maximize the inclusion of relevant articles and data.[58] The third author was consulted twice to decide on the inclusion of two articles, but this did not significantly affect our study results. We used content analysis to systematically identify and synthesize recurring themes within the definitions of RTP after acute hamstring injury.[29,30]

Limitations of the study

No search limits were placed on level of evidence, as is common in systematic reviews, because we did not statistically analyze outcome data as such. It should be borne in mind that none of the included articles had the aim of defining RTP or validating specific criteria to support the RTP decision. Another potential weakness is that not all of the studies defined hamstring injury or described the medical assessment. Thus it cannot be excluded that study participants had other injuries causing posterior upper leg pain (such as referred pain or adductor-related injuries), injuries for which different RTP definitions and criteria might apply.

Strengths and weaknesses in relation to other studies

As far as we know, this is the first review of the definitions and criteria for RTP after acute hamstring injury. In all the included articles, criteria for RTP focused on medical factors and thus results should be interpreted in the light of medical clearance for RTP. It has been suggested that modifiers of sport risk (e.g., type of sport, competitive level etc.) and decisions (e.g., pressure, fear of litigation etc.) should also be considered when determining readiness for RTP.[1] A practical decision-based RTP model of Creighton et al. guides us through three steps.[1] In step 1, medical factors such as age, injury history, psychological state, outcome of clinical tests and imaging are evaluated. In step 2, sport-specific risk modifiers, such as type, level of sport, and player position are evaluated. Finally in step 3, decision modifiers, such as timing in season, importance of match (e.g. final), external pressure, and financial conflicts of interest are considered. This means that the RTP decision should involve not only the medical doctor but also the player and other stakeholders.[2]

To date, none of the RTP-criteria have been validated with regard to the RTP-decision after hamstring injury. Only a few studies included had a primary focus on investigating specific criteria for RTP.[25,26] Reurink et al. described that at the time of RTP, 89% of all clinically healed hamstring injuries still demonstrated increased signal intensity on MRI.[26] Tol et al. found that two-thirds of the players in their study group demonstrated a > 10% deficit on hamstring isokinetic testing.[25] They did not find differences in isokinetic strength parameters in players who sustained a re-injury.[25] The relationship between these deficits at the time of RTP and the risk of re-injury is not known. In addition, it should be considered that owing to the multifactorial condition and complexity of the hamstring injury, a more comprehensive assessment of the different risk factors should be included.[59]

In a recent study, Mendiguchia et al. proposed a RTP algorithm that included criteria for progression through each rehabilitation phase, which could assist clinical decision-making regarding RTP after hamstring injury.[16] This algorithm considers all risk factors that potentially affect hamstring injury risk and incorporates the current literature on biology of muscle injury and repair. A new active hamstring flexibility test, called the "H-test", also seems a promising tool for assessing readiness for RTP after hamstring injury.[38] It is recommended that the test be performed at the end of rehabilitation, when other tests have indicated clinical recovery.[38] Askling et al. suggested that the risk of recurrent hamstring injury is significantly reduced if there are no signs of insecurity during the test.[38] These findings, if confirmed, may be an important first step to decreasing the high rates of re-injury and to optimizing RTP. Functional assessment peculiar to the given sport was also often suggested to support the RTP-decision.[25,26,37,42,43,45-48,50,51,53,56] However, more comprehensive description of assessment parameters and limit values allowing therapists to authorize (or delay) RTP, such as 'pre-injury-level' or 'asymmetry during running', needs to be provided.

The lack of an unambiguous definition of and clear criteria for RTP after hamstring injury makes it difficult to compare and interpret study results. For example, the study by Hamid et al.[36] used lack of pain on direct palpation, no pain on hamstring contraction, symmetrical range of motion, and equal hamstring strength between affected and unaffected legs as criteria for RTP. In the study by Reurink et al., participants were required to complete, without experiencing symptoms, a functional criteria-based four-staged physiotherapy program, which included a final supervised sport-specific (outdoor) training phase, and to have a < 10% difference in isokinetic strength between the affected and unaffected legs.[26] Additionally, athletes were advised to have 5 days of additional team training before participation in a match.[26] The study of Askling et al. differed from these studies in that RTP was self-registered by the study participants, with participants reporting they could train/perform their sport again, regardless of whether they had symptoms.[37] While these articles have contributed to our knowledge of hamstring injury management, the differences in definitions and criteria for RTP will inevitably lead to a different time to RTP. Moreover, the actual timing of RTP probably reflects the success of treatment less than the choice of definition and criteria for RTP.

Meaning of the study: possible implications for clinicians or researchers

We found a lack of definitions of and criteria for RTP after acute hamstring injury in the literature, which could lead to different research outcomes. Recurrence rates, which can in part be explained by premature RTP, are still extremely high.[8,9] Given the high recurrence rates and long rehabilitation for recurrent hamstring injuries, it is essential that clinicians have validated RTP criteria to support the RTP decision.

In the current literature, the definition of RTP after hamstring injury is based on the athlete reaching a pre-injury level of performance or being able to perform full sport activities and should be guided by medical advice. Clinical approval for RTP is commonly based on the athlete experiencing no pain, achieving a similar hamstring strength and flexibility as before injury, and performing properly on functional testing.

Establishing a definition and providing objective criteria for RTP after acute hamstring injury is essential for injury management, particularly the prevention of recurrent hamstring injuries. Therefore, future research should focus on achieving agreement on the definition of RTP and criteria to guide the RTP decision. Prospective studies are needed to validate these criteria and their correlation with successful RTP.

Conclusion

Only half of the included studies provided some definition of RTP after hamstring injury, of which reaching the athlete's pre-injury level of performance and being able to perform full sport activities were important elements. Numerous criteria are used to support the RTP decision, but none of these have been validated. Research is needed to reach consensus on the definition of RTP and to provide validated RTP criteria to facilitate hamstring injury management and reduce hamstring injury recurrence.

Acknowledgements

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Supplementary material

Appendix 7.1 Search strategies for all databases

Search database	Search string
PubMed	(hamstring[tiab] OR hamstrings[tiab] OR biceps femoris[tiab] OR semitendinosus[tiab] OR semitendinosus[tiab] OR semimembranosus[tiab] OR thigh[tiab] OR thighs[tiab] OR upper leg[tiab] OR upper legs[tiab]) AND (return to play[tiab] OR return to action[tiab] OR return to sport[tiab] OR return to sports[tiab] OR return to sporting activities[tiab] OR return to activity[tiab]OR return to competition[tiab] OR return to training[tiab] OR sports participation[tiab] OR return to level[tiab] OR sport participation[tiab] OR match fitness[tiab] OR training fitness[tiab] OR return to action[tiab] OR full fitness[tiab] OR repetitive injury[tiab] OR recurrent injuries[tiab] OR repetitive injuries[tiab] OR recurrent strain[tiab] OR repetitive strain[tiab]) OR recurrent strains[tiab] OR repetitive strains[tiab])
Embase - Medline	(hamstring:ti,ab OR hamstrings:ti,ab OR "biceps femoris":ti,ab OR semitendinosus:ti,ab OR semitendinosis:ti,ab OR semimembranosus:ti,ab OR thigh:ti,ab OR thighs:ti,ab OR "upper leg":ti,ab OR "upper legs":ti,ab) AND ("return to play":ti,ab OR "return to action":ti,ab OR "return to sport":ti,ab OR "return to sports":ti,ab OR "return to sporting activities":ti,ab OR "return to activity":ti,ab OR "return to competition":ti,ab OR "return to training":ti,ab OR "sports participation":ti,ab OR "return to level":ti,ab OR "sport participation":ti,ab OR "match fitness":ti,ab OR "training fitness":ti,ab OR "return to action":ti,ab OR "full fitness":ti,ab OR "repetitive injury":ti,ab OR "recurrent injuries":ti,ab OR "repetitive injuries":ti,ab OR "recurrent strain":ti,ab OR "repetitive strain":ti,ab OR "recurrent strains":ti,ab OR "repetitive strains":ti,ab)
CINAHL	hamstring OR hamstrings OR biceps femoris OR semitendinosus OR semitendinosus OR semimembranosus OR thigh OR thighs OR upper leg OR upper legs AND return to play OR return to action OR return to sport OR return to sports OR return to sporting activities OR return to activity OR return to competition OR return to training OR sports participation OR return to level OR sport participation OR match fitness OR training fitness OR return to action OR full fitness OR repetitive injury OR recurrent injuries OR repetitive injuries OR recurrent strain OR repetitive strain OR recurrent strains OR repetitive strains
PEDro	hamstring AND return
Cohrane Library	(hamstring or hamstrings or "biceps femoris" or semitendinosus or semitendinosus or semimembranosus or thigh or thighs or "upper leg" or "upper legs") and ("return to play" or "return to action" or "return to sport" or "return to sports" or "return to sporting activities" or "return to activity" or "return to competition" or "return to training" or "sports participation" or "return to level" or "sport participation" or "match fitness" or "training fitness" or "return to action" or "full fitness" or "repetitive injury" or "recurrent injuries" or "repetitive injuries" or "recurrent strain" or "repetitive strain" or "recurrent strains" or "repetitive strains")

Appendix 7.1 continues on next page

Appendix 7.1 *Continued*

Search database	Search string
Scopus	(TITLE-ABS-KEY((hamstring or hamstrings or "biceps femoris" or thigh or thighs or "upper leg" or "upper legs"))) AND (TITLE-ABS-KEY(("return to play" or "return to sport" or "return to sports" or "return to competition" or "sports participation" or "full fitness" or "training fitness" or "match fitness")))
SportDiscus	hamstring OR hamstrings OR biceps femoris OR semitendinosus OR semitendinosus OR semimembranosus OR thigh OR thighs OR upper leg OR upper legs AND return to play OR return to action OR return to sport OR return to sports OR return to sporting activities OR return to activity OR return to competition OR return to training OR sports participation OR return to level OR sport participation OR match fitness OR training fitness OR return to action OR full fitness OR repetitive injury OR recurrent injuries OR repetitive injuries OR recurrent strain OR repetitive strain OR recurrent strains OR repetitive strains

Chapter 8

Return to play after hamstring injuries in football (soccer): a worldwide Delphi procedure regarding definition, medical criteria, and decision-making

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Abstract

Background There are three major questions about return to play (RTP) after hamstring injuries: How should RTP be defined? Which medical criteria should support the RTP decision? And who should make the RTP decision?

Hypothesis/purpose This study aimed to provide a clear RTP-definition and medical criteria for RTP, and to discuss RTP consultation and responsibilities after hamstring injury.

Study design Delphi procedure.

Methods The results of a systematic review were used as a starting point for the Delphi procedure. Fifty-eight experts in the field of hamstring injury management selected by 28 FIFA Medical Centres of Excellence worldwide participated. Each Delphi round consisted of a questionnaire, an analysis, and an anonymized feedback report.

Results After four Delphi rounds, with more than 83% response for each round, consensus was achieved that RTP should be defined as "the moment a player has received criteria-based medical clearance and is mentally ready for full availability for match selection and/or full training". The experts achieved consensus on the following criteria to support the RTP decision: medical staff clearance, absence of pain on palpation, absence of pain during strength and flexibility testing, absence of pain during/after functional testing, similar hamstring flexibility, performance on field-testing, and psychological readiness. It was also agreed that RTP decisions should be based on shared decision-making, primarily via consultation with the athlete, sports physician, physiotherapist, fitness trainer, and team coach.

Conclusion Experts achieved consensus on RTP definition, medical criteria, and decision-making regarding RTP after hamstring injuries in football. The results are reported in the RTP model for hamstring injuries in football.

Clinical relevance The consensus regarding aspects of RTP should provide clarity and facilitate the assessment of when RTP is appropriate after hamstring injury, so as to avoid or reduce the risk of injury recurrence because of a too early RTP.

Introduction

Hamstring injuries are the most prevalent muscle injury in football and 12–33% of all athletes with a hamstring injury experience a recurrence within a year after the initial injury.[1-5] This high prevalence of injury causes an average of 18 days and three matches missed per season.[5] Professional football clubs experience between 0–16 hamstring injuries among players per season, which corresponds to 15 matches and 90 days missed per club per season because of hamstring injuries.[1,5] The inability to play affects the individual player and team performance. A lower injury burden and higher match availability are significantly associated with a higher final league ranking, points per league match, and success in the Union of European Football Association Champions league or Europa League.[6]

After the initial hamstring injury, all those involved in the rehabilitation process should make an effort to reduce the risk of injury recurrence. Recurrent injuries require more extensive rehabilitation than initial injuries, and previous injury is an undisputed risk factor for future injury.[7,8] Particularly alarming is the observation that recurrence rates have not improved over the last 30 years.[9-11] High recurrence rates are suggested to occur due to inadequate rehabilitation and/or too early return to play (RTP).[12,13] Of all recurrences, more than half occur within the first month after RTP.[14,15] This has prompted interest in RTP after hamstring injury.[16-20]

Unfortunately, different concepts of RTP make it difficult to analyse and compare various studies of RTP after hamstring injury.[21-22] It is recognized that diversity in definitions and methodologies causes significant differences in the results and conclusions obtained from sports injury research.[23-26] However, in accordance with the Strategic Assessment of Risk and Risk Tolerance (StARRT) framework (Figure 8.1), it is commonly agreed that any RTP decision should be based on an assessment of the risk and the acceptable risk tolerance threshold.[27] This threshold is determined by factors such as external pressure, pressure from the rehabilitating athlete, and timing in the season. For instance, a higher risk threshold might be considered more acceptable if there is an important play-off match than if there is a friendly match, because of competitiveness and potential financial benefit.[28] The risk assessment is made by assessing tissue health (e.g., patient demographics, symptoms, medical history, and examination} and tissue stresses (e.g., type of sport, field position, competitive level, psychological readiness, etc.). So far, no studies have specified how risk should be assessed when giving a player RTP clearance

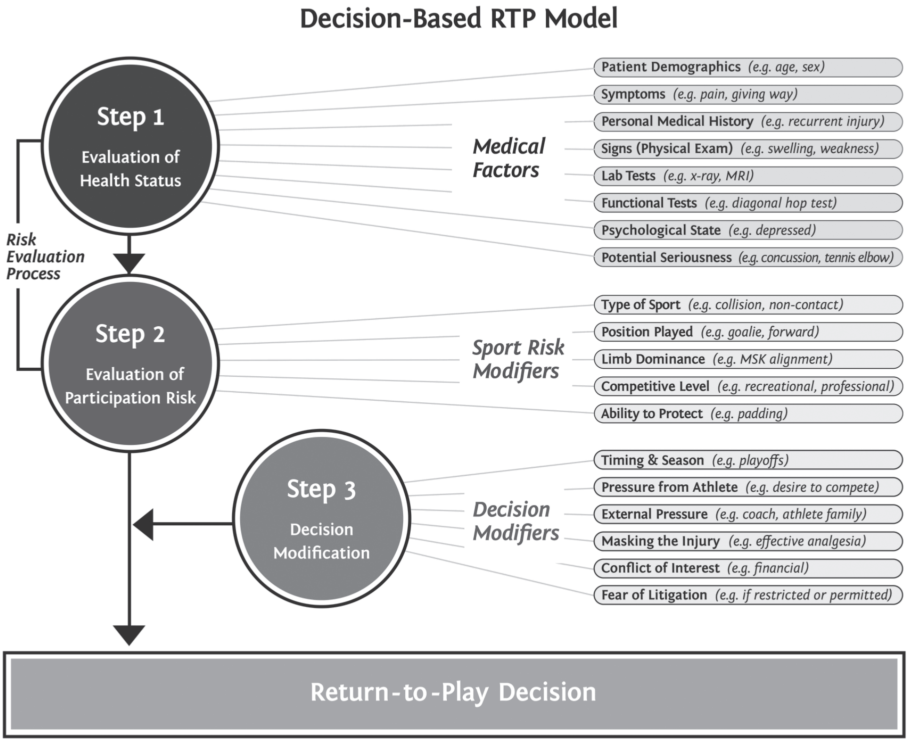

Figure 8.1 The Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for RTP decisions.[27]

after hamstring injury, although this moment is vital if injury recurrence is to be prevented. A recent systematic review of the literature showed that there is great diversity in how RTP after hamstring injury is defined and which criteria are used to assess RTP readiness.[21] Furthermore, because multiple stakeholders have their own reasons why RTP should be accelerated or delayed, it is imperative to provide clarity on who is to be consulted and who is responsible for the RTP decision.

The aim of this Delphi procedure was to provide a clear definition of, and specific criteria for, RTP and to clarify responsibilities for RTP after hamstring injury.

Materials and methods

Study design and setting

This study, the HIPS (Hamstring Injury Prevention Strategies) Delphi study, used a Delphi procedure to achieve consensus on the terminology, definition, and medical criteria for RTP and who should be involved and responsible for the RTP decision after hamstring injury. This study was carried out by the Department of Rehabilitation, Physical Therapy Science, and Sport at the University Medical Centre of Utrecht, the Netherlands. Before the start of this project, a systematic review of the definition of, and criteria for, RTP after hamstring injury was performed.[21] The results of this review were used as a starting point for the Delphi procedure.

Delphi procedure

A Delphi procedure is basically a series of sequential questionnaires or "rounds", interspersed by feedback, that seeks to achieve consensus of opinion among a panel of experts.[29,30] This scientific method was originally developed in the 1950s and has since been effectively used in sports medicine research.[31-34] Each Delphi round comprised a questionnaire, an analysis, and a feedback report.

Steering committee

The steering committee that facilitated and guided this Delphi study consisted of a full professor in sports medicine, a senior researcher with experience in Delphi procedures, a team doctor of a national football team, and a PhD student. All members have a clinical (sports medicine, (sports) physical therapy) and scientific background. The steering committee was responsible for preparing and analysing the questionnaires, as well as for reporting the results in anonymized feedback reports.

Expert panel

The FIFA Medical Centres of Excellence, which have a demonstrable record of leadership in football medicine and have been accredited through a strict selection process by FIFA, provide a network of knowledge and experience in research and clinical management of hamstring injuries. All FIFA Medical Centres of Excellence (n = 40) were invited to select one to three experts in hamstring injury management, adhering to the inclusion criteria as listed in Table 8.1. After selection, the steering committee contacted all experts via email to provide information on aim, methods, and privacy statements for this Delphi study.

Table 8.1 Experts' inclusion criteria for participation to the Delphi study

Criterion number	Description
1	The selected FIFA Medical Centre of Excellence considers this expert to be a key person in the field of hamstring injury management
2	The expert is a researcher OR medical / health professional with experience in hamstring injury rehabilitation in a sport setting
3	The expert has sufficient knowledge of English
4	The expert has an evidence-based attitude

Procedure

Online surveys were used and adhered to principles of respondent anonymity and feedback between rounds.[29] For all Delphi rounds, experts were approached by e-mail with a link to an online questionnaire. Experts were given 6 weeks to complete the questionnaire, with reminders e-mailed at 3 and 5 weeks. A structured web-based questionnaire was developed consisting of three parts: Part I for general questions about RTP consultation and responsibilities, Part II for the definition of RTP, and Part III for criteria to support the RTP decision after hamstring injury. During the whole procedure, we used structured questions, such as: "*Do you feel this item should be a part of the RTP definition?*" or "*Do you feel this item should be a criterion to support the RTP decision after hamstring injury?*" Answer options were '*yes*', '*no*', or '*no opinion*'. Experts were encouraged to provide argumentation for their answers. Topics on which no consensus was achieved were included in the next Delphi round. For some questions, the steering committee added a 'note from the steering committee', based on expert opinion or the literature.

Cut-off point for consensus

A cut-off score of ≥ 70% agreement was proposed for consensus, because this cut-off is often used in Delphi procedures.[35-37]

RTP terminology

The expert panel was asked to discuss which overall term for return to play in sports should be adopted (e.g., return to sport, return to play, return to competition, etc.).

Definition of RTP after a hamstring injury

Before the start of this Delphi strategy, potential terms regarding the definition of RTP after hamstring injury were systematically reviewed.[21] Results from this systematic review (see Table 8.2) were included and used to start the discussion about the definition of RTP. Experts were asked which terms should or should not be included in the definition for RTP. Experts were also invited to respond to the definition of RTP after hamstring injury in an open-ended fashion.

Medical criteria to support the RTP decision after a hamstring injury

Similar to the definition of RTP, potential criteria to support the RTP decision after hamstring injury were systematically reviewed from literature[21] and used as a starting

Table 8.2 Items* included to start discussion on definition and criteria for RTP after hamstring injury

Items for discussion on definition of RTP after hamstring injury
Availability for match selection and/or full training
Clearance by medical staff
Player's positive mental attitude (athlete readiness)
A completed game
Full activity
A 100% recovery score on fitness and skill testing
Absence of symptoms on injured leg
Completion of a rehabilitation program
Reaching pre-injury level
Items for discussion on criteria for RTP after hamstring injury
Medical staff clearance
Absence of pain
Similar hamstring strength
Similar hamstring flexibility
Functional performance

* All items were derived from a systematic review by Van der Horst et al. on definition and criteria for RTP after hamstring injury.[21]

8

point for discussion on criteria to support the RTP decision. Experts were asked which criteria should or should not be used to support the final RTP decision and to provide additional criteria they though relevant.

RTP responsibilities

Stakeholders regarding RTP decision-making were derived from the literature.[38,39] Experts were additionally asked to name other stakeholders involved in RTP consultation and decision-making.

Data analysis

Data from all Delphi rounds were extracted from the online survey database in SPSS version 22.0 and anonymously reported in feedback reports. For questions with a "*yes*/*no*/*no* opinion" answer format, the percentage of answers in each category was calculated. Qualitative data (i.e., expert answers and argumentation) were analysed and discussed by the steering committee. This information and the main arguments of the experts were summarized and included in a 'note from the steering committee' and added to each question. If consensus was not achieved on a topic, these notes could be included in a follow-up question on a related subject, or used to rephrase the original question or to compose new questions on this topic.

Results

After four consecutive Delphi rounds, performed between July 2015 and July 2016, full consensus was achieved on all topics. The final consensus is presented in the RTP model for hamstring injuries in football (see Figure 8.2).

Expert panel

Fifty-eight experts were recruited from 28 FIFA Medical Centers of Excellence worldwide (participating experts are included in the acknowledgements section). The experts held different functions, such as full professor, medical director, lecturer, sports physician, orthopaedic surgeon, physical therapist, performance coach, athletic trainer and/or

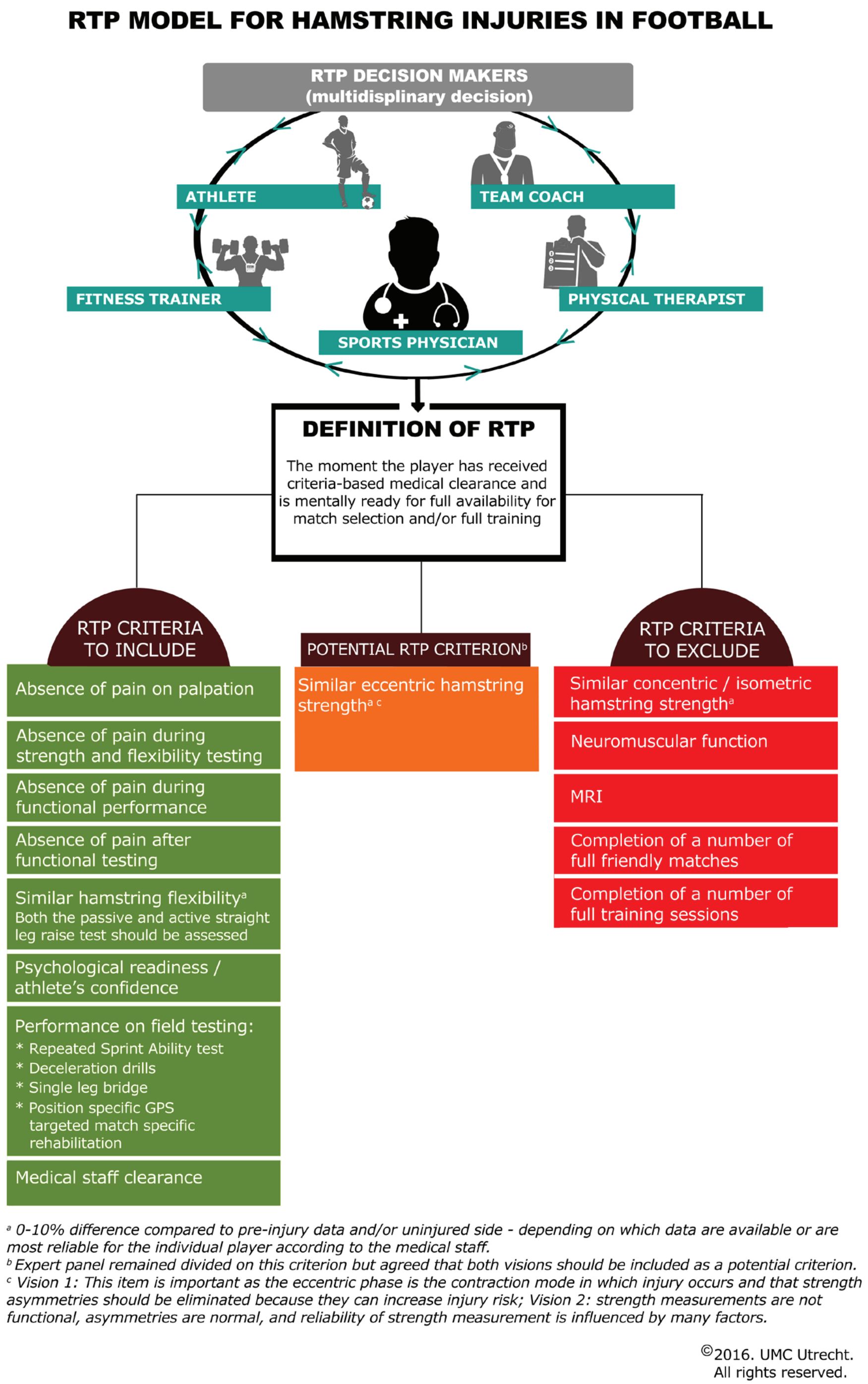

Figure 8.2 The RTP model for hamstring injuries in football for RTP decision-making, RTP definition and RTP criteria after hamstring injury.

researcher. All experts had expertise in the field of hamstring injury management. Most members had written a number of high-quality international publications in addition to their clinical experience in sports medicine, with an average of 15.8 (SD ± 8.2; range 3–35) years of experience in the field of hamstring injury management in football. Response rates in this Delphi procedure were 93% (round 1), 90% (rounds 2 and 3), and 84% (round 4).

Cut-off point for consensus

In Delphi round 1, the expert panel agreed that a cut-off score of ≥ 70% would be used to define consensus.

RTP terminology

In Delphi round 1, most experts chose either 'return to play' or 'return to competition' as the overall term to describe the final RTP moment. In Delphi round 2, consensus was achieved to adopt return to play – including its acronym RTP – as the overall term, arguing that it is simple, well-known, and adopted worldwide at many levels, including conferences and publications. It was agreed that 'return to competition' should be included in the definition of the generic term 'return to play'.

Definition of RTP after a hamstring injury

In the first Delphi round, consensus was achieved to include 'availability for match selection and/or full training' and 'clearance by medical staff' as part of the RTP definition after a hamstring injury. There was also consensus that 'a completed game' should not be included in the RTP definition, because RTP clearance should be given before a player resumes play and availability to play a match might be based on non-medical (e.g. tactical, team-based) factors or decisions. The expert panel additionally suggested considering inclusion of 'a player's positive mental attitude (athlete's readiness)' in the definition of RTP after hamstring injury. Therefore, this item was included in Delphi round 2.

In Delphi rounds 2 and 3, there was consensus that 'full activity', 'a 100% recovery score on fitness and skill testing', 'absence of symptoms on injured leg', 'completion of a rehabilitation programme', and 'reaching pre-injury level' should not be included in the definition of RTP after hamstring injury. It was argued that these items are not specific enough and/or should be considered as criteria for RTP, but not for RTP definition. In Delphi round 3, consensus was achieved on including 'a player's positive mental attitude (athlete readiness)' in the definition of RTP, because mental readiness was considered important to eliminate anxiety, and because a positive mental attitude is perceived to diminish the risk of reinjury and to improve performance.

The expert panel achieved consensus that RTP should be defined as "the moment a player has received criteria-based medical clearance and is mentally ready for full availability for match selection and/or full training".

Criteria to support the RTP decision after a hamstring injury

After discussion and specification of criteria through all rounds of this Delphi consensus procedure, the following criteria were included: medical staff clearance, similar hamstring flexibility (compared to pre-injury data and/or uninjured side – depending on which data are available or are most reliable for the individual player according to the medical staff), performance on field-testing, psychological readiness, and absence of pain on palpation, strength testing, flexibility testing and/or functional testing. Additionally, the expert panel stated that specification of criteria was required. The experts agreed that 'similar hamstring flexibility' could involve a 0–10% difference between injured and uninjured leg or compared with pre-injury data. The expert panel additionally achieved consensus that hamstring flexibility should be assessed by means of both the active and the passive straight leg raise test, as these are the most valid tests used in daily practice and it is important to measure both the active and passive component.

With regard to 'performance on field-testing', the expert panel mentioned a number of field tests used in clinical practice to support the RTP decision after hamstring injury (see Table 8.3). In Delphi round 3, the experts were asked whether they had practical experience with other field tests of functional performance and whether they would recommend using these tests to support the RTP decision after hamstring injury (see Table 8.3). Consensus was achieved that the Repeated Sprint Ability test,[40] deceleration drills, single leg bridge, and position-specific global positioning system (GPS)-targeted match-specific rehabilitation were relevant functional performance tests to support the

Table 8.3 Expert advice on functional performance tests to assess eligibility for RTP after hamstring injury

Clinical test	%*	Clinical test	%*
Position specific GPS targeted match specific rehabilitation	82	20 metre sprint	57
		Nordic Hamstring Exercise	55
RSA (Repeated Sprint Ability) test	76	Triple Hop Test	53
Single Leg Bridge	71	Muscular Endurance	45
Deceleration drills	71	YoYo / Shuttle Run Test	43
Acceleration drills	68	Speed testing	39
T-test	63	Functional Movement Screen	35
40 metre sprint	61	Single Hop Test	33
H-test	58		

* Experts stating this test could be suggested for functional performance assessment.

RTP decision after hamstring injury. The experts also commented that functional testing should involve explosive movements to mimic the actual football performance.

No consensus was reached for the inclusion of 'similar eccentric hamstring strength' as a criterion to support the RTP decision after hamstring injury. The expert panel remained divided, with two irreconcilable opinions. One group of experts stated that similar eccentric strength assessment is important as a criterion for RTP as the eccentric phase is also the contraction mode in which injury occurs and strength asymmetries should be eliminated because they can increase the risk of injury. The other group of experts stated that strength measurements are not functional, asymmetries are normal, and that too many factors influence the measurement of strength, so that reliable measurements are not possible. In Delphi round 4, consensus was reached for the following criterion 'similar eccentric hamstring strength' (compared to pre-injury data and/or uninjured side – depending on which data are available or are most reliable for the individual player according to the medical staff) to support the RTP decision.

The experts agreed that 'neuromuscular function' should not be included as a criterion for RTP after hamstring injury. Although the experts stated that neuromuscular function is always important, the concept and assessment of neuromuscular function could not be specified and was therefore not included as a criterion. The exclusion of MRI assessment as a potential criterion for RTP decision-making after hamstring injury was supported by recent studies.[19,41] Baseline MRI parameters are not predictive of hamstring re-injury, and MRI is not of additional predictive value compared with baseline patient history and clinical examination alone.[42] Completion of a number of full training sessions was also excluded as a criterion as 'availability for full training and match selection' was already included in the definition of RTP after hamstring injury.

RTP responsibilities

In Delphi round 2, the experts agreed that the sports physician, physiotherapist, fitness trainer, and athlete are the primary stakeholders to be consulted regarding the RTP decision. There was discussion about the role of the team coach, who not being medically qualified might allow an early RTP to improve team performance, despite potential medical risks. However, in Delphi round 3, the expert panel reached consensus on the inclusion of the team coach for RTP consultation because of his ability to assess the sport-specific performance level, his role in team selection, and his function in the multidisciplinary team staff. The sports physician (as head of the medical staff) was chosen to be ultimately responsible for the RTP decision, based on input provided by the multidisciplinary team and the athlete.

Discussion

This Delphi study involving 58 experts from 28 FIFA Medical Centers of Excellence worldwide reached consensus on a clear definition and specific criteria for RTP after hamstring injury and who should be consulted about RTP and take ultimate responsibility for the RTP decision (see Figure 8.2).

Definition and medical criteria for RTP

The absence of clear and uniform definitions and medical criteria for RTP has been a methodological issue in studies of different musculoskeletal domains, such as RTP after anterior cruciate ligament injury, ankle injury, and concussion.[43-46] If we want to prevent injuries and avoid significant differences in results because of differences in definitions and criteria used when investigating risk factors, prognostic factors, intervention programmes, and so forth for RTP, it is crucial that there is a clear definition of RTP.[23-26] Differences in the definition and criteria for RTP after hamstring injury make it difficult to compare study results and leads to uncertainty about which findings should be implemented in clinical practice.[21] A recent study defined the *return to sport* process.[47] Essentially, a definition that includes multiple stages of rehabilitation is similar to a criteria-based rehabilitation definition and is very useful for rehabilitation purposes as it considers the entire rehabilitation and recovery process.[47] However, it is important to differentiate between the return to sport *process* and the final RTP *decision*, where RTP is viewed as an endpoint (or primary outcome) of the return to sport process. This Delphi study explicitly focused on the final RTP decision (when the player is fully available for match selection and full training) and involved consensus among experts in the field of prevention and treatment of hamstring injuries. Although not yet studied and validated in clinical practice, this consensus statement may help clinicians faced with the problem of when an athlete should RTP after a hamstring injury. Furthermore, both the definition and criteria can be used in research, potentially leading to greater uniformity and promote comparability of research.

Medical criteria for RTP after hamstring injury

Absence of pain and psychological readiness. Absence of pain on palpation of the hamstrings, during strength and flexibility testing, and during or after functional performance was considered important as pain is an indicator of incomplete tissue healing. This is supported by recent evidence from De Vos et al., who showed that patients with localized discomfort on palpation just after RTP were four times (AOR 3.95; 95% CI 1.38–11.37) more likely to sustain a re-injury than athletes without discomfort on palpation.[19] However, pain perception is not only influenced by tissue damage, but also by cognitive factors such as fear of re-injury or fear of pain.[48,49] The fear of pain or re-injury generates avoidance behaviour.[49,50] In addition, athletes mention fear of re-injury as the main reason for not returning to sport.[51] This relationship between fear of re-injury and unsuccessful RTP led to the suggestion that psychological readiness be included in RTP guidelines.[52-54] We included psychological readiness in both the definition and criteria for RTP after hamstring injury. However, relatively little is known about the exact relationship between (hamstring) injury risk and psychological factors and it remains an important topic for future research.

Similar hamstring strength and hamstring flexibility. De Vos et al. also found an isometric knee flexion force deficit just after RTP to be associated with an increased risk of hamstring injury.[19] Our expert panel did not achieve consensus on the potential inclusion or exclusion of 'similar eccentric hamstring strength' as a potential criterion to support the RTP decision, although consensus was achieved that other contraction modes should not be included as a criterion to support the RTP decision. Previous research did not find different strength assessments to be associated with an increased risk of hamstring re-injury.[8] Hamstring peak torque, quadriceps peak torque, and conventional concentric hamstring:quadriceps (HQ) ratios (as measured with different test speeds and muscle contractions) were not found to be associated with an increased risk of hamstring re-injury.[8] The concentric hamstring to opposite hamstring ($H:H^{opp}$) ratio was also not associated with an increased risk of re-injury. However, eccentric strength asymmetries were predictive of hamstring muscle injuries in football players.[55] Furthermore, in a study of professional football players, 67% of all players clinically recovered from hamstring injuries had at least one hamstring isokinetic testing deficit of more than 10%.[20] Thus elimination of isokinetic strength asymmetries is not a requirement for RTP, although it is not known whether isokinetic strength deficits are associated with the risk of hamstring injury.[20]

From a biomechanical perspective, it is important to assess strength in a (sub)maximally stretched position.[56-59] There is ongoing debate regarding the relationship between hamstring flexibility and risk of hamstring injury.[7,8] Many studies have not found hamstring flexibility to be a risk factor for hamstring injury.[8,60] However, an active hamstring flexibility test, called the H-test, showed promising results as a complement to clinical examination.[61] Experts in this Delphi study stated that this test seems promising as it involves an active flexibility component as well as assessment of insecurity in the athlete. However, there was no consensus on the inclusion of this test to support the RTP decision because experts stated there was insufficient evidence to support use of the test and because the test lacks functionality.

Performance on field-testing. Performance on field-testing was considered vital when assessing RTP readiness, as it mimics the actual sports requirements. Furthermore, many criteria-based hamstring injury rehabilitation protocols have suggested including performance-based criteria in the end-phase, such as a normal week of training sessions,[62] sport-specific scenarios,[20] and functional phase training.[16] As most hamstring injuries occur in the latter stages of a match or training, fatigue and its associated decline in functional performance need to be considered in addition to field-testing.[5,63,64] Therefore, one could argue that both qualitative and quantitative assessment of functional performance should be performed in a fatigued state.[12] Future research should focus on the development of a sport-specific test battery for RTP after hamstring injury, in which functional aspects, fatigue, hamstring flexibility, absence of pain, and potentially hamstring strength are assessed in the light of the RTP decision.

Hamstring RTP decision-making

Owing to the complexity of RTP decision-making, as well as potential competing interests and different views of various stakeholders, it is commonly agreed that RTP decisions should be based on multidisciplinary consultation.[22,39,65] Although the sports physician is best qualified to synthesize medical information, step 3 of the Creighton model describes some important RTP decision modifiers (e.g., financial interests, timing in season, internal pressure, etc.).[28] Generally, the sports physician is only responsible for the medical part of the RTP decision and does not have the final say over these decision modifiers (such as financial, legal or team-tactical issues). Hence, the sports physician may have responsibility for the decision without authority to make it.[65] Ultimately, the best interests of the athlete are decisive and this covers more than just the medical risk assessment.[27,28,39] Therefore, in our opinion, different stakeholders with different views should be involved in the final RTP decision, bearing in mind the best interests of the athlete.

Strengths and weaknesses of this study

Delphi studies have the advantage of utilizing the knowledge and expertise of participating experts to reach consensus.[29,66,67] This Delphi study involved a multidisciplinary sample of clinical and academic experts with extensive experience in hamstring injury research and rehabilitation. Although there is no scientifically proven minimally acceptable response rate, a response rate of 60% has been used as the threshold of acceptability.[68] This Delphi consensus study had an excellent response rate of > 83% for each Delphi round.

The results of Delphi studies should be viewed in the light of the expert panel's opinion at any given point in time,[66] because opinions may change in the light of new evidence and paradigm shifts.[69] Therefore, both the definition and criteria for RTP after hamstring injury should be re-evaluated in the future, based on new research findings.

When drafting this consensus, no limitations regarding (medical) staff and tools were considered. This makes the consensus more suitable for a professional setting compared to an amateur setting due to differences regarding team staff and (access to) tools such as GPS tracking systems. Teams with limited access to a comprehensive team staff are advised to still consider and acknowledge the multi-faceted nature of the RTP-decision, as discussed in this manuscript. This Delphi consensus procedure additionally advised simpler functional tests if GPS tracking systems and/or speed measurement equipment is unavailable (e.g. RSA test, deceleration drills etc.), although position specific GPS targeted match specific rehabilitation was considered an important functional assessment by the majority of our expert panel due to its ability to mimic sport specific function.

Lastly, this study provided *medical* criteria to assess the health status of the athlete. This is only the first step in the three-step RTP assessment after hamstring injury (see Figure 8.1).[27,28] In addition to the health status evaluation, the assessment of tissue stresses (from type of sport, level of play, etc.) and RTP decision modifiers (timing and season, pressure from the athlete or external, financial issues, etc.) should form a solid basis for RTP decision-making.[27,28]

Meaning of the study

Although experts' opinions are considered to be a low level of evidence, we consider this study to be an important first step in standardizing and improving the final RTP decision after hamstring injury. In addition, the criteria to support the RTP decision were generated by clinical and academic authorities in the field of hamstring injury management. These criteria will help both clinicians and (clinical) researchers to assess the risk of RTP after hamstring injury.

Unanswered questions and future research

For future research, the authors emphasize the need for high-quality prospective research to validate RTP criteria. Considering the multidimensional nature of hamstring injuries, RTP criteria should not be validated as univariate factors but interaction between criteria as well as the varying weighting of criteria due to time and circumstances need to be considered.

Conclusion

Experts worldwide achieved consensus on RTP terminology, definition, and medical criteria for RTP after hamstring injuries in football. The results are reported in the RTP model for hamstring injuries in football. Although experts' opinions collected in a Delphi procedure are considered a low level of evidence, we consider this study to be an important first step in standardizing the terminology, consultation, definition, and criteria for RTP after hamstring injuries in football. The consensus may help both clinicians and (clinical) researchers to assess RTP risk after hamstring injury. Validation of RTP criteria, including tools and cut-off values, should lead to the ongoing development of this consensus. This will support RTP decision-making with a view to reducing hamstring injury recurrence as a result of a too early RTP.

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AT = Austria; BE = Belgium; BR = Brazil; DE = Germany; DZ = Algeria; ES = Spain; GB = United Kingdom; FR = France; JP = Japan; MX = Mexico; NL = Netherlands; NO = Norway; NZ = New Zealand; PL = Poland; PT = Portugal; QA = Qatar; SE = Sweden; SW = Switzerland; TR = Turkey; US = United States; ZA = South Africa.

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Chapter 9

General discussion

General discussion

The aim of this thesis was to improve strategies for preventing hamstring injuries during soccer. The rationale behind the studies was threefold: 1) there is a high incidence of hamstring injuries in male soccer players, 2) these injuries affect players and team performance, and 3) the Royal Netherlands Football Association (KNVB) would like to reduce the number of hamstring injuries in soccer. Two large projects were designed to improve and/or develop evidence-based strategies targeting hamstring injury prevention.

The first project, called HIPS (Hamstring Injury Prevention Strategies), focused on the prevention of hamstring injuries by means of a tailored exercise programme, called the Nordic hamstring exercises (NHEs), carried out during soccer training. This study also investigated the association between hamstring flexibility and the occurrence of hamstring injuries. The second project, called HIPS-2, focused on return to play (RTP) after hamstring injuries in soccer. Definitions, criteria, and decision-making regarding RTP after hamstring injuries were investigated.

The main findings of both projects, NHEs, hamstring injury risk factors, RTP after hamstring injury, and implementation issues are discussed individually in this chapter, covering primary findings, methodological issues, and future directions. Furthermore, based on the primary findings, advice and recommendations for clinical practice are provided.

Main findings

This thesis kicked off with a systematic review of the literature on the effectiveness of exercise-based injury prevention programmes for soccer players (**Chapter 2**). We found that evidence for many of these general exercise-based prevention programmes is conflicting. Compliance with the intervention and the specificity of the intervention programme were found to be important determinants of effectiveness.

The first HIPS study focused on the effect of an eccentric strength-training programme for preventing or reducing the occurrence of hamstring injuries in amateur soccer players (**Chapter 3**; study protocol). In a randomized controlled trial (RCT), we concluded that incorporating a tailored NHE programme into the training schedule of amateur soccer players significantly reduces the incidence of hamstring injury (**Chapter 4**). Furthermore, the HIPS study analysed the relationship between hamstring flexibility and hamstring injury risk. Population-based reference values for a hamstring flexibility test were established (**Chapter 5**), and a subsequent study found that hamstring flexibility is not associated with hamstring injuries in male amateur soccer players (**Chapter 6**).

The second HIPS study focused on the prevention of recurrent hamstring injuries in soccer players after they return to play. In a systematic review, it was concluded that the concept of RTP is still poorly defined and that a wide variety of criteria are used to support the RTP decision, none of which have been validated (**Chapter 7**). Subsequently, the results of this systematic review were used to perform a worldwide Delphi consensus strategy, in which an expert panel discussed and reached consensus on the definition and criteria for RTP after hamstring injury (**Chapter 8**).

Nordic Hamstring Exercise (NHE)

Nordic hamstring exercise and hamstring injury prevention

The risk of a hamstring injury was reduced 3- to 4-fold in male amateur soccer teams that incorporated our tailored NHE programme into their regular training programme. NHE programmes have previously shown their worth in preventing hamstring injury in professional football.[1-3] But due to some essential differences between professional and amateur soccer players with regard to the availability of medical staff, level of play, training exposure, training intensity, and compliance with preventive measures, the findings for professional players could not be extrapolated to amateur players, until now. Important factors that should be considered for effectiveness of NHEs in amateur soccer players are optimizing the dose-response relationship, inspiring compliance, and tailoring the intervention programme to the amateur soccer season.

Methodological considerations

Dose-response relationship. Our study showed that NHEs can reduce hamstring injury risk in amateur soccer players. However, in a previous study performed by our research group, NHEs were performed in the same population and under the same conditions, but did not show a preventive effect on hamstring injuries.[4] One of the major limitations discussed by van Beijsterveldt et al. was the fact that the dosage (e.g., frequency, intensity, timing in training and season) of the exercises, specifically addressing NHEs, might have been too low in their intervention programme to decrease the injury rate.[4]

To date, no studies have investigated the dose-response relationship of NHEs. The protocol as performed in this thesis had a preventive effect that was maintained throughout the soccer season or during a 1-year follow-up, but no studies have collected data for longer than one year. Furthermore, alongside these quantitative aspects, it is important to investigate how well the exercises of the NHE protocol are performed. The active fixation of the hips and the amount of range of motion over the knee joint (e.g., the range of the forward falling motion) during the exercise as well as the speed with which the exercise is done can alter the intensity and potentially effectiveness of NHE protocols.[3] Therefore, team coaches and medical staff are advised to supervise both quantitative and qualitative aspects when their players are performing NHEs.

On the basis of personal clinical experience, I would recommend that the NHE protocol should be tailored based on risk stratification. For instance, players with a minimal risk (e.g., no history of hamstring injuries) can probably suffice with the protocol used in our study. However, players at risk of hamstring injuries (e.g., with a history of one or more hamstring injuries) should perhaps repeat the protocol again after each summer or winter break, or prolong the maintenance phase of the protocol throughout the season. There is some indirect evidence to support this view, as Petersen et al. showed that NHEs are particularly effective for players with a history of hamstring injuries,[1] but the effect of tailoring the exercise protocol based on risk stratification warrants further research.

Compliance. With a reported rate of 91%, compliance in our study was excellent. We considered clear instructions to team coaches and staff members on the importance of injury prevention for both injury reduction and team performance to be essential, because coaches and staff are the primary stakeholders involved in explaining preventive measures to players. Furthermore, we explained to all players that Delayed Onset of Muscle Soreness (DOMS) is a normal side-effect of the NHE programme, in order to eliminate potential drop-out or poor intervention compliance due to DOMS.[3,5] Many studies have shown that poor compliance with preventive measures significantly influences study outcomes,[6,7] so any research group or clinician is advised to stimulate compliance to optimize effectiveness of the injury prevention programme.

Tailoring prevention programmes. Our NHE protocol was tailored to the amateur soccer season, as it is recognized that tailoring exercises to a specific type of sport potentially improves compliance.[8] There has been anecdotal criticism of NHEs by physical trainers and exercise therapists, on the basis that NHEs are not sport-specific enough to stimulate running or soccer biomechanics. Our research group has taken these remarks into consideration and are currently conducting a new national RCT into the effectiveness of a bounding (alternate leg jumping) exercise programme for hamstring injury prevention. However, a recent review has provided indisputable evidence of the functional consequences of different contraction modes for exercises.[9] On the basis of this knowledge, eccentric training via exercises such as NHEs should be viewed as a key element for functional training and injury prevention. Furthermore, I believe that the statement that exercise-based injury prevention must always be sport specific should be countered. The proven effectiveness of NHEs with regard to hamstring injury prevention keeps players on the pitch for more matches per season, and this is ultimately the aim of injury prevention.

Future directions for NHEs

The NHE protocol, an eccentric strengthening programme, has proven its worth in field studies and in fundamental and biomechanical studies. Hence, one should acknowledge Kristian Thorborg's statement that "hamstring eccentrics are hamstring essentials".[10] But effective interventions only work if people do them. Factors that motivate or discourage individual soccer players and staff members to perform these exercises need to be investigated and addressed. Furthermore, considering DOMS and training schedules, more insight into the optimal dose-response relationship for the NHE programme could benefit its effectiveness and usefulness.

Risk factors for hamstring injury

Hamstring flexibility as a risk factor for hamstring injury

We concluded that hamstring flexibility is not associated with hamstring injury risk. Potential confounders, such as age and previous hamstring injury, did not influence this relationship. This means that, on the basis of our results, the sit-and-reach test (SRT) for hamstring flexibility should not be used to identify players at risk of hamstring injury. Although flexibility imbalances are particularly interesting in the risk factor model for hamstring injuries because this is modifiable, evidence is still contradictory.[11,12] One important methodological limitation regarding research on hamstring flexibility as a risk factor for hamstring flexibility risk is that no hamstring flexibility test has both good validity and good reliability.[13,14]

Methodological considerations

Hamstring flexibility testing. The HIPS study used the SRT to measure hamstring flexibility. While the SRT has excellent reliability, is quick, easy to perform, and requires minimal skill and training, other tests can also be used to measure hamstring flexibility. Flexibility is typically recognized as the maximum ROM in a joint or series of joints.[15] Angular tests that specifically measure hip flexion with the knee extended (active straight leg raise test and passive straight leg test) or the range of knee extension with the hip in 90 degrees (knee extension test) measure hamstring extensibility.[13] However, angular tests are time consuming and need sophisticated instruments and trained and experienced assessors.[13,14] Hence, angular tests are recommended for individual assessment by a clinician (e.g., sports physician, physical therapist), but the SRT is preferable for large-scale evaluation of hamstring flexibility in a field setting.[13,14,16,17]

(Anti-)Reductionism. When putting research into risk factors for hamstring injuries into a broader perspective, an important methodological limitation needs to be considered. A major issue in research into hamstring injuries – but also in sports injury research in general – derives from the philosophical model of reductionism, in which researchers try to simplify and reduce a complex phenomenon, such as a hamstring injury, into its most elementary parts and then hypothesize how these parts interact and lead to a hamstring injury.

The majority of reductionist research into risk factors for hamstring injuries has applied correlation-based analytical methods (e.g., regression), where a linear and unidirectional cause and effect is hypothesized. Although useful for identifying linear relationships, these methods are unable to establish and test a web of causal relationships, which may include varying weighting of variables and feedback loops.[18] Attempts to include larger sample sizes (200 subjects) and a higher incidence of hamstring injury (20–50 injuries) in research designs, to enable the use of multivariate analyses,[19] would have the same limitations. Overlooking or obscuring data because of reductionist methodology may cause oversimplified interpretations and justifications for predictive models. Consequently, there is often a discrepancy between the 'high-quality predictive models' used in research and the everyday situation in the clinic.

As such, our knowledge of how hamstring injuries develop could potentially benefit greatly from *anti*reductionist thinking and modelling. Quatman et al. advocated this paradigm shift from a reductionist to an antireductionist view with regard to musculoskeletal injuries.[20] Based on this antireductionist view, Mendiguchia et al. already proposed a model in which tissue architecture, injury history, fatigue, strength, flexibility, and core stability all interact with each other, providing a better understanding of the multifactorial nature of a hamstring injury (see Figure 9.1).[21]

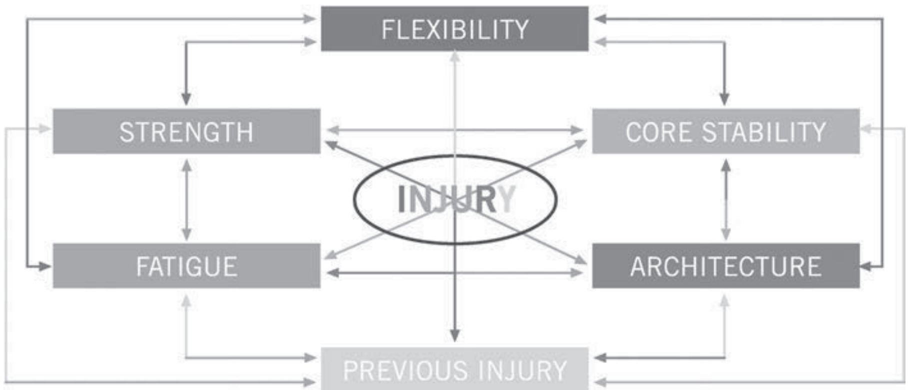

Figure 9.1 Model for hamstring strain injury by Mendiguchia et al.[21]

For example, studies have shown that neural tension is not a risk factor for hamstring injury.[12,22] However, adverse neural tension can influence ROM.[15] A reduced hip ROM is associated with loss of strength,[15,23] and strength deficits in turn are associated with an increased risk of hamstring injury.[12,24-27] This simplified example could potentially show how a variable that is not actually considered a risk factor may become a risk factor in combination with other factors, increasing the likelihood of injury.[21]

Future directions for risk factor analysis

The model for hamstring strain injury proposed by Mendiguchia provides a solid basis for clinicians and researchers, but in my opinion the model still lacks some potential risk factors, such as psychosocial, environmental, and proprioceptive factors.[28-32] Psychological factors, such as trait anxiety, negative life events, stress, and daily hassles, are significantly associated with both injury and illness.[33] The role of proprioceptive aspects in relation to injury risk and how some of the clumsiness that occurs after intense (eccentric) exercise may be proprioceptor mediated have been thoroughly described by Proske and Gandevia.[31] As proprioception decreases with fatigue, fatigue could also contribute to an increased injury risk and is worth further investigation.[31]

I feel that in future studies of risk factors for hamstring injury, Mendiguchia's conceptual model should be extended to include other factors that are potentially related to hamstring injury risk. Furthermore, it seems clear that the antireductionist conceptual model, which shows the inter-relationships between different factors involved in hamstring injuries, provides a better understanding of the multifactorial nature of the hamstring injury. It emphasizes the more 'real-world' context of the hamstring injury problem, moving away from the reductionist view and methodology that prevails in current scientific literature.

Key points HIPS project

- Nordic hamstring exercises are an effective tool for hamstring injury prevention.
- Nordic hamstring exercises can easily be incorporated into regular amateur soccer training.
- Compliance with the Nordic hamstring exercise programme is a key factor.
- Male amateur soccer players have reduced hamstring flexibility compared with a general (athletic) population.
- Hamstring flexibility measurements on the sit-and-reach test are not related to the incidence of hamstring injury.
- Hamstring flexibility does not have a linear and unidirectional association with the incidence of hamstring injury, but the role of hamstring flexibility and the interaction with other risk factors for hamstring injuries remains unclear.

RTP after hamstring injury

Definition of Return-to-Play after hamstring injury

In our Delphi consensus study, we concluded that RTP as a primary outcome should be defined as "the moment a player has received criteria-based medical clearance and is mentally ready for full availability for match selection and/or full training". This definition should not be confused with recent work from Ardern et al., who published a consensus statement on the definition of return to sport.[33] They defined the RTP *process*, which I feel is no different from current rehabilitation concepts.[34,35]

In our study, we aimed to define *the end-stage* for RTP and which criteria could assist clinicians to make this final decision on whether a player can resume play or not. As more than 60 internationally acknowledged experts in the field of hamstring injury management reached consensus on a clear and specific definition for RTP after hamstring injury, clinicians and researchers involved with RTP after hamstring injury are advised to adopt this definition.

Criteria for RTP after hamstring injury

The consensus from our Delphi strategy stated which criteria should and should not support the final decision regarding RTP readiness in order to prevent re-injury. It is important to appreciate that our Delphi project aimed at providing clear and specific *medical* criteria to support the RTP decision after hamstring injury. In a recent study in which similar criteria were used, it was concluded that a combination of initial and follow-up physical therapy examinations predict the time to RTP.[36] This emphasizes the importance of a thorough clinical examination of the athlete's health status for RTP decision-making. However, as described in the three-step framework of Shrier et al., evaluating health status is only the first step in the RTP decision-making process (see Figure 9.2).[37] Assessment of medical criteria can only support the final RTP decision if tissue stresses (Step 2) and RTP decision modifiers (Step 3) are also considered. For example, with regard to tissue stress, players in different playing positions experience different forces and therefore have different injury risks (e.g., a forward will generally sprint more per game than a goalkeeper).[38-40] Risk tolerance modifiers are factors that may change the decision if only Steps 1 and 2 of the model are considered.[37,41] For instance, time in the playing season can modify the RTP decision because it may be less important if the player can resume playing earlier during the off-season. In contrast, for a final or important play-off match (potentially leading to trophies, bonus payments, scholarship, promotion, and so forth), the same level of injury risk might change the balance of advantages and disadvantages of the RTP decision into early RTP.[37]

The medical criteria and arguments for these criteria mentioned by our Delphi consensus experts will help clinicians to assess the health status of the athlete. These criteria in combination with the assessment of the risk of sports participation and RTP decision modifiers will contribute to a thorough assessment of the risks and benefits of any RTP decision.

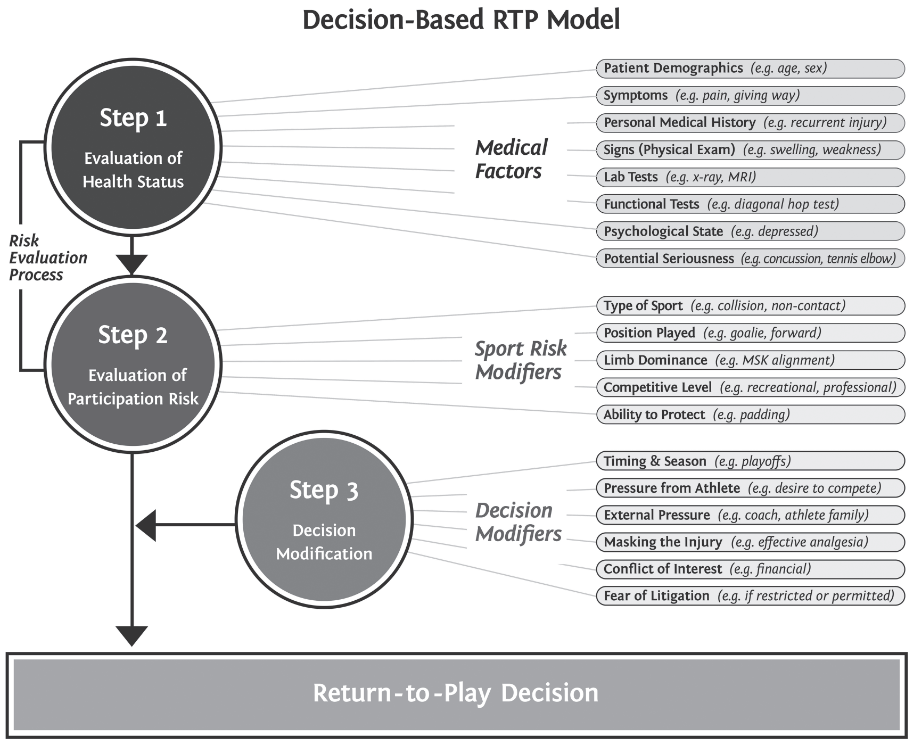

Figure 9.2 The Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for return-to-play (RTP) decisions.[37]

RTP: who is responsible?

The question about who is responsible for making the RTP decision is complex. Different stakeholders (e.g., athlete, team physician, physical therapist, coach, sponsor, agent, athletics trainer, etc.) may have different views regarding the RTP decision. All stakeholders weigh the pros and cons of returning the athlete to play, which include not only the risk of re-injury (determined by tissue health and tissue stress), but also the importance of the competition, financial considerations, and legal liability.[37,41,42] To complicate this even more, we know that different clinicians weigh RTP factors differently and provide different restrictions given the same clinical context.[43] In a survey by Shrier et al, medical doctors, physical therapists, and athletic therapists were all asked to indicate which profession was best able to evaluate the RTP criteria.[44] Each clinician group generally believed that their own profession was best able to evaluate the RTP criteria.[44] Regardless of ability, the question remains whether the sports physician (or any other clinician) is in the best position to make the final RTP decision because they may have the responsibility but not the authority to do so.[45] This again emphasizes the importance of shared decision-making when faced with the RTP question.

In my opinion, the discussion about RTP responsibility should not be about which stakeholder is ultimately responsible, but about the focus of all stakeholders. This focus should always be on the best interests of the player, and these interests are not necessarily a low risk of re-injury, game participation, or financial gain. All stakeholders have the responsibility to consult and inform both the player and each other about the risks and benefits of any RTP decision, with the best interests of the player as top priority.

Methodological considerations

Delphi procedures are still considered low level of evidence as Delphi procedures may lead to a weakened version of the best opinion and that anonymity may lead to a lack of accountability of views expressed and encourage hasty decisions.[47] However, our HIPS-2 study included an impressive expert panel, including 58 world-leading experts with extensive track records in the management of hamstring injuries. Any Delphi procedure mainly relies on the combined expertise of the expert panel,[46] which brings a wide range of direct knowledge and experience to the decision-making process. Ultimately, Delphi procedures benefit from a democratic and structured approach, where bias through status or dominant personality is avoided because of expert anonymity.[47] Of course, the results and expert consensus need to be critically assessed in future research to validate and further develop our RTP model for hamstring injuries in football.

Future directions for RTP after hamstring injuries

The StARRT model (Figure 9.2) provides a great framework for RTP decision-making.[37] However, it is unclear how RTP is defined in this model. Furthermore, while the framework provides clinical considerations, it is not specific about how these considerations contribute to the final RTP risk assessment. The results from our Delphi strategy could be a first step toward clarifying and specifying the RTP risk assessment as proposed by the StARRT framework. In future research, RTP criteria after hamstring injury suggested by our expert panel need to be validated in prospective studies. Based on the findings of such studies, the RTP model for hamstring injuries in football can be updated to improve RTP decision-making after hamstring injury, resulting in a reduced risk of recurrent hamstring injuries as a result of a (too) early RTP.

Key points HIPS-2 project

- When discussing RTP, it is imperative that all researchers and clinicians are clear and unambiguous about the definition of RTP.
- Criteria to support the RTP decision after hamstring injury are described in this thesis and should be integrated in any RTP decision-making process after hamstring injury
- The RTP decision should always be based on shared decision-making, with priority given to the best interests of the athlete.

From research to real world prevention: implementation

This thesis does not include a separate chapter specifically focusing on implementation. However, it is recognized that there is a gap between research and the real-world context. Considering the content of our studies and the lack of knowledge transfer from research to clinical practice, it is essential to discuss some implementation issues.

Implementation models

In order that measures that have proven effective in an experimental setting actually prevent the occurrence of injury in a real-world context, the measures need to be acceptable, adopted, and complied with by the intended users (e.g., athletes, sports participants etc). The HIPS study was designed and tailored to the amateur soccer population, with a view to the future implementation of its findings. Dissemination of study results was achieved by adopting the Knowledge Transfer Scheme with the cooperation of the Royal Netherlands Football Association (KNVB), amateur clubs, different platforms where technical and medical staff members of clubs are trained, and the Dutch Association of Sports Medicine (VSG).[48]

Methodological considerations

The gap between research and real-world context. The implementation of evidence-based injury prevention programmes is still a challenge.[49-52] In spite of a well-designed dissemination strategy, unpublished data from a follow-up study of our first HIPS project confirm that there is a gap between our effective research results and implementation in the real-world context. The majority of participants from the original HIPS study (68% from intervention group and 94% from control group players) indicated that – although mostly aware of the preventive effect – they seldom or never performed the NHE programme 3 years after the HIPS study (publication in preparation). Personal motivation, effectiveness, and knowledge of the NHE programme were indicated as important factors for adherence to the NHE programme, and these findings are in accordance with other literature.[51,53] Most interestingly, a recent publication by Bahr et al. confirmed the lack of NHE implementation in 50 professional Champions League and Norwegian Premier League teams.[54] In that study, only 10.7% of the teams performed the full NHE protocol, and 83.3% of these teams were reported to be non-compliant with the NHE programme despite compelling evidence of its effectiveness.[54]

In our HIPS study, we found that team coaches had a crucial role in compliance. In other words, injury prevention is not only the domain of the medical staff. At an amateur level, coaches will have to make time in their training schedule for the exercises and in some cases even monitor the performance of NHEs, which could hinder compliance.[51,52] However, players generally carry out their team coach' orders, and so preventive strategies will only work if supported by the team coach. Players, coaches, and medical staff are largely aware of the benefits of injury prevention, but this does not necessarily mean that soccer teams adopt preventive strategies.

Future directions for implementation

So how can we bridge the gap between research and real-world context? Although there is a long way to go regarding the implementation of preventive strategies in sports injury prevention, researchers in this field have the opportunity to be involved in the implementation process. Researchers need to engage relevant stakeholders and end-user groups during a study and develop multifaceted strategic approaches towards injury prevention in a real-world context.[50] The RE-AIM framework appears to be a good tool for the scientific evaluation of implementation of preventive measures.[55] The RE-AIM framework aims to evaluate the public health impact of health promotion interventions through assessment of Reach, Efficacy, Adoption, Implementation, and Maintenance.[55] These important aspects of implementation research have recently been integrated in a tool that has been specifically developed to bridge the gap between science and practice, called the 'Knowledge Transfer Scheme' (KTS).[48]

Advice for clinical practice

The aim of this thesis was to improve strategies for hamstring injury prevention in soccer. On the basis of our findings and experience, the following advice is relevant to clinical practice:

- There is no such thing as a generic exercise-based injury prevention programme for soccer players. Unfortunately, evidence shows that we cannot prevent all injuries with one exercise programme. Soccer teams consist of multiple (often 18–23) players, and each player has his/her own injury risk profile. Pre-selection based on injury risk profiling is essential to provide targeted injury prevention and increase the likelihood of reducing soccer-related injuries.
- Performing a NHE protocol in regular training can reduce (3-to 4-fold) the risk of hamstring injuries. This is important for both the injured player and team performance, as high injury rates are associated with reduced team performance.[56]

However, compliance with the protocol is critical, both quantitative (e.g., following the protocolled sessions, sets and repetitions) and qualitative (e.g., performing the NHE conform instructions). Clinicians, medical staff, and other stakeholders in preventing hamstring injury should make an effort to optimize compliance and supervise the qualitative performance of the NHE programme.

- Hamstring flexibility scores on the SRT should not be used to identify soccer players at risk for future hamstring injury. Considering the multifactorial nature of hamstring injuries, other risk factors, such as previous injury, strength, fatigue, architecture, and core stability, should be considered as interacting risk factors and thus be assessed and addressed. While hamstring flexibility was not identified as a risk factor, more knowledge is needed about the interaction of hamstring flexibility with other (potential) risk factors and its role in hamstring injury prediction.

- Any clinician assessing the RTP readiness of a soccer player should consider testing for 'absence of pain on palpation', 'absence of pain during strength and flexibility testing', 'absence of pain during functional performance', 'absence of pain after functional testing', 'similar flexibility', 'psychological readiness / athlete's confidence', 'medical staff clearance', and 'performance on field testing' (e.g., the repeated sprint ability test, deceleration drills, single leg bride, and position specific GPS targeted match specific rehabilitation). It is not advised to include 'MRI findings', 'similar concentric or isometric strength', 'neuromuscular function', and 'completion of a number of full friendly matches/training sessions' as criteria to support the RTP decision. Assessment of the factors to support the RTP decision can assist in the evaluation of tissue health. To make the final RTP decision, assessment of the risk of specific activities (e.g., type of sport, competitive level, etc.) and risk tolerance (e.g., timing and season, pressure, etc.) need to be considered as well.

- The RTP decision should be a multidisciplinary decision, including consultation of sports physician, physical therapist, fitness trainer, team coach, and last but not least: the athlete. The best interests of the athlete should always be the main focus, even though on some occasions this might conflict with the interests of some stakeholders. Hence, open communication between all stakeholders is essential when faced with RTP decision-making.

- Narrowing the gap between research and the real-world context is a responsibility of both the research community and clinicians. The research community (especially applied research) should not strive for effective interventions, but for fewer injuries in a real-world context. This means that the development of effective interventions is only one aspect, but end-users need to adopt these interventions in order for them to truly work. Hence, researchers should already consider implementation strategies in the development phase of a new study.

- Furthermore, as more and more evidence for strategies to prevent hamstring injury becomes available, clinicians should incorporate this knowledge into daily practice. Clinicians need to be actively involved in identifying factors that obstruct the implementation of effective, evidence-based preventive strategies, to improve efforts to reduce the incidence of soccer-related hamstring injuries.

Conclusion

Hamstring injuries in amateur soccer can be prevented by incorporating a NHE programme in regular amateur soccer training. Owing to the multifactorial nature of hamstring injuries both clinicians and scientific researchers need to acknowledge that eccentric strengthening is just one component of the prevention of hamstring injuries and that different components can vary in time and due to differing circumstances. If, in spite of prevention programmes, all goes wrong and the player sustains a hamstring injury, experts have reached consensus about specific criteria that should guide the decision about whether a player can return to play.

Ultimately, developing and validating injury prevention programmes is not enough.[53] Anyone affiliated with sports injury research should take on the responsibility to support the implementation of preventive strategies to reduce hamstring injuries, so that research findings actually benefit injury prevention in a real-world context. And end-users need to be made aware of the potential of hamstring injury prevention strategies.

After all, *an ounce of prevention is worth a pound of cure.* - Benjamin Franklin (1706–1790)

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Summary of chapters

The aim of the studies reported in this thesis was to investigate strategies for the prevention of hamstring injuries. Soccer is the most popular sport worldwide, and regularly playing soccer has positive health effects. However, soccer also has high injury rates, with hamstring injuries being the most prevalent muscle injury of all. Hamstring injuries lead to personal suffering for the injured player, medical costs, work absenteeism, and decreased team performance. In spite of efforts to reduce the occurrence of hamstring injuries in soccer, injury rates have not decreased over the last three decades. Therefore, research on hamstring injury prevention is necessary to reduce hamstring injury rates.

Exercise programmes to reduce soccer injuries are easy to implement during regular training sessions, are cost effective, and can even improve performance. In **Chapter 2**, a systematic review of the literature was performed to analyse the effectiveness of general exercise-based training programmes in the prevention of soccer injuries. It was concluded that there is inconclusive evidence about the effectiveness of these programmes. Compliance with the exercise programme and tailoring the exercise programme to the intended users (based on injury type, age, sex differences, type of sport, etc.) were found to be important factors influencing the effectiveness of exercise programmes.

The studies described in **Chapter 3** (study protocol) and **Chapter 4** (study results) therefore focused on an exercise-based injury prevention programme that specifically aims to reduce the risk of hamstring injury, namely, the Nordic Hamstring Exercise (NHE). In a randomized controlled trial involving 579 high-level amateur soccer players, we found that a tailored 12-week NHE protocol implemented during regular amateur soccer training (compliance was excellent) resulted in a three- to fourfold reduction in the risk of hamstring injury, but it did not influence the severity of injuries (e.g. the number of days that elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection).

In the same high-level amateur soccer population, Sit-and-Reach Tests (SRT) were performed to assess hamstring and lower back flexibility. It is generally assumed that soccer players have reduced hamstring flexibility as a result of the long-term impact of soccer training and that this could increase the risk of hamstring injury. In the study reported in **Chapter 5**, population-based reference values for the SRT were obtained. We concluded that, compared with reference values reported in other (sports) populations, soccer players have lower scores on the SRT. In addition, SRT scores were found to be associated with the players' height, body mass index, and history of anterior cruciate ligament injury.

Chapter 6 presents our findings on the relationship between hamstring flexibility and hamstring injury risk. In a longitudinal cohort study, we found that there is no relationship between hamstring flexibility and hamstring injury risk. Possible confounders, such as age and previous hamstring injury, did not appear to influence this relationship.

If preventive measures fail and the athlete sustains a hamstring injury, the first thing almost every athlete wants to know is: "When will I be able to play again"? This question about return-to-play (RTP) after hamstring injury is a subject of growing interest in conferences, the media, clinical practice, and the scientific literature, although the concept of RTP remains unclear.

In the study described in **Chapter 7**, we systematically reviewed the literature on definitions of, and criteria for, RTP after hamstring injury used in clinical research. Only a few studies have given a definition of, or criteria for, RTP. Of the studies that reported a definition of RTP, "reaching the athlete's pre-injury level" and "being able to perform full sport activities" were identified as core themes to define RTP after hamstring injury. "Absence of pain", "similar strength", "similar flexibility", "medical staff clearance", and "functional performance" were core themes to describe criteria to support the RTP decision after hamstring injury.

On the basis of this literature review, we carried out a Delphi consensus procedure (**Chapter 8**) to clarify the definition of, and criteria for, RTP after hamstring injury. A worldwide panel of experts selected by the FIFA Medical Centers of Excellence achieved consensus that RTP after hamstring injury should be defined as 'the moment the player has received criteria-based clearance and is mentally ready for full availability for match selection and/or full training.' The expert panel also reached consensus that the absence of pain on palpation, during strength and flexibility testing, and during performance testing, similar hamstring flexibility, psychological readiness, performance on field testing, and medical staff clearance were important criteria to assess RTP readiness after hamstring injury. MRI findings, neuromuscular function, similar concentric/isometric hamstring strength, and completion of a number of full friendly matches/training sessions are NOT relevant to the RTP readiness assessment. Similar eccentric hamstring strength was included as a potential criterion.

Chapter 9 presents a general discussion of the main findings of our studies regarding Nordic hamstring exercises, hamstring injury risk factors, RTP after hamstring injury, and implementation issues. We need to consider the multifactorial nature of hamstring injuries in both research and clinical practice, and recognize that effective interventions will only lead to fewer hamstring injuries in a real-world context if these interventions are adopted by the intended end-users. Therefore, future research should focus on the implementation of preventive measures that have proven to be effective. After all, an ounce of prevention is worth a pound of cure!

Nederlandse samenvatting

Het doel van dit proefschrift was om preventieve maatregelen voor hamstringblessures in het voetbal te onderzoeken. Voetbal is wereldwijd de populairste sport en regelmatig voetballen leidt tot positieve gezondheidseffecten door versterking van kracht, uithoudingsvermogen en het neuromusculaire systeem. Deze gezondheidswinst wordt echter deels belemmerd door de vele blessures, en hamstringblessures zijn daarbij de meest voorkomende spierblessure. Hamstringblessures leiden tot persoonlijk leed voor de geblesseerde speler, medische kosten, werkverzuim, en slechtere teamprestaties. Ondanks grote inspanningen om het aantal hamstringblessures in het voetbal terug te dringen, is het aantal hamstringblessures in de afgelopen 30 jaar niet verminderd. Onderzoek naar preventieve maatregelen voor hamstringblessures in het voetbal blijft noodzakelijk om het aantal hamstringblessures terug te dringen.

Oefenprogramma's ter preventie van voetbalblessures zijn makkelijk uitvoerbaar in normale voetbaltrainingen, kosteneffectief en kunnen zelfs een positieve invloed hebben op prestaties. In **Hoofdstuk 2** analyseerden wij middels een systematisch literatuuronderzoek de effectiviteit van generieke oefenprogramma's op de preventie van voetbalblessures. We concludeerden dat er onvoldoende bewijs was voor een positief effect van generieke oefenprogramma's ter preventie van voetbalblessures. Therapietrouw aan het oefenprogramma en aanpassing van het oefenprogramma aan de wensen en omstandigheden van de eindgebruikers (op basis van blessuretype, leeftijd, geslacht, sporttype, enz.) werden benoemd als belangrijke factoren voor de effectiviteit van oefenprogramma's.

Hoofdstuk 3 (studieprotocol) en **Hoofdstuk 4** (studieresultaten) beschrijven een studie naar de effectiviteit van een preventief oefenprogramma, genaamd de Nordic hamstring exercise (NHE), dat zich specifiek richt op het verminderen van het risico op hamstringblessures. In een gerandomiseerd onderzoek met controlegroep werden 579 amateurvoetballers uit de KNVB 1^{e} klasse geïncludeerd. De resultaten toonden aan dat de groep die een speciaal voor amateurvoetballers ontwikkeld 13-weeks NHE-protocol uitvoerde (met uitstekende therapietrouw), drie tot vier maal minder risico hadden op het oplopen van een hamstringblessure vergeleken met de controlegroep. De blessure-ernst (het aantal dagen afwezig vanaf het moment van blessure tot terugkeer naar teamtraining en wedstrijdbeschikbaarheid) was niet verschillend tussen de twee groepen.

Bij dezelfde KNVB 1^{e} klasse amateurvoetballers werden ook metingen afgenomen om de hamstringflexibiliteit in kaart te brengen. Er wordt algemeen aangenomen dat voetballers stijvere hamstrings hebben als gevolg van een functionele aanpassing door het langdurige voetballen. Deze stijfheid van de hamstrings zou in relatie kunnen staan met een toegenomen hamstringblessurerisico.

In **Hoofdstuk 5** beschrijven we normatieve waarden voor de Sit-and-Reach test (SRT), een simpele test voor hamstringflexibiliteit, vanuit onze populatie mannelijke amateur-voetballers. Vergeleken met referentiewaarden uit andere sporten had onze populatie voetballers lagere scores op de SRT. De scores op de SRT werden positief geassocieerd met de lichaamslengte, body mass index, en voorgeschiedenis met voorste kruisbandreconstructie.

Hoofdstuk 6 beschrijft onze bevindingen over de relatie tussen hamstringflexibiliteit en hamstringblessurerisico. In een prospectief cohortonderzoek werd geconcludeerd dat er geen relatie is tussen hamstringflexibiliteit en hamstringblessurerisico. Mogelijke confounders leeftijd en voorgeschiedenis met hamstringblessure leken deze relatie niet te beïnvloeden.

Als het ondanks de preventieve maatregelen toch mis gaat, stelt iedere voetballer dezelfde vraag: "*Wanneer mag ik weer spelen?*" Deze vraag over het zogenaamde Return-to-Play (RTP) moment kan in de praktijk lastig te beantwoorden zijn. Enerzijds wil de speler zo snel mogelijk terugkeren, anderzijds moet een herhaling van de hamstringblessure voorkomen worden. Vanwege de complexiteit van de RTP-beslissing heeft RTP in de laatste jaren steeds meer aandacht gekregen in de wetenschappelijke literatuur, praktijk, media en op (inter-)nationale congressen. Desondanks is het concept RTP nog onduidelijk.

In **Hoofdstuk 7** onderzochten we daarom de wetenschappelijke literatuur naar definities van RTP en criteria die werden gehanteerd om de RTP-beslissing na een hamstring-blessure te ondersteunen. Weinig studies beschreven een definitie of criteria voor RTP. De studies die dat wel deden, benoemden 'het bereiken van het niveau van voor de blessure' en 'alle sportactiviteiten kunnen uitvoeren' als kernthema's voor de definitie van RTP na een hamstringblessure. Criteria die werden gebruikt om de RTP-beslissing na een hamstringblessure te ondersteunen werden ingedeeld in de kernthema's 'geen pijn', 'gelijke kracht', 'gelijke flexibiliteit', 'functionele prestatie', en 'vrijwaring van de medische staf'.

Op basis van dit literatuuronderzoek werd vervolgens een Delphi consensusprocedure uitgevoerd (**Hoofdstuk 8**) om helderheid en specificiteit te verkrijgen over de definitie en criteria voor RTP na een hamstringblessure. Een wereldwijd expertpanel dat werd samengesteld door de FIFA Medical Centers of Excellence (bestaande uit 58 experts) bereikte overeenstemming dat de definitie van RTP na een hamstringblessure zou moeten zijn: 'het moment dat de speler op basis van criteria vrijwaring heeft gekregen van de medische staf en mentaal klaar is om beschikbaar te zijn voor volledige training en wedstrijden'. Criteria ter ondersteuning van de RTP-beslissing na een hamstringblessure zijn: geen pijn bij palpatie, bij kracht- en flexibiliteitstesten, en bij functionele prestatie, gelijke hamstringflexibiliteit, mentale gereedheid, functionele prestaties, en vrijwaring van de medische staf. MRI-bevindingen, neuromusculaire functie, gelijke isometrische/concentrische kracht, en het voltooien van een aantal trainingen/wedstrijden zouden NIET gebruikt moeten worden als criterium. Gelijke excentrische kracht werd geïncludeerd als een mogelijk criterium.

Hoofdstuk 9 sluit af met een algemene discussie over de belangrijkste bevindingen van onze studies, de Nordic hamstring exercises, risicofactoren voor hamstringblessures, RTP na een hamstringblessure en implementatie. Er wordt benadrukt dat we het multifactoriële karakter van de hamstringblessure moeten erkennen in zowel onderzoek als praktijk. Verder leiden effectieve interventies alleen tot minder hamstringblessures als interventies ook daadwerkelijk blijven worden uitgevoerd door de beoogde eindgebruikers. Toekomstig onderzoek zal zich dan ook moeten richten op de implementatie van bewezen effectieve maatregelen naar het voetbalveld. Immers, voorkomen is beter dan genezen!

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Voetballen en onderzoek doen. Beiden zijn zonder teamgenoten niet mogelijk. "Alleen kan je niks, je moet het samen doen" zei Johan Cruijff (1947-2016).

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About the author

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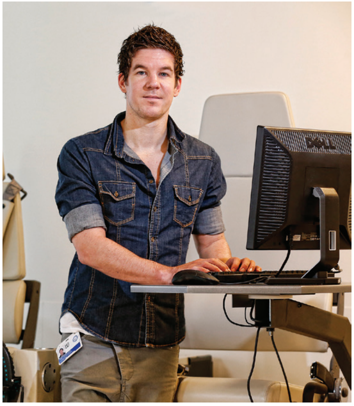

Nick van der Horst was born 14 February 1986 in Utrecht, the Netherlands. He more or less grew up on the soccer courts. After he left the Koningin Wilhelmina College in Culemborg when he was 16, he started studying physiotherapy at the Hogeschool Utrecht. He followed internships at the UEFA Under 21 EURO Championship, the professional Dutch soccer club N.E.C. Nijmegen, and the Academie Instituut Utrecht, which has been his primary employer ever since. At the Academie Instituut Utrecht, his work involves orthopaedic sports-related primary health care, supervising internships, and teaching bachelor and master students of (sports) physiotherapy. During his studies for a Masters degree, he followed courses in clinical exercise physiology and applied sports psychology at the Free University, Amsterdam, and additionally specialized in musculoskeletal ultrasound. In 2012, he was awarded a Masters degree in Physical Therapy Sciences from the University of Utrecht.

The personal drive to study soccer injuries and their prevention brought him into contact with Prof. Dr. Frank Backx, who offered him with an internship within the SCORE project. The SCORE project, which primarily focused on the effectiveness of the 'FIFA11' warm-up programme in soccer, was supervised by Dr. Anne-Marie van Beijsterveldt and led to a follow-up study of hamstring injury prevention strategies (HIPS). In 2012, Nick was appointed junior researcher in the HIPS study, which was initiated in close collaboration with the Royal Netherlands Football Association (KNVB).

When not treating, studying, or investigating soccer injuries, Nick can still be found on the soccer court with his son Jayson, under the loving supervision of his beautiful wife Dione.

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Van der Horst N, van de Hoef S, Reurink G, Huisstede BMA, Backx F. Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria. *Sports Med* 2016;46(6):899-912.

Van der Horst N, Backx FJG, Goedhart E, Huisstede BMA. Return to play after hamstring injuries in football (soccer): a worldwide Delphi procedure regarding definition, medical criteria, and decision-making. *Br J Sports Med* [accepted with minor revisions].

National, peer reviewed publications

Van der Horst N. Hoe omgaan met hamstringblessures? Deel I. *Sportgericht* 2015;1:28-34.

Van der Horst N. Hoe omgaan met hamstringblessures? Deel II. *Sportgericht* 2015;2:28-32.

Van der Worp M, Drechsler H, **van der Horst N**. Het iliotibiale bandsyndroom bij hardlopers. *Physios* 2016;1:9-14.

PhD portfolio summary

Name PhD student:	Nick van der Horst
UMC Utrecht department:	Sports Medicine
PhD period:	28.09.2012 – 09.03.2017
Promotor:	Prof. dr. F.J.G. Backx
Supervisors:	Dr. D.W. Smits, dr. B.M.A. Huisstede

1. PhD training	Year
Courses	
• Basiscursus Regelgeving en Organisatie van Klinische trials (BROK), UMC Utrecht, the Netherlands	2016
• Workshop systematic reviews of clinimetric properties of measurements, VUMC Amsterdam, the Netherlands	2013
(Inter)national conferences - attendance	
• Danish Sports Medicine Annual Congress (2x), Kopenhagen, Denmark	2015, 2017
• Dutch Sports Medicine Society Annual Congress (5x), Ermelo & Eindhoven, the Netherlands	2012–2016
• Society of Physiotherapists in Professional Football (VFBV) Annual Congress, Zeist, Utrecht & Arnhem, the Netherlands	2013, 2015, 2016
• Symposium Sports Injury Prevention VeiligheidNL, Amsterdam, the Netherlands	2016
• FIFA Football Medicine Conference, London, Great Britain	2016
• The Scientific College Physical Therapy (WCF) of the Royal Dutch Society for Physical Therapy (KNGF) Annuall Congress, Amersfoort, the Netherlands	2016
• 1st World Congress of Sports Physical Therapy on Return to Play, Bern Switzerland	2015
• EFSMA 9th European Congress on Sports Medicine, Antwerp, Belgium	2015
• IOC World Conference on Prevention of Injury & Illness in Sport, Monaco	2014
(Inter)national conferences – podium presentations	
• Return to Play criteria and re-injury risk in acute hamstring injuries Danish Sports Medicine Annual Congress, Kopenhagen, Denmark – Invited lecture	2017
• No relationship between hamstring flexibility and hamstring injuries in male amateur soccer players: a prospective study Dutch Sports Medicine Society Annual Congress, Ermelo, the Netherlands	2016
• Definition and medical criteria for return to play after hamstring injuries: results of a worldwide Delphi procedure Dutch Sports Medicine Society Annual Congress, Ermelo, the Netherlands	2016
• Return to play after hamstring injuries: a systematic review on definitions and criteria Dutch Sports Medicine Society Annual Congress, Ermelo, the Netherlands	2015
• Hamstring injury prevention in amateur soccer EFSMA 9th European Congress on Sports Medicine, Antwerp, Belgium	2015

• Hamstring injury prevention in amateur soccer Danish Sports Medicine Annual Congress, Kopenhagen, Denmark – Invited lecture	2015
• Effective hamstring injury prevention in male amateur soccer using the Nordic hamstring exercise – an RCT IOC World Conference on Prevention of Injury & Illness in Sport, Monaco	2014
• The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer Dutch Sports Medicine Society Annual Congress, Ermelo, the Netherlands	2014
• Normative values of the Sit-and-Reach Test for hamstring flexibility in male amateur soccer players Dutch Sports Medicine Society Annual Congress, Ermelo, the Netherlands	2013
• HIPS – Hamstring Injury Prevention Strategies Society of Physiotherapists in Professional Football (VFBV) Annual Congress, Zeist, the Netherlands – Invited lecture	2013
(Inter)national conferences – poster presentations	
• Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria FIFA Football Medicine Conference, London, Great Britain	2016
• Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria 1st World Congress of Sports Physical Therapy on Return to Play, Bern Switzerland	2015
Other podium presentations	
• Preventive exercises for hamstring injuries MarkTwo Symposium, Ede, the Netherlands – Invited lecture	2016
• Hamstring Injury Prevention Dutch Society of Physical Therapy in Sports Health care (NVFS) general assembly – Invited lecture	2016
• Clinical Health Scientist… and now?! "Meet the expert", Physical Therapy Sciences, Utrecht University, the Netherlands – Invited lecture	2016
• Hamstrings in running performance and running injuries Seminar running injuries, Utrecht, the Netherlands – Invited lecture	2014

2. Teaching activities	
• Masterclass hamstring injuries (with Dr. G. Reurink) NPi, Arnhem, the Netherlands	2017
• Masterclass hamstring injury management Utrecht University of Applied Sciences, Utrecht, the Netherlands	2016
• External reviewer bachelor theses Physiotherapy Fontys Hogeschool, Eindhoven, the Netherlands	2013–2016
• Hamstring injuries: etiology, diagnostics, management and prevention MSP Educations, Leiden, the Netherlands	2013

3. Supervising	
• Adherence to prevention programs in amateur soccer within a real-world context: a follow-up study. P. Van Otterlo, Master of Physical Therapy and Sports student, Avans+ Breda, the Netherlands	2016
• The long-term effect of the Nordic hamstring exercise on hamstring injuries in a real-world context: a follow-up study. M. Klein, Master of Physical Therapy and Sports student, Avans+ Breda, the Netherlands	2016
• Playing again after hamstring injury in amateur soccer players: expert opinions on return to play criteria. P.A. van de Hoef, Physiotherapy Science student, Utrecht University, the Netherlands	2014
• The preventive effect of the Nordic hamstring curl in male amateur soccer players: the differences in hamstring injury incidence between subgroups at risk and optimization of tailored training programs. K.J. Polman, Physiotherapy Science student, Utrecht University, the Netherlands	2014
• Hamstring flexibility as a risk factor for a hamstring injury in male amateur soccer players: a prospective cohort study. M.C.M. van Doormaal, Physiotherapy Science student, Utrecht University, the Netherlands	2014
• Reference values for the Sit-and-Reach test in Dutch male adult amateur soccer players and player characteristics associated with hamstring and lower back flexibility. A. Priesterbach, Selective Utrecht Medical Master student, Utrecht University, the Netherlands	2013

4. Other	
• Reviewer for international journals: British Journal of Sports Medicine American Journal of Sports Medicine Sports Medicine Journal of Sports Sciences: Science and Medicine in Football Medicine & Science in Sports & Exercise	2014–2017